Paper
Lean Construction Implementation: Case Study

Devin J Merker
California Polytechnic State University
San Luis Obispo, California

Lean construction offers a collaborative approach to traditional construction practices and has the primary goal of increasing value to the client. With the proper use of lean construction tools on projects and the adoption of a lean culture, construction companies have recognized real benefits in terms of cost, productivity, and schedule while increasing customer satisfaction. The construction industry has been slow however in adopting the lean construction practices that have proven to be successful. The research in this study will familiarize the reader with the principles of lean construction, and address why the demand for lean construction is rising. In this case study, participants from two construction companies, a leading lean contractor and a non-lean contractor, were interviewed to evaluate the different lean construction “journeys” taken by each company. The interviews and analysis in this study primarily focus on the lean culture, use of lean construction tools, common barriers, lean education, and industry outlook from each of the companies. Suggestions for the future growth of lean construction were provided based on the interview responses.

Key Words: Lean Construction, Implementation Barriers, Construction Culture, Lean Education

Introduction

One of the first success stories attributed to lean construction is that of the Empire State Building, which was completed more than fifty years before the concepts of lean were even published. By basing the design of the project on the owners’ requirement that the building be completed by a specific date, the Empire State Building was designed, engineered, permitted, had existing buildings demolished, and was constructed in just 20 months (Ghosh & Robson, 2014). The construction industry has been slow in the adoption of lean construction practices however. Some industry professionals estimate that “only a very small minority of firms truly understand what it means to be lean” (Warcup, 2015 p.39). If construction companies operating in the current market climate want to realize the same benefits of lean that successful implementers have reported, then there needs to be a greater emphasis on lean construction and the adoption of lean theory. Lean construction has proven to be a successful business model for construction companies who have been able to implement it successfully. McGraw Hill’s Construction Research and Analytics (2013) surveyed contractors on the benefits of implementing lean construction and found that more than 60% of respondents reported: higher quality (84%), greater customer satisfaction (80%), improved productivity (77%), reduced costs or improved profitability (64%), improved safety performance (77%), and reduced project schedules (74%).

Definition of Lean

According to Paul Akers in his book 2 Second Lean (2016), lean is a way of thinking which exhibits two foundational principles: eliminating waste and continuous improvement. In Akers’ opinion, “90% of everything we do is waste” and can be categorized into any of the eight categories that he outlines. The eight wastes as defined by Paul Akers are as follows: 1) Overproduction, 2) Over-processing, 3) Excess Inventory, 4) Defects, 5) Transportation, 6) Wasted Motion, 7) Waiting Time, 8) Unuseful Employee Genius. These eight wastes can always
be identified and eliminated at both a company and personal level in an effort to continually improve and add value to the customer, which is another central concept of lean thinking (Akers, 2016 p.25). Before the details of lean construction can be addressed, it is important to first understand these foundational principles.

*Figure 1: The 8 Wastes of Lean (Akers, 2016).*

**Definition of Lean Construction**

Lean construction applies these foundational principles of lean to traditional construction methods in order to better meet the industry’s growing demand. This is achieved by: optimizing projects as a whole, removing waste, generating value, focusing on process and flow, and continuous improvement (Lean Construction Institute). Previous studies defined a successfully lean construction company as “a company that utilizes lean planning techniques, uses multiple lean tools and concepts, encourages a lean culture, and has completed several lean projects” (Warcup, 2015 p.21). Through the combination of applying lean thinking strategies, lean construction tools, and a focus on continuous improvement, construction companies can fully implement a lean culture which fosters growth, creativity, and success.

**Literature Review**

**Common Tools for Lean Construction**

It has been mentioned that the use of “lean tools” is a contributing factor in what determines a lean construction company. To better understand what was meant by this, extensive research was done to pinpoint the most common lean tools that were being used by construction companies. These tools are inspired by lean concepts and have been adapted to deal with the wastes produced by traditional building practices (Jørgensen, 2008). Each of the tools discussed can be applied on almost any construction project, either individually or in combination, without requiring a change to company culture.

**Last Planner® System (Pull Planning)**

The Last Planner® System is a form of collaborative planning which is achieved through creating a predictable workflow and minimizing waste on a construction project (Ghosh & Robson, 2014). Pull planning is one of the most common aspects of the Last Planner® System that is currently practiced in today’s construction industry. Pull planning requires all trades involved on a project to assemble and work backwards from an established milestone in order to clearly define the resources (e.g., time, labor, materials, etc.) that will be required on a project (Ghosh & Robson, 2014). As written by Leong Wong and Mohammed Ahmed (2018) in their research, “This pull type of system ensures that only the necessary resources and work are being delivered, hence reducing the need for physical buffers (e.g., storage space or time)” (p.5). This aligns with lean principles through the process of collaboration, continual improvement, and eliminating wastes.
**BIM Technologies**

Building Information Modeling (BIM) refers to a 3D model-based process that gives architecture, engineering, and construction professionals the insight and tools to more efficiently plan, design, construct, and manage buildings and infrastructure (“What is BIM?”). By utilizing a 3D virtual model of a project, construction teams can effectively identify design issues, trade clashes, and resolve conflicts before they arise on the construction site. Furthermore, BIM softwares can incorporate other “dimensions” of a construction project (e.g., cost, schedule, efficiency, and maintenance) directly into the model to provide a single location for project information that is easy for anyone to visualize (Changali, 2015). It is estimated that 51% of contractors are currently using BIM technologies and 82% of BIM users report a positive return-on-investment (Ellis, 2018). BIM technologies comply with lean principles because of the collaboration between owner, architect, engineers, and contractor during the creation of the model.

**Modular Construction (Prefabrication)**

Modular construction refers to the off-site prefabrication methods of construction elements that would traditionally be performed by tradesmen on-site. Off-site construction allows for factory-controlled conditions that ultimately increase the quality of the product and eliminate the risk of weather conditions that continually plague on-site productivity (Lee & Kim, 2018). The range of prefabricated elements for construction projects is wide and can contain anything from pre-wired lights fixtures to entire bathroom pods that are ready to “plug-and-play” on the project (Bunch, 2017). Other benefits of modular construction can include: lower costs, safer working conditions, shortened schedules, increased collaboration in design, and a reduction in on-site requirements (Bunch, 2017). Modular construction has applied lean manufacturing principles to offer builders an alternative solution to traditional practices by eliminating wastes and increasing the overall value of the project.

**Collaborative Contracting**

Collaborative contracting is perhaps the most beneficial and least utilized of all of the lean construction tools that have been discussed. Collaborative contracting approaches, such as IPD, encourage a lean culture from the project definition phase all the way through the completion of the project, and sometimes even beyond. In contrast to the traditional design-bid-build contracting - still the most common contracting methodology - collaborative contracting brings in the owner, design team, contractor, and sometimes even subcontractors early on, before the design is finished (Ghosh & Robson, 2014). This allows the various parties to work together and simultaneously establish solutions in design, constructability, and the construction process as a whole before any construction activity is ever performed. Research by Robert Warcup (2015) suggested that this collaboration must continue through the duration of the project for it to be the most successful. The principles behind collaborative contracting approaches are nearly identical to those of lean in that it eliminates waste in projects and stresses the importance of continuous improvement.

**Establishing a Lean Culture**

The importance of implementing a lean culture, rather than relying solely on lean construction tools, was previously researched by Robert Warcup (2015). Warcup’s study interviewed professionals from leading lean construction companies to suggest a path in becoming a successful lean construction contractor. The researcher concluded that in order to operate as a lean construction company and recognize the full benefits lean construction has to offer, it was imperative to establish a lean culture within the entire company. It was also added that in order to establish a lean culture, it required a complete and full commitment from management (Warcup, 2015). Commonalities between the companies that were interviewed allowed the Warcup to develop a suggested approach for implementing a lean culture and becoming an established lean construction company. Warcup’s suggested approach was used to evaluate and compare the lean approaches used by the construction companies interviewed in this study.
Challenges to Adopting Lean Construction

Extensive research went into Warcup’s (2015) previous study to address the common challenges and barriers that prohibit many contractors from transitioning to lean construction. The most prevalent barrier in all cases studied was that there was too much ambiguity with lean construction. A participant in Warcup’s study estimated that “only a very small minority of firms truly understand what it means to be lean. There is not a textbook you can open up that [explains] ‘Here’s how you do [lean]’” (Warcup, 2015 p. 68). By not understanding what is meant to be lean, construction firms are not allowed the benefits of implementing a lean culture. Education was also cited as being a significant barrier as research suggests. Warcup’s study stated that academia has been “too slow to change” and is roughly ten to twenty years behind the industry standards of current lean construction practices (2015, p.104). Other common barriers found in the study included: poor commitment from management, overemphasis on lean construction tools, resistance from subcontractors and field staff, and failure to continually improve (Warcup, 2015). The barriers that have been previously identified will be used to compare to those that are discovered from the interviews in this study.

Construction Productivity

Despite the efforts by companies to keep up with the growing demands of the industry, construction productivity has been declining for over fifty years (Changali, 2015). According to Warcup (2015), this declining productivity is partly because “the construction industry is not a whole lot different than it was fifty years ago. It hasn’t innovated a great deal” (p.92). This lack in innovation could potentially be stemmed from the failure of more construction companies to adopt lean construction tools and culture. Conversely, the industry demands are currently higher than ever before and if there was ever a time that lean construction would be necessary, it would be now. There is an estimated 85% growth in the volume of construction output by 2030 (Ellis, 2018). In a survey of owners performed by KPMG (2015), 69% claimed that poor contractor performance was the single biggest reason for project underperformance and 58% of owners said they have used or plan to use design-build, moving away from the traditional design-bid-build methodology. The significant increase in industry demand cannot be handled by the traditional construction practices that are still being employed by many of the firms in the industry, especially when underperformance is already an issue. Lean construction offers contractors the opportunity to outperform these demands and thrive in both the current and future construction markets.

Figure 2: Construction Productivity vs. Non-Farm Productivity from 1964-2012 (Warcup, 2015).
Methodology

The methodology used in this research was primarily qualitative data achieved through a case study approach. In order to perform this case study, a series of exclusive interviews among several industry professionals at two different construction companies was conducted. The decision to explore qualitative rather than quantitative data during this research was made in an effort to better concentrate on the theories and various approaches of lean construction implementation. Quantitative data tends to focus too much on the impacts attributed to lean construction tools rather than the importance of establishing a lean culture. These types of results were not desired for this study. The information received from the interview questions will provide accurate insight from industry professionals regarding the implementation of lean construction within their own companies, as well as highlight the common challenges that are contributing to the slow adoption by the industry.

The purpose of this case study was to:
- Examine the approaches of lean construction implementation used by two construction companies
- Offer suggestions for the future success of lean construction adoption

Case Study

Two construction companies were interviewed, via telephone calls, and evaluated based on their lean construction practices to provide a better insight on the adoption of lean thinking into more construction firms. The selection of the companies was deliberate in the sense that a leading lean contractor and a non-lean contractor were chosen. This was done in effort to easily highlight both the successful and unsuccessful approaches of lean implementation within each company. Both companies selected are general contractors that have over 100 years of construction experience (each), headquarters on the east coast, commercial construction operations nationwide, and are members of the Lean Construction Institute. The interviews focused primarily on examining each firm’s: company culture, use of lean construction tools, lean education, barriers, and industry outlook in relation to lean construction adoption.

To encourage full participation from the participants, and to avoid revealing any proprietary information, both the company’s and participants’ names were kept confidential. The companies will therefore be referred to as “Company A” and “Company B” for the remainder of this study. In addition, the following references will be used for the participant responses (in relation to their current position):

**Company A**
- Participant 1 - Division Vice President
- Participant 2 - Project Manager
- Participant 3 - Superintendent

**Company B**
- Participant 4 - Director of Field Operations
- Participant 5 - Senior Project Manager
- Participant 6 - Assistant Project Manager

Results

*Company Culture*

Company A exhibited a very lean company culture which was to be expected considering their rapport in the lean construction industry. First, a more horizontal business structure has been adopted by the company to “increase employee knowledge” and encourage continual improvement. Participant 1 gave an example of this when they stated:

“An employee may be titled a ‘project manager’ on their current project, but may have the title of ‘project engineer’ and tasked with managing a specific trade when they move their next project. Better yet, they may not be placed on a project at all, they may be pulled into the office and become an estimator. Wherever we see the most value; for both the employee and company, that’s where they are going to go.”
Company A also utilizes lean leaders which was recommended by Warcup’s (2015) previous studies. Participant 1 explained that this group of lean leaders constantly evaluates and implements improvements into the company in order to foster innovation and continual improvement of the firm and its employees. They continued that through the complete adoption of lean culture within the company, client satisfaction improved and repeat clients became more common. This allowed Company A to be more selective with their work and participate in more design-build contracts. Participant 2 noted that new employees are taught about lean “from day one” as they are given the book 2 Second Lean (also a favored book among successful companies in Warcup’s (2015) study) and can be quizzed on its contents at any time or asked to apply the concepts to their own lives.

Company B did not seem to have a lean company culture, but it was not due to the lack of commitment from upper management like many previous firms have experienced. Though a traditional, vertical, business structure was present in the company, it did allow for some horizontal movement and showcased collaboration efforts. Participant 4 stated:

“Employees are encouraged to move horizontally if they feel it will better advance their career and learning opportunities. If we [upper management] agree that it is a good fit, we will pretty much let them move around as they please.”

The concept of value was not stressed as importantly in the reassignment of employees by Company B as it was in Company A. Additionally, Company B has no designated estimating department which means that project teams are responsible for bidding on their own future projects. This approach has the benefit of creating incentive for workers to bid projects successfully (unless they want to be stuck in the office), earlier collaboration with designers, greater knowledge of project requirements, and more softwares for employees to get comfortable with according to Participant 5. While collaboration seemed to be a key component of Company B’s culture, all participants responded that they did not believe a lean company culture was fully adopted. Participant 5 noted that an “emphasis from upper management on lean could be felt” and more lean tools were being utilized on projects. It has been discovered that the older field crews with traditional methods seem to be the biggest prevention in adopting a lean culture for Company B.

**Lean Construction Tools**

Company A consistently uses lean construction tools, such as the ones mentioned earlier in this study, on all of its construction projects. Prefabricated construction is used “whenever it makes sense” Participant 2 stated. Participant 1 shared the successes of a recently completed project that saw major benefits from lean construction tools. In this project, 700 prefabricated bathroom pods were used which effectively saved 100 working hours per bathroom, and saved 70,000 in total. It was not only the decision to use prefabrication that saved the company time, money, and stress however. Instead, it was the combination of multiple lean tools (prefabrication, BIM, IPD contract) that were employed on the project as well as [the company’s] culture that was able to find the solutions that added the most value, according to Participant 1. Additionally, the company has its own dedicated BIM department and pull planning is used on every project. Company A favors IPD and design-build contracts and wants to move away from the traditional design-bid-build approach. Previous research by Warcup (2015) suggested that daily huddles might be an additional tool for establishing and maintaining a lean culture at the project level, though it was not studied. Company A performs daily huddles with all subcontractors on site before work starts each morning. Participant 3 shared that during the morning huddles, different field workers are provided the chance to lead the stretches, give a short safety presentation, and share any other ideas that might improve the jobsite or employees. The use of daily huddles seem to be an effective lean construction tool which promotes collaboration and enhances a lean culture.

Company B also used lean construction tools such as BIM, modular construction, and pull planning but not with the same successes as Company A. Pull planning was the most common lean construction tool used by Company B, and Participant 4 had the following to say about it:

“I love pull planning and I am trying to get more projects to do it. I have used it on every one of my complex projects, and in my opinion it is the most effective way to continually plan any project.”
Participant 6 realizes however that it is challenging to continue using pull planning, and other lean construction tools, when project teams are continually forced to move to a new project and have to start fresh with a new team who may not understand how, or want to use lean construction tools. Company B does not have a designated BIM department which means all project members are required to have some working knowledge of BIM software if they use a model for their project. This can be seen as a top-down approach to lean construction from Company B as management is forcing the use of these programs, or tools, onto the lower project levels.

Education

Innovation and education are some of the top priorities for Company A in terms of lean construction. The company constantly trains employees on the concepts of lean and introduces them to new processes, technologies, and ideas that can be applied to help reduce waste. As mentioned earlier, the company teaches employees how to be lean “from day one” and continually engages them in a collaborative work environment. Company A also holds seminars, summits, and prizes for innovation to continually improve the lean thinking of the company. When participants were asked to judge academia in its role on lean construction implementation in the industry, they were not as excited as they were by their own company’s own efforts. All of the participants responded that they felt higher education, though it encourages collaboration, has not been doing it’s job in terms of equipping employees with the proper tools and mindsets to be successful with lean construction. Participant 2 exclaimed:

“The new hires that are well-equipped with lean tools or mindsets upon entering the workforce often claim that they learned about the tools or concepts from elective courses or extra-curricular activities such as student competitions.”

Company B made efforts towards the continual learning and improving of its employees as well. Participant 6 mentioned that the company hosts a “tech/innovation” focus group which meets weekly, via Skype, and discusses new tools that can be used to improve the company’s current processes. The group then gives a presentation to the rest of the company, also via Skype, on a monthly basis to share these ideas. Participant 6 is an avid member of this focus group but claims that meeting attendance has been low due to it being loosely enforced, and hosted through a Skype call:

“There are weeks where it is just me and one other person joining the call, and we aren’t really able to discuss anything or get anything done because there aren’t enough people involved to collaborate. Most of the other employees also don’t join the monthly calls to see the new things we are trying to share. It makes makes it really difficult to spread our own employees’ great ideas that everybody can benefit from.”

Additionally, the same concerns were addressed by Company B as were felt by Company A in regards to higher education and its role in lean construction. All of the participants from the interviews felt that higher education was failing to equip students with the adequate skills needed to practice lean construction. Participant 5 mentioned:

“A lot of new hires come in and know what pull planning is, but they don’t know how to do it. They know what lean construction is and they learned about it in school, but they never practiced it and they don’t understand lean.”

Barriers

The most significant barrier for Company A’s implementation of lean construction was the resistance from subcontractors and field crews. These hardened veterans are perhaps the best performers on projects because of their abilities to problem solve when issues arise on the job. Lean construction practices often contradict the way in which these veterans have been operating their entire careers. Participant 3 suggested the classic phrase “You can’t teach an old dog new tricks” to further explain. Full commitment from every employee was also noted as being a barrier for Company A, but as the transition to becoming a lean contractor was underway, those who did not want to adapt to the new culture eventually left as Participant 1 noted.
Company B seemed to be facing the same challenges from field crews that Company A faced, but it was also discovered that lean construction tools seemed to be another barrier. Participant 5 said:

“I have no problem investing in technology if employees feel it will better benefit their project or the company. My concern is when technology is wasted. I have an active project which currently has 15 SmartSheet licenses for it, 13 of which are being unused.”

The Company has also recently rolled out a personalized software to help improve employee productivity and allows upper management to easily oversee production rates on a project. The software however is cited as being “clunky, slow, and not user friendly” which has lead to frustration and resistance to use the program, specifically from superintendents. Participant 6 noted that it has also been difficult getting subcontractors on board with pull planning sessions and give full commitment:

“It can be encouraged by management and included in a [subcontractor’s] and that’s one thing, but the people in the field don’t deal with contracts. They do not know what’s going on, and they are the people who want to change their ways the least.”

Company B’s top-down approach at implementing lean construction has shown to be challenged at the project-level. This has led to the researcher’s suggestion of a bottom-up approach, starting in the field, which will be discussed later in the analysis.

Industry Outlook

All participants from both companies interviewed shared the same view on the future of lean construction. “The future is going to be lean construction, it has to be,” was the response from Participant 2. All of Company B’s participants stated that though the company may not have already fully implemented lean construction, they felt the company was already making the transition. Both companies have observed that other contractors were beginning to implement lean construction practices more frequently and are seeing positive results from doing so.

Analysis and Discussion

It can be seen that the lack of adopting a lean culture has been the largest contributing factor to Company B’s failure to implement lean construction practices. By instilling a lean company culture that is adopted by every employee, from upper management all the way down to the field (or vice versa), the other barriers that have been addressed can potentially take care of themselves. Troubles at the project-level were experienced by both companies however, with resistance from subcontractors and field crews being the main concern. This appeared to be the most significant barrier for Company B to fully adopting a lean culture with all of its employees. Company B’s lean construction implementation struggles can also be attributed its failure to continually educate and improve their own employees. The low attendance at innovation meetings and lack in employee training (e.g., of learning modules, seminars, innovation awards, etc.) seemed to be a detriment to the advancement of lean construction culture for Company B. In order to establish, maintain, and encourage a lean culture in construction companies, these forms of continued education should be emphasized.

If lean tools are relied upon too heavily, they can become barriers. This was the case for Company B. Paul Akers (2016) states in his book *2 Second Lean* that “using lean as only a tool will leave you disappointed. It is much more than that” (p.37). Technologies should be intensely researched and their value to the company should be evaluated before making the decision to use them. This would counteract the issues that Company B faced with unused software licenses and poor-performing personalized software. Perhaps more input from field crews and project teams would also be beneficial for the development in personalized softwares due to the fact that these are the employees who will be using them the most.
The industry is not completely at fault for the slow transition to lean. It seems as though higher education has also contributed to the slow adaptation. Participant responses from the interviews confirmed the previously discovered challenges regarding academia’s role in the slow progression of lean construction. Both companies exhibited concerns that new employees are often not well-equipped with knowledge of lean construction or have ever practiced it. By integrating lean construction into more higher education curriculum and developing practical hands-on applications, perhaps new employees will be ready to employ their lean construction skills upon entering the workforce. Warcup’s (2015) previous study suggested that academia is 10-20 years behind the construction industry in terms of its teachings on lean construction. Instead, it is necessary for academia to realize the importance of lean construction and advise students on the most current, and perhaps even emerging, trends in the industry.

Both Company A and Company B exhibited top-down approaches in implementing a lean culture. This type of approach starts with implementing a lean culture at the top level (upper management), then having it trickle down through the company’s various departments before finally reaching the bottom, project-level (e.g., project teams, subcontractors, and field crews). Although Company A found great success with this approach, Company B did not have the same results. Because of this, an alternative bottom-up approach may be suggested for future construction companies to test. This type of approach would be the exact opposite of the previously suggested top-down approach, with implementing both lean construction tools and culture at the bottom (project-level), and having it work up through the company’s various departments before finally reaching the top (upper management). Akers (2016) also recommended a more bottom-up approach for traditional manufacturing companies, “if it’s simple enough for even those at the ‘bottom level’ to understand, they will get it and it will take off” (p.91) If project teams, including field crews and subcontractors, can visually see the positive results (e.g., shorter schedule, increased productivity, enhanced collaboration, etc.) from using lean construction tools and having a lean culture, they might be more encouraged to continue using these tools on future projects and share their skills with others. Pull planning sessions and daily huddles might be the easiest lean construction tools to implement on projects to begin this approach.

**Conclusion and Future Research**

Lean construction offers real benefits to contractors, designers, and owners when it is properly implemented and practiced. These benefits (e.g., shorter schedules, reduced costs, enhanced collaboration, increased client satisfaction, etc.) have been proven for nearly 100 years in examples such as the Empire State Building in 1931. Despite these remarkable accomplishments, many construction companies have yet to make the transition to lean construction. It is now evident that establishing a lean culture is a necessary step for becoming a lean construction company. Without fully adopting a lean culture, construction companies may never be able to realize the remarkable benefits that lean construction has proven to offer. Subcontractors and field crews are the largest barriers, to fully adopting a lean culture, that were expressed by the companies in this study. Academia was also cited as an additional barrier in that students have not been sufficiently trained on lean construction principles. With construction productivity steadily declining and owner expectations rising, the time for lean construction is now. In order for lean construction to prosper in the future however, a massive change will need to be performed by the industry.

Implementing a lean culture through a bottom-up approach, starting in the field, can potentially be a solution to the lack in company commitment that has been prevalent in this research. Future research might explore the effect of a bottom-up lean implementation approach within construction companies. This might be able to provide a more clear path for contractors to follow if they want to make the transition to lean construction as well as offer an alternative to the top-down approaches that have been tried and tested with limited success.
References


Paper References
Report: Design-build to deliver almost half of US projects by 2021

By Kathleen Brown
Published July 9, 2018

Design-bid-build (DBB) is the most widely used project delivery method in the United States, according to the Lean Construction Institute of America and other groups. Under this method, an owner contracts separately with a designer, who provides complete design documents, and a contractor, who provides the most attractive price bid to execute that design.

But new research from consulting firm Fails Management Institute (FMI) indicates that the design-build (DB) delivery method, where an owner contracts with a single entity to perform both design and construction, is quickly gaining traction in the industry. According to the June 2018 “Design-Build Utilization” report, DB methods will represent nearly half, or 44%, of construction put-in-place (CPIP) spending across many market segments by 2021.

FMI’s findings were based on 82 interviews and 101 survey responses from construction firms in all revenue categories, ranging from ENR top-10 ranked companies to small firms. FMI assessed commercial, highway/street, educational, manufacturing, office, transportation, healthcare, lodging, recreation, water/wastewater, communication, public safety and religious construction market segments.

FMI predicted that collective DB CPIP spending in these segments will increase 18% between 2018 and 2021, swelling from $274 billion to $324 billion in value. Manufacturing,
educational and highway/street segments are expected to comprise the top three market shares of 16%, 15% and 14% by 2021, respectively, followed by commercial with a 13% share.

**No longer the “alternative”**

Design-build and other alternative delivery methods like construction manager at risk (CMAR) and construction manager/general contractor (CMGC) have become more attractive options to owners wanting to tighten up project budgets and/or timelines, according to the study. Alternative methods were “indicated to provide the best avenue to achieve the originally identified cost,” the report found.

While 82% of owner respondents said they’ve used or plan to use DBB in the next five years, 58% of owners said they’ve used or plan to use DB.

Given the popularity of DBB, just over half of owners surveyed said usage would stay about the same over the next five years while 32% predicted a decrease and only 15% predicted an increase. Meanwhile, 29% of owners said DB adoption would stay the same while 67% predicted increased utilization.

One reason that DB methods have gained momentum, according to the report, is the passage of state legislation that facilitates the use of alternative project delivery methods. Last year, for example, Virginia legislators expanded design-build authority to all local governments, the New York governor’s budget added new state entities to the list of those authorized to use design-build and the Washington state legislature recommended design-build for construction of a bridge. Legislation in 38 states that enables use of public-private partnerships also plays a role in boosting DB utilization, the report found.

“The use of alternative delivery methods in general is growing and will continue to do so, particularly design-build, as projects become more complex and need to be delivered in an expedited
fashion,” said FMI consultant Paul Trombitas in a webinar hosted by the Design-Build Institute of America (DBIA).

**Advantages, obstacles to adoption**

Design-build methods promote a “culture of collaboration” that’s not always present in traditional contracting arrangements, Trombitas said. From the start of a project, designers and contractors in DB projects share decision-making and pitch unified project recommendations to the owner for meeting the owner’s schedule and budget, according to DBIA.

Seventy-six percent of owner respondents to FMI’s survey rated their experience with DB as “very good” or “excellent.” They cited increased opportunities to innovate and the ability to fast-track a project as the top two benefits of DB.

In contrast, “the almost contentious relationship that design-bid-build or low-bid pricing creates doesn’t allow for the innovation, early collaboration and identification of effective solutions to deliver projects,” according to Trombitas.

Plus, traditional project delivery methods can pit the designer and contractor against each other when project obstacles arise or changes are required, DBIA says, sometimes leading to litigation and project delays. In a collaborative DB relationship, however, change orders by the owner are less likely.

While DB contracting offers potential time and cost savings, making the switch to this alternative model sometimes requires owners to make a cultural shift. Owners often have to adapt their contract management practices and adjust to a smaller role in the design process. Another potential disadvantage for owners is less competition because of the smaller number of companies that can pull together an effective DB team.

However, FMI expects DB use to pick up as owners gain more exposure to the advantages of the approach. “A continued
The Rise Of The Prefabricated Building

Developers, general contractors and subcontractors swap stories that sound too good to be true about prefabricated construction: a student housing project that cut its delivery time by a third or a hospital that installed hundreds of bathrooms in three days with only five laborers. Though the practice of off-site construction dates back thousands of years, the last real estate cycle has pushed prefabricated construction to prominence.
“We think the recession actually benefited our industry,” Modular Building Institute Executive Director Tom Hardiman said. During the last recession, many skilled laborers left the construction industry and did not return, Hardiman said. That, coupled with developers needing to find greater efficiency, made prefabricated buildings more appealing.

“The construction industry is very reluctant to change. When things were going well, developers and general contractors may not have felt the pain or need to change,” Hardiman said. “Now they do, and there’s no turning back.”

Off-site construction, also called prefabricated or modular construction, allows various building elements — anything from bathrooms to pre-wired light fixtures to exterior walls — to be built in a factory and transported to a construction site.

“We’ve found it helpful to think about modular as a construction process rather than a specific type of building,” Hardiman said. “It describes how the building was constructed, not what the building is.”
One downside to constructing off-site is decreased flexibility to update buildings in the field.

“What we’re talking about doing is rethinking decisions that are made too late and advancing them upstream,” DPR Construction Project Executive and National Prefabrication Leader Zach Murphy said. “[Prefabrication] isn’t good for making last-minute changes, but it’s about making those decisions earlier.”

DPR also uses virtual design and construction, a type of computer modeling, to solve problems with subcontractors and building partners in the virtual world before building in a factory or in the field.

But that loss in flexibility once ground is broken makes it imperative to commit to design, Trammell Crow principal Jeff DeBruin said.

“For instance, if you add prefab racks in your restrooms, and then at the eleventh hour you want to add another sink, your racks are no longer useful. You’re banking on consistency and redundancy, and any changes make you less adaptable.”

When done correctly, off-site construction can benefit a project’s schedule, budget and skilled labor requirements.
“When you just prefab for sake of prefab, you can add in a lot of cost by overbuilding structures to be rigged and set into place,” Murphy said. “From our view, there’s economic decision to make at each point: Is this better done in a factory or in the field?”

Certain asset classes have more opportunity to build modular, particularly sectors with redundancies such as student housing, education buildings, hospitals, data centers and senior housing.

Some asset class do not lend themselves to prefabrication.

“Unlike hotels and senior living facilities, mixed-use and office space is not ideal for prefabricated solutions where tenants are likely to require reconfigurations from time to time,” DPR Regional Leadership Team's Peter Read said. "This is problematic with load-bearing interior walls."

But Hardiman has seen increased interest in healthcare, commercial retail and institutional buildings such as prisons and police stations.
In May, Marriott International announced plans to modularly construct 13% of its North American developments in 2017.

The rise in popularity has many developers determining how off-site construction can help their projects pencil.

Maximizing labor resources has been the primary driver to prefabrication construction, DeBruin said.

“I don’t think it inordinately helps speed to market. It might be more of a cost mitigator than cost saver. But anytime you can prefab in a controlled setting, there’s a propensity for enhanced quality control,” he said.

With skilled labor shortages impacting more of the U.S., off-site construction is a way to build projects in less affected areas, and to provide workers with safer working conditions in a prefab factory than out in the field.

“It isn’t as simple as that there are not enough skilled laborers,” DPR Project Executive Sean Ashcroft said. “It’s also about geographies of where skilled
laborers are located versus where they are needed. If you have skilled labor in range, you can give them a better job in a safer workplace. Then if you have local fluctuation [in labor markets], you take out that element of shortage.”

Prefab offers more control and flexibility with labor.

“We often think about how many bodies we have in some area of a project,” Ashcroft said. “We have more controlled outcomes in a shop with less exposure to elevated working areas and things like that. It’s less strain on your workers.”

For Hardiman, the benefits of building off-site make its value a no-brainer for general contractors and developers.

“No one would question how we build cars today. It would be comical to have all the parts delivered to your driveway with a dozen workers to build it,” Hardiman said. “Yet we build our homes, schools and offices in this inefficient and wasteful manner every day.”

For more news about commercial real estate, visit www.bisnow.com or check us out on Facebook and Twitter.

We are Bisnow, an international digital media company that publishes daily newsletters and produces events focused on commercial real estate trends, personalities, and happenings. Whether it’s through our coverage of the industry, or through the hundreds of commercial real e... MORE
The construction productivity imperative

By Sriram Changali, Azam Mohammad, and Mark van Nieuwland

How to build megaprojects better.

Around the world, ever-larger capital projects are being undertaken. Better project management and technological innovation can improve the chances of success.

Three factors are defining the future of large-scale capital projects. First, investment is growing fast. In 2013, global investment in energy, infrastructure, mining, and real-estate-related projects was about $6 trillion; by 2030, that, could be $13 trillion, according to McKinsey research (Exhibit 1).
Exhibit 1

Infrastructure investment will double in the next 15 years.

Global infrastructure investment by industry¹
Selected years, constant 2005 prices and exchange rates, $ trillion

Megaprojects' share in the future²
12% by number of projects
77% by project value

¹Forecast assumes price of capital goods increases at same rate as other goods and assumes no change in inventory.
²Project award date 2015 and beyond.

McKinsey&Company

Second, billion-dollar-plus megaprojects will account for a greater share of these developments. Third, the industry does poorly completing megaprojects on time, on budget, and to specifications. Our research estimates that 98 percent of megaprojects
suffer cost overruns of more than 30 percent; 77 percent are at least 40 percent late (Exhibit 2).

98% of projects incur cost overruns or delays.
- The average cost increase is 80% of original value.
- The average slippage is 20 months behind original schedule.

Source: Companies’ public annual reports; IHS Herold Global Projects Database, November 19, 2013; press releases

McKinsey&Company
There are many reasons for this poor record. Start with productivity—or, rather, lack of it. Construction productivity has been flat for decades, according to McKinsey research. In manufacturing, by contrast, productivity has nearly doubled over the same period, and continuous improvement has been the norm (Exhibit 3).

Productivity in manufacturing has nearly doubled, whereas in construction it has remained flat.

**Overview of productivity improvement over time**

Productivity (value added per worker), real, $ 2005

$ thousand per worker

Source: Expert interviews; IHS Global Insight (Belgium, France, Germany, Italy, Spain, United Kingdom, United States); World Input-Output Database

McKinsey&Company
A variety of factors account for poor productivity and cost outcomes. Among them are the following:

- **Poor organization.** Decision-making and procurement processes do not have the speed and scale required.

- **Inadequate communication.** Inconsistencies in reporting mean that subcontractors, contractors, and owners do not have a common understanding of how the project is faring at any given time.

- **Flawed performance management.** Unresolved issues stack up because of lack of communication and accountability.

- **Contractual misunderstandings.** The procurement team typically negotiates the contract, and this is almost always dense and complicated. When a problem comes up, project managers may not understand how to proceed.

- **Missed connections.** There are different levels of planning, from high-end preparation to day-by-day programs. If the daily work is not finished, schedulers need to know—but often don’t—so that they can update priorities in real time.

- **Poor short-term planning.** Companies are generally good at understanding what needs to happen in the next two to three months, but not nearly so much at grasping the next week or two. The result is that necessary equipment may not be in place.

- **Insufficient risk management.** Long-term risks get considerable consideration; the kinds that crop up on the job not nearly as much.
• **Limited talent management.** Companies defer to familiar people and teams rather than asking where they can find the best people for each job.

These problems are serious, systemic, and all too common. Still, some companies do manage to succeed. Through our analysis of more than $1 trillion worth of capital projects over the past five years, we have found that improving “basic” project-management skills offers the most potential to improving site performance. This article discusses 15 practices that can help to improve productivity in the three phases of project delivery—concept and design, contracting and procurement, and execution.

**Concept and design**

The concept-and-design phase is where the most project value can be gained (or lost). These seven principles offer the most promising ways to improve performance, and therefore financial returns.

**Build only what is needed.**

Design-to-value (that is, design based on understanding and minimizing the elements that drive up costs) and the minimal technical solution (MTS, design to deliver only the necessary value-added requirements) are two concepts that can be used to reduce capital investments to what is required—no more, no less. Consider the example of two utility companies who needed to build a similar substation building. One spent substantial time and money building a full shell, including floors, walls, a roof, and so on; this required many approvals, followed by a long and difficult construction schedule. The other utility defined the MTS to be “protection against the weather, while retaining ease of access during maintenance;” on that basis, it built a retractable roofing structure with pillars. This latter option required much less time and money to build.

**Maintain a life-cycle perspective.**
Companies typically observe a certain rigor in managing up-front capital costs; less often, however, do they consider the full life-cycle costs of construction and operations. Ensuring that design engineers and project managers are familiar with life-cycle metrics, such as net present value (NPV), could help. So could linking incentive structures to NPV improvement. One approach that is gaining traction is competitive front-end engineering and design, where companies invite multiple engineering, procurement, and construction companies to apply. Bidders win by coming up with designs to optimize overall project costs. It’s important for procurement specialists (see next section) to keep life-cycle costs in mind as well, evaluating not only the acquisition price but also efficiency, maintenance, and disposal.

**Strengthen scenario planning.**

Developing options under various scenarios reduces risk and enhances predictability of project returns. The plans for many infrastructure, real estate, and energy projects are based on estimated capacity, such as airport passenger loads, or on production profiles, such as those for oil-and-gas developments. Companies pay a great deal of attention to developing this base case. Less often, however, do they put in the same effort in evaluating alternative scenarios that could affect the success of the asset or require expensive modifications. If developers thought harder about the worst-case scenarios, they would do a better job ensuring that they had the flexibility to cope with the unexpected.

**Optimize around site constraints.**

This seems obvious, but unfortunately it is not practiced consistently enough. Too many companies work out the design in the office and therefore do not take into consideration actual site conditions, such as climate conditions, soil characteristics, terrain, and weather. It’s usually easier (and cheaper) to tweak a building design than a landscape. One example of good practice would be the Olympic Stadium in London; the designers planned the structure around a natural slope to minimize the need for excavations.

**Think modular design and standardization.**
Standardizing and modularizing components can save costs and time. Nevertheless, a significant number of companies do not apply this principle; exploration-and-production companies, for example, often use different specifications for their wellhead platforms. India’s Reliance Industries shows what can be achieved through standardization. When Reliance built a second refinery in Jamnagar, it was almost an exact replica of the first one, with some updates to accommodate new technologies. The decision to replicate shaved six months off the engineering schedule. On a smaller scale, utility companies are increasingly using standard design for new substations. This also improves life-cycle costs, because spare parts can be used across assets. The use of standard designs should be considered on a case-by-case basis, taking into account local conditions or the latest technologies, to avoid using suboptimal design. However, it is typically more efficient to start with the last design and adjust, rather than to start from scratch.

**Consult construction and procurement teams, beginning in the design phase.**

Construction and procurement teams bring different expertise to the table; it makes sense to bring them in from the start to evaluate concepts and designs. A construction expert, for example, might notice that a design choice will have costly ripple effects down the line; procurement managers can suggest new ways to minimize costs. In short, sometimes great design ideas can come from outside the design team. T-REX, a highway/light-rail project in Denver, Colorado, finished almost two years ahead of schedule, in part because contractors developed a way to do certain tasks at the same time, rather than sequentially. That would not have happened if they had not been in the room from the beginning.

**Optimize engineering processes and choices.**

Companies are usually stringent about managing time lines during construction. But often they do not pay the same attention during the preconstruction phases, even though the work done during this period can have a disproportionate effect on the project value. There is substantial room for improvement in engineering productivity, with respect to time and quality of output, to prevent rework in the construction phase. For example, during a recent refinery project, the owner ordered the engineering firm to set up a 24-
hour global “engineering factory.” This enabled the company to save several months in the engineering phase. In another example, a company with an engineering team based in a number of different places analyzed the data analytics associated with its e-mail traffic. This helped the company optimize locations, team sizes, and work flows, and resulted in productivity improvements of up to 25 percent.

The use of Building Information Modeling (BIM) helps improve productivity as projects progress, because all information is contained in a single location. BIM tools are based on 3-D models, and they help planners avoid design clashes. Some companies are exploring adding dimensions, such as cost, time, and resources, in order to smooth project management in the execution phase and facilitate maintenance during operations.

The use of aerial, laser, and radar technology can rapidly improve surveying productivity. For example, in the design of transmission lines, the ground survey can be conducted with helicopter-mounted radars rather than having ground crews do manual surveys.

**Contracting and procurement**

It is important to define a contracting-and procurement approach that minimizes cost and risks—and to think this through for each project. It’s awkward but true: practices that worked well on one project may not be suited to another. Companies cannot always do things the same way. Here are some best practices that can help companies avoid delays and save money.

**Integrate risk allocation into the contract.**

It is tempting for those paying for construction to try to transfer all risks to the contractors—even when the latter lacks the required financial capacity. A more balanced approach that assigns contractors only those risks that they can influence may be preferable, not only for good relations but also for economic reasons. When contractors are forced to assume risks that aren’t naturally theirs, then they wind up paying higher insurance premiums; these costs, of course, are passed on to the customer. T-REX again provides an example of better practice. During the bidding period, the different
100 Construction Industry Statistics To Improve Productivity

Equip Your Project With the Right Stats for Success

Construction industry statistics and data are playing an increasingly important role in the building sector. From measuring bid-to-win ratio, to how much a project is over budget or schedule, and KPIs, the more numbers you can put behind your work, the better. Data not only allows for more visibility into the state of a particular project, but relevant industry statistics and facts can provide valuable information needed to make important future decisions regarding preconstruction planning, productivity tools, risk assessment, and workforce efficiency.

Undoubtedly, the construction industry is very complex. Although project needs are increasing worldwide, productivity is declining—but how is this even possible if construction demand is gaining momentum worldwide?

Below, we’ll help you make sense of this trend, providing you with all the important construction industry statistics you need to understand the current state of affairs, as well as how poor productivity and increasing costs are actually inhibiting individual project growth. Additionally, we’ll explore how your company and project can avoid becoming another statistic through the power of technology and construction productivity tools.
Construction is 14.7% of global GDP—up from 12.4% in 2014. [GCP] | Click to Tweet

$1.18 trillion is the worth of U.S. construction industry in 2017. [Capital Plus] | Click to Tweet

$57 trillion in infrastructure is needed by 2030 to keep up with global GDP growth. [McKinsey Global Institute] | Click to Tweet

1.2 million new housing units planned annually in the U.S. — up from 583,000 in 2009. [Census Bureau] | Click to Tweet

Estimated 85% growth in the volume of construction output to $15.5 trillion by 2030. [PWC] | Click to Tweet

3.6% is the estimated growth of global construction in 2018. [IMF] | Click to Tweet

Estimated 11% increase in U.S. 2018 commercial construction. [FMI] | Click to Tweet

72% of construction CEOs expect to increase revenue in 2018. [ENR] | Click to Tweet

93% of contractors expect to see equal or greater profit margins in 2018. [CCI] | Click to Tweet

99% of contractors feel confident for the demand for commercial construction in 2018. [CCI] | Click to Tweet

58% of owners said they've used or plan to use design-build, moving away from traditional design-bid-build. [FMI] | Click to Tweet

6% increase in modular construction by 2022 is predicted. [UA Builders] | Click to Tweet

Over Time and Over Budget Is a Common Theme
• Over 50% of engineering and construction professionals report one or more underperforming projects in the previous year. [KPMG] | Click to Tweet

• In 2018, a 2-3% increase in overall construction costs is expected in the U.S. [Oldcastle Building Solutions] | Click to Tweet

• Additionally, 3-4% higher construction labor costs are predicted. [Oldcastle Building Solutions] | Click to Tweet

• Estimated 2-3% increase in material costs in the U.S. in 2018. [Oldcastle Building Solutions] | Click to Tweet

• 69% of owners say poor contractor performance is the single biggest reason for project underperformance. [KPMG] | Click to Tweet

• Just 25% of projects came within 10% of their original deadlines in the past 3 years. [KPMG] | Click to Tweet

• And only 31% of all projects came within 10% of the budget in the past 3 years. [KPMG] | Click to Tweet

• Large projects typically take 20% longer to finish than scheduled and are up to 80% over budget. [McKinsey Global Institute] | Click to Tweet

• 98% of megaprojects become delayed or over budget. [McKinsey Global Institute] | Click to Tweet

• 77% of megaprojects around the globe are 40% or more behind schedule. [McKinsey Global Institute] | Click to Tweet

• U.S. $42.8 million was the global average value of construction disputes. [Arcadis] | Click to Tweet

• 14 months was the global average length of construction disputes. [Arcadis] | Click to Tweet

• 45% of construction professionals report spending more time than expected on non-optimal activities. [PlanGrid + FMI] | Click to Tweet
• Percentage of young construction workers declined by 30% from 2005-2016. [BuildZoom] / Click to Tweet

• 40% of construction jobs were lost between 2006-2011 due to the recession, and industry has struggled to get back since then. [eSUB] | Click to Tweet

• 56% of builders reported that they were suffering due to the effects of the skilled labor shortage. [National Association of Home Builders] | Click to Tweet

• 200,000 unfilled construction positions in 2016 alone. [The Bureau of Labor Statistics] | Click to Tweet

• 21.4% industry wide turnover rate, making it one of the highest rates of all industries. [Bureau of Labor Statistics] | Click to Tweet

• 16-20% of an individual's base salary is the average cost of a turnover. [American Progress] | Click to Tweet

• 26% of construction workers say they are frustrated by the lack of tools they need to do their jobs better. [TINYpulse] | Click to Tweet

Workforce at a Glance
In 2017, 210,000 jobs were added in the industry, a 35% increase from 2016. [The Bureau of Labor Statistics] | Click to Tweet

More than 180 million people work in construction around the world. [WEIGO] | Click to Tweet

42 years old is the average age of a U.S. construction worker, one year older than the average age of the workforce. [NAHB] | Click to Tweet

Construction accounts for only 4% of workers but 21% of workplace-related deaths in the U.S. [The Bureau of Labor Statistics] | Click to Tweet

16% increase in U.S. construction workers deaths in 2015 over 2012. [The Bureau of Labor Statistics] | Click to Tweet

Only 13% of construction firms are women owned. [Womenable] | Click to Tweet

57% of contractors expect to hire more workers in the next 6 months. [CCI] | Click to Tweet

Only 9.1% of the construction workforce is female. [NAWIC] | Click to Tweet

Problems in Productivity

Only 1% increase in construction sector’s annual productivity in the last 20 years.
• $1.53 trillion could be saved annually from infrastructure productivity changes. [McKinsey Global Institute] | Click to Tweet

• 35% of construction professionals time is spent (over 14 hours per week) on non-productive activities including looking for project information, conflict resolution and dealing with mistakes and rework. [PlanGrid + FMI] | Click to Tweet

• In all, non-optimal activities will cost the U.S. construction industry over $177 billion in labor costs in 2018 alone [PlanGrid + FMI] | Click to Tweet

• 50% or more impact on productivity as a result of issues with construction logistics. [MCAA] | Click to Tweet

• 10% impact on productivity as a result of late crew build-up. [Whirlwind Steel] | Click to Tweet

• 50% variation in productivity of two groups of workers doing identical jobs on the same site and at the same time. This gap in productivity was found to vary by 500% at different sites. [Sourceable] | Click to Tweet

• Only 11% of contractors consider jobsites to be very efficient. [CCI] | Click to Tweet

• 30.9% of construction industry professionals say that the top reason for miscommunication is unresponsiveness to questions/requests. [PlanGrid + FMI] | Click to Tweet

Scope of Work and Changes Are Impacting Risk

• Average of 35% of all construction projects will have a major change. [Project Analysis Group] | Click to Tweet

• Up to 30% of initial data created during design and construction phases is lost by project closeout. [Emerson] | Click to Tweet
78% of engineering and construction companies believe that project risks are increasing. [KPMG] | [Click to Tweet](#)

43% of construction firms prioritize immediate financial goals over organizational resilience. [Constructing Excellence] | [Click to Tweet](#)

34.4% say the top cause of poor project data and information is erroneous or incorrect project data. [PlanGrid + FMI] | [Click to Tweet](#)

---

**Rework Has Become an Expensive Standard**

---

Around 30% of the work performed by construction companies is actually rework.

---

Up to 70% of total rework experienced in construction and engineering products are a result of design-induced rework. [Quality] | [Click to Tweet](#)

52% of rework is caused by poor project data and miscommunication. [PlanGrid + FMI] | [Click to Tweet](#)

Meaning, $31.3 billion in rework will be caused by poor project data and miscommunication in the U.S. alone in 2018. [PlanGrid + FMI] | [Click to Tweet](#)

Roughly 4-6% of total project cost is the median cost of rework—but only taking into consideration direct cost or reported rework. [Navigant Construction Forum] | [Click to Tweet](#)

9% of total project cost is closer to the actual total cost of rework—considering both direct and indirect factors combined. [Navigant Construction Forum] | [Click to Tweet](#)

As much as $4.2 billion a year in the U.S. is the cost of rework caused by poor document control. [Seattle Government] | [Click to Tweet](#)

---

**A Paper Based Industry but Mobile Is Making Waves**
40% of construction companies are still using paper plans on the job. [JB Knowledge]  
| Click to Tweet

Nearly 50% of the construction professionals manually prepare and process daily reports. [JB Knowledge]  | Click to Tweet

But only 18% of firms reported consistently using mobile apps to access project data and collaborate. [PlanGrid + FMI]  | Click to Tweet

75% of construction companies use cloud storage. [CITE + Dropbox]  | Click to Tweet

75% of construction companies provide PMs and field superintendents with mobile devices. [PlanGrid + FMI]  | Click to Tweet

77% of contractors and 65% of owners use mobile technology to complete their construction and engineering projects. [KPMG]  | Click to Tweet

36% of construction firms use 5 or more mobile business apps to complete projects. [Canvas]  | Click to Tweet

However, only 29% use apps routinely on all their projects. [KPMG]  | Click to Tweet

Opportunity for Digitization

Nearly 50% of construction companies report spending 1% or less on technology annually.
emphasis toward educating owners and project stakeholders on the process and benefits associated with design-build will facilitate continued adoption and greater utilization,” the report found.

**Recommended Reading:**

[Design-Build Institute of America](https://designbuild.org)

*Design-Build Utilization: Combined Market Study June 2018*
Analyzing the Empire State Building Project from the Perspective of Lean Project Delivery System

Somik Ghosh, PhD and Kenneth F. Robson, AIC, CPC
University of Oklahoma
Norman, Oklahoma

The Empire State Building was the tallest building in the world when it was officially opened on May 1, 1931. It held that distinction for over 40 years. In 20 months the building was designed, engineered, permitted, demolition of an existing building completed, and the building constructed. In order to complete the Empire State Building under the allotted 18 month schedule, Starrett Bros. & Eken, the contractors employed innovative construction methods and techniques. Many of these construction methods qualify as tools of lean construction practiced in today’s construction industry. Comparing the design and construction processes employed by Starrett Bros. & Eken with the theoretical constructs of Lean Project Delivery System (LPDS), it is evident that several lean construction principles were employed during the construction of Empire State Building, a quarter of a century before lean concepts were formalized. Using archival records and historical accounts, this paper examined the design and construction processes of the Empire State Building and compared them with the LPDS processes that are increasingly employed in the construction industry today.

Key Words: Lean construction, Project management, Project delivery methods, Planning

Introduction

The Empire State Building is arguably one of the most famous buildings in the world. It was the tallest building in the world when it was officially opened on May 1, 1931. It held that distinction for over 40 years. In 20 months the building was designed, engineered, permitted, existing buildings were demolished, and the building constructed. At the peak of construction, framework rose 4 ½ floors a week. The Empire State Building was completed on time and under budget. The contracts with the architects were signed in September 1929 and the first structural columns were set in April 1930. Only one year later, the building was fully enclosed, with a height equivalent to 102 stories and 1.2 million square feet of rentable space (Willis, 1998).

In a project such as the Empire State Building, where 57 thousand tons of structural steel and over 62,000 cubic yard of concrete were erected involving almost 3500 workers on peak days (Willis, 1998), the approach to design and project management played a crucial role for the successful completion of the project. gly, designers and contractors view any construction project as a transformation process where total production can be broken down into smaller production units, and the total production can be managed by managing the smaller units. The inherent problem with this approach is the failure to acknowledge the interdependencies of the smaller units, as if those units are independent from each other. The Empire State Building project, an anomaly to the traditional practices of design and project management strived to adopt a production management based approach to design and construction. The paper argues that the management philosophy of the Empire State Building was rooted in what has come to be referred as lean construction, and bears a close resemblance to the Lean Project Delivery System (LPDS).

This paper analyzes the design and construction of the Empire State Building project from the perspective of LPDS. In the following sections, the paper presents the conceptual framework of LPDS, discusses how it is different from the traditional approach, and illustrates the resemblance of the production process of the Empire State Building Project with that of LPDS.

Lean Project Delivery System (LPDS)

LPDS has been designed as a framework for a production management based approach to design and constructing capital facilities in which “the project is structured and managed as a value generating process” (Ballard, 2000). The
main intention of LPDS is to provide rules for decision making, procedures for execution, and tools for implementation of production management. Within the lean construction paradigm, a construction project is envisioned as a “project based production system” where resources and value-engineering processes are strategically arranged for new product development.

The LPDS framework (Ballard, 2003) consists of 15 modules, 11 modules are organized in five interconnected triads or phases extending from project definition to design, supply, assembly and use. Two additional production control modules and the work structuring module are conceived to extend through all project phases. The post-occupancy evaluation module, which links the end of one project to the beginning of the next, completes the learning loop (Fig 1).

![Figure 1: Framework of Lean Project Delivery System (LPDS) (Ballard 2003)](image)

While the individual components contained in the five interconnected triads are considered by the authors to be self-explanatory to the audience of this paper, the two other components that warrant additional discussion are work structuring and production control. Work structuring in lean construction is defined as developing a project’s process design while trying to align engineering design, supply chain, resource allocation, and assembly efforts (Ballard, 1999) with the goal of making “work flow more reliable and quick while delivering value to the customer” (Ballard, 2000). At the beginning of project, work structuring focuses on designing the overall system. As the project progresses, the focus shifts on to guide the design and execution of interdependent work. According to Ballard (1999), work structuring views a project as consisting of ‘production units’ and ‘work chunks.’ Production unit refers to an individual or group of workers (of any skill) that share responsibility of direct production of similar work. A work chunk is a unit of work that can be handed off from one production unit to the next. Production units continue adding value to a work chunk until it becomes completed work. The handing off of work chunks also bears significant meaning in the context of work structuring. Hand off specifically refers to the declaration of completion of work chunk by a production unit and subsequent release to the next unit, with the acceptance of the released work by the next unit.

While work structuring produces strategies for successful completion of the project, production control ensures that works are executed as planned. Thus in the context of LPDS, production control is essentially governing execution of planned work and not just identifying variances between planned and actual work put in place (Ballard, 2000).
Production control uses the look-ahead process to manage work flow control and weekly work planning to manage production unit control (Ballard, 2000). Typically, during the project definition and lean design phases, planners (designers, contractors, suppliers, and other key stakeholders) develop and compare various work structures to determine the appropriate combination for that particular project. During the lean supply and lean assembly phases, project participants start executing the predefined work structures. However, these work structures can always be modified by the participants, if they find they cannot execute certain aspects of the selected work structure based on their resource capabilities. This approach makes work structuring an ongoing, adaptive process throughout the project. Finally, during the facility’s use phase, project participants determine if the executed work structure successfully met customer needs. The lessons learned from one project are then used to guide work structuring efforts on future projects (Howell & Ballard, 1999). Thus, work structuring and production control are complementary and managed concurrently during all phases of project delivery.

**Difference of LPDS from Traditional Project Delivery**

The main difference between LPDS and traditional project delivery lies in the way projects are viewed. By traditional delivery method the authors are referring to design-bid-build approach. In the design-bid-build approach, design and construction are viewed as two independent non-overlapping processes. The designers and contractors rarely consider how to manage the entire production system. In general, planners use a work breakdown structure (WBS) to break down a project into work packages to create a framework for project planning, scheduling, and controls. In this approach, designers and contractors view production primarily as a transformation process where entire production can be managed by breaking it down to smaller units, and managing the units. As a corollary to this disintegrated process, designers often leave interface resolution (interface between product and process design) to the contractors (Tsao, Tommelein, Swanlund, & Howell, 2004). While the design of each part may appear to be reasonable and logical upon inspection (MCAA, 2003), the design of the overall assembly may not be optimal. This method fails to recognize the interdependent and dynamic nature of the construction tasks, and does not take advantage of overlapping disciplines. The uncertainties and errors created upstream (during design) may prove to be detrimental to performance downstream (during installation) (Tommelein, Riley & Howell, 1999).

In contrast, LPDS adopts a production management approach and manages the entire construction project as a system. In addition to the transformation view, the primary thrust of LPDS is on flow view and value generation view. The three views of transformation, flow, and value, have been collectively termed “TFV theory of production” (Koskela, 2000). The goal of LPDS is to provide a structured framework that guides project participants to make work flow more predictable and faster while delivering value to the customer (Ballard, 2000).

**Key Stakeholders in the Empire State Building Project**

The key organizations in the design and construction of the Empire State Building project were Empire State, Inc., the owners, Shreve, Lamb and Harmon, the architects, and Starrett Bros. and Eken, the contractors. These organizations were comprised of many individuals. There were, however, key individuals within each organization that committed their companies to the team approach that was so influential to the success of the project. Their background influenced the management of the project that was close to lean principles, even before lean construction was formalized.

The backgrounds of the key stakeholders were varied and undoubtedly played an important role in the management processes of the Empire State Building’s design and construction. The Empire State Building was John J. Raskob, Pierre du Pont and Alfred Smith’s first entry into the building/real estate market. Raskob, the driving force of Empire State, Inc., had worked for the du Pont de Nemours Company, and was a trusted advisor to Pierre du Pont. Raskob was a seasoned businessman and advised Pierre du Pont to invest in the stock of General Motors that eventually made du Pont the chairman of GM, and Raskob became the vice-president. Raskob’s experience in the automobile industry empowered him to envision construction akin to the manufacturing process. Al Smith provided the public face of the project. His working career included a variety of jobs until he became the governor of New York.
Both Shreve and Lamb were college educated, with Shreve having graduated from Cornell’s College of Architecture in 1902. Lamb graduated from Williams College and then attended Columbia’s School of Architecture before graduating from Paris’ Beaux Arts in 1911. Both joined the architecture firm of Carrere & Hastings and eventually formed their own firm of Shreve and Lamb. Harmon joined the firm in 1929 and it became Shreve, Lamb and Harmon.

Paul Starrett had been employed in the architectural firm of Burnham and Root in Chicago. It was here that he discovered his passion for building while working as a construction superintendent for the firm. Later, working for other general contractor and the War Industries Board he earned his reputation as an efficient builder. Continuous lookout for efficiency perhaps encouraged Starrett Brothers to adopt management techniques that bore resemblance with the lean concepts. In 1922, Paul and William joined forces with Andrew Eken, to form Starrett Bros. & Eken. The key players’ careers and management philosophies were developed during a time of rapid change in America - continued industrialization, World War I and the roaring twenties had a great influence on American industry at that time.

**Comparison with LPDS**

Upon examination of archival documents of the Empire State Building project, it was evident that various aspects of the management of the project bear close similarities with the principles of LPDS. Starting from realizing the importance of collaboration to taking appropriate steps to improve the whole system resonate the underlying principles of lean. The following sections highlight some of the processes adopted during the design and construction the Empire State Building, and compare them with that of LPDS.

**Project Definition and Design Phase**

Empire State, Inc. was quick to realize that the design of the project could not be planned by the architects alone. They assembled an expert team including the owners, contractors, architects, structural and mechanical engineers, elevator consultants, and rental agents was required to collaborate, first to define the problem and then to solve it. This approach of collaborative production and decision making by involving key stakeholders other than the designer from the early stage of the project is suggested by LPDS during the project definition. Further, this provided an opportunity to use inputs from traditional sources for design programming as well as the inputs from the perspective of post-occupancy evaluation from the rental agents. Interesting to note, the requirements of the elevators affected the building’s form in both massing and height based on purely economic grounds (Willis, 1998). This approach of design articulates the value generation approach advocated by lean. The importance of the collaboration was realized by the architectural firm of Shreve, Lamb and Harmon; they believed the challenges presented by a project such as the Empire State required the “ability, experience and organization beyond the scope of a single professional unit, or would, if undertaken by the architect’s office, involve a duplication of effort and loss of time too expensive to be tolerated in an operation requiring large capital investment” (Shreve, 1930). This resonate the underlying concept of lean project delivery to optimize the system by identifying and eliminating waste in the system.

Unlike the traditional approach, estimations of costing and project duration were integrated with the production of the project definition of the Empire State Building. The design of the project was driven by its schedule. All the design decisions were made based on the owners’ requirement that the building be completed by May 1, 1931. This was influenced by the real estate practices of that time when the lease agreements used to be of annual terms commencing on May 1st (Willis, 1998). Thus, if the building was not leasable by that date, the owners would have lost one year’s revenue from rent. In addition, a longer schedule would add to the running costs of interest and taxes, which were estimated to be $10,000 per day (Willis, 1998). The tight schedule for the Empire State Building was influenced by these various financial factors, which in turn interacted and produced a complex equation that influenced the building’s final form. This concept of translating needs into design criteria has been advocated by LPDS during the project definition phase. However, it is not known whether any formal method of translating needs to design criteria was used (such as Quality Function Deployment). LPDS also encourages the establishment of a target cost whenever appropriate during the project definition phase. Ballard (2000) mentioned that target costs are appropriate for clients whose business case is based on a return-on-investment strategy such as commercial building developers as in the case of Empire State, Inc. That target cost approach was adopted in the Empire State Building
project is evidenced in Starrett’s comment: “When the architects made their preliminary sketches, they found that
eighty-five office floors reached about the height which could be consumed with the money available.”

The design strategies of the Empire State Building resemble various aspects of the lean design process. The main
ideology of lean design is to simultaneously design the product and the process – work structuring. In the Empire
State Building project, the stakeholders realized the importance of considering the process design along with the
product design. As time was of essence, they tried to produce a product design that would simplify site installation.
The work structure of the outer shell of the building was designed as an assembly of stainless steel mullions,
limestone faced piers, aluminum spandrels, and metal window with the intention to create “a sort of kit of parts that
would speed both fabrication and erection.” (Willis, 1998). During the design process of the Empire State Building,
the expertise of the specialty contractors were utilized for some of the design elements required close collaboration
of the design team and the manufacturer. Within the lean design paradigm, the specialty contractors are encouraged
to assist in the design process with process design, if not acting as a designer.

To produce a design for the world’s tallest skyscraper (at that time) and to ensure it could be constructed in less than
20 months, it was important to design the process itself. The Building Committee of the Empire State Building
project simplified the design process so much that they could produce 16 design variations in a span of four weeks’
time with an average cycle time of less than two days for each option. Each new design required input from the
consultants and revised cost estimates. In this process, every effort was made to maximize customer value in the
making of trade-offs between needs and objectives. Finally, the 17th version, Scheme K was adopted on October 3,
1929 by the owners. The contractors, engineers and subcontractors had taken just 2 hours the night before to give
their approval to “Scheme K” (Tauranac, 1995).

As suggested by Ballard (2000), the design phase transitions to the supply phase upon the development of the
product and process designs from the project definitions, which have translated the customers’ needs and
stakeholders’ input.

**Detailed Design Development and Construction Phase**

The phase consisting of detailed engineering of the product design produced during the design phase, followed by
fabrication, purchasing, and logistics management of deliveries and inventories is called the lean supply phase. The
detailed engineering design of the Empire State Building project was created a few floors at a time, with input from
Starrett Bros. and Eken, and then sent to subcontractors and suppliers for detailing and fabrication. To ensure
smooth workflow during the production process (to avoid any confusion that might result in delays) the detailed
specifications were prepared to express the consensus of opinion and experience of the architects, contractors, the
engineers, and the owner, as mentioned by Shreve (1930). Immediately after the preliminary drawings were
produced, the architects developed a set of outline specifications. These specifications were sent to the builders,
owners, subcontractors and material suppliers for comments and inputs. Decisions reached collaboratively on the
working documents, contracts and the job schedule were made with an eye to maximize the value generation.

With the production of detailed design, the design of the production process is also further detailed in this phase. In
the lean supply phase, Ballard (2000) recommended the use of lean manufacturing techniques to fabrication shops.
Interestingly, due to his background in manufacturing industry, Raskob believed that construction was akin to the
manufacturing process. This belief was translated in the form of pull system and just-in-time deliveries being
utilized in the construction of the Empire State Building project. Structural steel is a prime example of the pull flow
in the project, beginning at the design level. Designers would detail several floors at a time from the bottom up as
work chunks and provide those drawings to the steel fabricators for detailing “just in time.” Fabrication of the steel
began only hours after receipt of drawings and detailing (Sacks & Partouche, 2010). In order to avoid variability of
the workflow, structural steel was procured from multiple suppliers so as not to create a backlog based on the
capabilities of each supplier.

It is rumored that the just-in-time, pull flow of materials to the site was so efficient that “steel beams arrived from
the steel forging plants to the building site too hot to touch with bare hands” (Munson, 2005). Whether this is true or
not, it provides a vivid picture of how well the information and materials flowed – from design, to fabrication to
delivery to installation. Due to limited space on the site, inventories were minimized and deliveries were sized so that materials were typically used after no more than three days following their arrival to the site. Prefabricated items were stored at offsite staging areas, pulled to the site when needed and immediately set in place. As described in an article in the New York Times, “trucks drove directly into the belly of the building and the material they carried never hit the ground; it was snatched right off the truck beds and hoisted immediately to the floors where it was needed” (Kelly, 2006). This is as close as it can get to “one-touch material handling” ideals advocated by lean assembly principles.

To ensure predictable supply of materials, Starrett Bros. & Eken kept a close control of the supply chain by pre-qualifying suppliers, manufacturers and subcontractors to determine if they had the desire, facilities, manpower and capacity to accomplish a job of this magnitude. For example, the steel erection was let to Post & McCord, who attacked its problem on its own initiative and worked out a plant layout and performance schedule highly satisfactory to the builder. Prior to and during the construction of the Empire State Building, Starrett Brothers & Eken employed expeditors to determine the production capacities at quarries in Italy, Belgium and Germany, study of railroad facilities to ports and connections with Atlantic shipping. On the basis of the facts thus developed, a production, shipping, milling and placing schedule was worked out (Carmody, 1931).

Lean supply transitions to lean assembly with the beginning of delivery of tools, labor, materials or components to the worksite, or in other words, when physical change in the worksite is visible. In this phase, production control becomes of prime importance to conform execution to previously developed plans and strategies. William Starrett (1928) mentioned that a contractor’s function was “not to erect steel, brick or concrete, but to provide skillful, centralized management for coordinating the various trades, timing their installations and synchronizing their work according to a predetermined plan, a highly specialized function the success of which depends on the personal skill and direction of capable executives.”

Work structuring was applied in the Empire State Building project to create work chunks that facilitated predictable work flow. For example the work chunk for steel erection consisted of two floors at a time, and caulking between steel trim and floor consisted of five floors (Sacks & Partouche, 2010). By organizing the work chunks in this way, unnecessary traffic could be limited and more work could be completed. On a project the size of the Empire State Building, the contractors could have harmed themselves more than they helped if they had not divided the work in manageable chunks. The pace of the entire schedule for the Empire State Building project was controlled by four major structural operations: erection of structural steel, construction of floor arches, exterior metal trim and aluminum spandrel, and exterior limestone. The intention was to control the production of more than 60 major trades grouped into four streams, each led by a pacemaker. In lean assembly, establishing work flow predictability is of paramount importance – a set amount of time for specific activities helps to regulate production levels more than any other technique. The pacemaker approach adopted in the Empire State Building project allowed Starrett Brothers & Eken to know exactly how far ahead or behind they were on any particular task. On a close examination of the schedule, it was evident that time buffers were incorporated for decoupling of tasks (Sacks & Partouche, 2010) with the purpose of absorbing variability in the workflow.

Lean thinking focuses on the elimination of non-value added activities. One such non-value added activity is extra movement performed by a worker to obtain tools or materials that could be eliminated simply by having the materials needed close to the worker when they are needed and located in a place that requires very little effort by the worker to obtain. Methods used on the Empire State Building project to transport materials to where they were needed, when they were needed, were not only innovative, but they were efficient. The site contained 11 derricks – nine of these dedicated to lifting steel and two for large machinery, 17 hoists and two concrete plants. The derricks and hoists took care of the vertical movement of materials and on-site concrete plants allowed for the concrete to be immediately moved to where it was needed as opposed to losing time having to wait on it. Figure 2 below shows the layout of a typical floor. One of the most effective tools on the project was the rail cars that were built and provided the horizontal material transportation. There were four overhead monorail systems used for transporting material to the main floor and narrow railways – with carts that could hold eight times the amount of a wheelbarrow – with a complete loop on each floor. When material arrived on site, it was either lifted upward by a hoist or derrick or put in a rail car and sent to the appropriate floor.
In order to ensure smooth flow of work, Starrett Brothers and Eken realized the essence of “keep moving with a continuous feed of materials to the men” and “getting men and materials present when and where they were needed” (Willis and Friedman 1998). The movement of bricks to the masons was an example of how redundant movements were eliminated to ensure constant feed of materials to workers. Bricks in those days were typically dumped in the street and then the masons would move them by wheelbarrow to the place in which they were needed, as they were needed. For the Empire State Building project this method simply would not have worked. With 10 million bricks to be laid, a more efficient method had to be devised. Answering the need for innovation, the construction team designed a chute that led to a hopper in the basement where the bricks were dumped. When bricks were needed the hopper would release them into rail cars and they would be moved to the correct floors where they were needed.

Conclusion

The stakeholders of the Empire State Building was guided by the sole goal of building the tallest building in the world and have it completed and ready for tenants by May 1, 1931. In order to achieve the goal, the stakeholders of the project adopted the Transformation-Value-Flow model of production management in place of the transformational model that was prevalent at that time. Empire State, Inc. set up a building committee to make timely decisions in order not to impede progress on the plans and construction. Shreve, Lamb and Harmon made innovative design decisions in consultation with the committee to speed construction. Starrett Bros. & Eken continued to look for more efficiency by improving the system. They were able to realize that in order to achieve their goal they had to focus on the overall system. Thus, they could simplify the overall system of design and construction, and were able to identify the wastes in the system and eliminate them. This simple understanding forms the underlying principle of lean construction. The collaborative team approach, united under the common goal of providing the owner with the tallest building in the world, with approximately 1.2 million square feet of rentable space, in record setting time was a unique concept employed during the management of the design and construction of the Empire State Building.

Comparing the various techniques adopted in the Empire State Building project, it is evident that they bear very close resemblances with that of the lean principles. Interestingly, these techniques were practiced at a time when principles of lean construction were not formalized, or the term ‘lean’ was not even coined.
References


Mechanical Contractors Association of America (MCAA). (2003). “CSI reverses course on proposed revision to Masterformat.” The MCAA National Update


Lost in transition: the transfer of lean manufacturing to construction

Bo Jørgensen
ConProC, Copenhagen, Denmark, and
Stephen Emmitt
Department of Civil and Building Engineering, Loughborough University, Loughborough, UK

Abstract

Purpose – The purpose of this paper is to explore the transfer of lean manufacturing/production from the Japanese manufacturing industry to the construction sector in the west.

Design/methodology/approach – Research literature from the fields of lean manufacturing/production and lean construction was reviewed. This revealed a number of characteristics that are specific to lean construction, most notably the recognition that critical research findings have been slow to emerge but appear to be gaining momentum.

Findings – In the transition from manufacturing to construction the process losses appear to be related to critical aspects and the challenges surrounding practical application to a different context. Lean is highly interpretive and there is no shared definition or understanding of what is meant by lean, lean production, and lean construction. The focus has been mainly on production system design, planning and management, and implementation. This narrow focus has meant that some important issues concerning the wider aspects of lean have been overlooked. There is a need for a “back to basics” discussion on many other aspects of the approach, such as whole-life value and waste identification.

Research limitations/implications – The work is limited to an extensive literature review.

Originality/value – The extensive literature review makes an original contribution to the lean construction field and provides a valuable resource for researchers.

Keywords Construction industry, Lean production, Manufacturing systems, Transfer processes

Paper type Literature review

Introduction

Originally adopted from manufacturing the lean approach to construction has become an established theme within the architectural, engineering and construction (AEC) sector where it has been promoted as a means to increase productivity and project performance (e.g. via the Egan report, DETR, 1998). Although the promotion of lean construction (and to a lesser extent lean design in AEC) has been highly visible in countries such as the USA, UK and Denmark, critical debate has been scarce. Success stories reporting significant and even revolutionary results following the application of lean approaches, tools, and systems from volume manufacturing are common in the construction sector, although in many cases documentation is weak or absent. At the same time the proponents of lean construction have continued to ignore the extensive critical literature on lean manufacturing, a point repeatedly made by Green (1999a,b;
supporting their arguments (e.g. Womack et al., 1990; Cooper and Slagmulder, 1999) have relied heavily on information provided by the management of the organisations studied. They do not refer to any examples of rigorous research methods for validating the descriptions of the practices reported. This is important in relation to a discussion of the transfer of lean to construction, because well-known management books and lean production publications have, and continue to be, taken as the conceptual starting point for most lean construction publications. Thus one could argue that the foundations for many lean construction publications are not built on very strong ground. This is an issue that deserves more attention from researchers.

When considering the transfer of lean production (processes) to construction (projects) it is necessary to consider the main characteristics of organisational concepts. First, they leave considerable room for interpretation. Second, they promise performance improvements. Organisation concepts that become management fashions also tend to become de-coupled from their original meanings as they are diffused, interpreted, translated, adopted and adapted (Abrahamson, 1996; Kieser, 1997). This phenomenon has had signifcant impact on the diffusion of lean production, resulting not only in the term being de-coupled from its original meaning, now covering many different kinds of initiatives, but also in widespread rhetorical adoption often dominating over substantial adoption (Benders, 1999; Benders and van Bijsterveld, 2000).

**Common elements**
In spite of the variety of meanings ascribed the label “lean”, there appears to be a few common elements:

- A focus on eliminating/reducing waste and sources of waste in relation to the delivery of artefacts or services that represent value to the end customer.
- End customer preference is adopted as the reference for determining what is to be considered value and what is waste.
- Management of production and supply chain from a (customer) demand pull approach.
- Approaching production management through focus on processes and fows of processes.
- An (at least to some degree) application of a system’s perspective for approaching issues of waste elimination/reduction.

The concept of customer is central to lean thinking. A main principle is to consider all downstream operations as customers, while value is defined only as perceived by the final/end customer (often referred to as the “ultimate customer”). This involves some important implications when applying lean to construction, where “end customers” are multiple and the construction client rarely can be considered the single ultimate customer. Another crucial aspect is time. Typically built artefacts deliver their value and generate their waste over a very long time perspective. This is contrasted to the definition of end customer value adopted by Womack and Jones (1996, p. 16) who state that value is “only meaningful when expressed in terms of a specific product (a good or a service, and often both at once) which meets the [end] customer’s needs at a specific price at a specific time”. This, nevertheless, constitutes the single dominant reference to
customer value in the lean literature. The implication for built artefacts is addressed in more detail below.

**Lean in a construction context**

Lean entered construction a couple of years after it had gained momentum in western manufacturing industries. Its application to the built environment was first discussed by Koskela (1992), who investigated what he (then) referred to as “the new production philosophy” and its application to construction. In a later PhD thesis Koskela (2000) argued that efforts to improve production (of physical artefacts, e.g. buildings and other structures) suffer from the absence of a general theory of production, and he argued that such a theory would need to encompass three fundamental elements of transformation, process, and value. Koskela concluded that most production practice and research (in construction, manufacturing and other industries) has been dominated by a focus on addressing production simplistically from a transformation perspective, with process and value generation aspects being under-emphasised. Koskela’s work formed the foundations for what has become known as lean construction. Early ideas were also adopted from lean manufacturing and production, as can be seen from Alarcon (1997) and some of the contributions from the 1st International Workshop on Lean Construction (e.g. Koskela, 1993; Tanskanen et al., 1993; Ballard, 1993). Although Koskela’s work is frequently cited, few have discussed the entire framework, preferring to concentrate on discrete aspects. The most dominant of these have parallels with the common features identified in lean manufacturing (bullet points above) and can be summarised under three themes.

1. **Production planning, control and management**

Two issues have dominated this theme, namely the last planner system of production control (LPS) and questions regarding scheduling techniques and work structuring. Approaches and methods for addressing waste through reduction of variability and uncertainty, especially via the last planner system of production control (LPS), have been widely promoted and discussed (e.g. Ballard, 1993; 2000; Ballard and Howell, 1998; 2003b). This appears to have become the most popular measure in applied initiatives, and in some local or national environments LPS has become largely synonymous with lean construction (Green and May, 2005) For example, Paez et al. (2005) conclude that daily huddle meetings and the LPS are essential aspects of lean construction because they deal with exceptions and uncertainty. LPS also features prominently in the relatively few publications on techniques for lean building design management (e.g. Koskela et al., 1997; Ballard, 2000; Ballard, 2002), thus further reinforcing the rather narrow interpretation of lean construction. A number of studies have discussed issues of activity scheduling and of structuring projects, assignments and tasks for the application of lean techniques to construction (design and production). For example structuring of task execution for optimising resource allocation (e.g. through optimising batch sizes and minimising buffers, inventories, and work in progress), achieving short production cycles etc. In the approach of the Toyota Production System and lean production this field is central to the pursuit of short lead times, continuous improvements. Examples include workflow scheduling and management (Tommelein et al., 1999; Kenley, 2004), work structuring (Tsao, 2005) and simulation of processes and of buffering and batching practices (Tommelein, 1999; Alves and Tommelein, 2004).
2. Production system design and construction project design
This theme is strongly connected to the one above. More general questions of how to structure construction projects (and recently also the degree to which these are to be approached as individual projects in the first place) have been a constant characteristic. Some examples are supply chain management topics (e.g. Vrijhoef and Koskela, 1999; 2000; Vrijhoef et al., 2003) and construction as a project-based production system (Ballard, 2005; Vrijhoef and Koskela, 2005; Koskela and Ballard, 2006; Winch, 2006).

3. Implementation and application
Aspects of implementation and application of tools (the LPS in particular), but few have looked into the wider impacts of lean diffusion beyond project or company level. Examples include empirical studies reporting different findings regarding project or process performance in connection to lean initiatives (CIB, 2002; Thomas et al., 2002, 2003; Alárcon et al., 2005), and qualitative studies investigating implementation and diffusion processes, reporting applied practice in comparison to formal procedures, identifying, e.g. obstacles and possibilities regarding implementation. Recent examples are provided by Miller et al. (2002); Johansen et al. (2004); Jørgensen (2006).

A common feature appears to be the adoption of a project structure as the organisational basis for designing and making. It is also possible to see that there has been a development in debate, understanding and practice within the field, which appears to follow a similar pattern to the development of the lean production literature. An indicator of an evolving field is found in Koskela’s work. Early works discussed lean production as applied to construction (see Koskela, 1992, 1993) while later publications have focused on the more fundamental issues of developing a general theory for production (Koskela, 2000; 2001; Koskela and Kagioglou, 2005), with lean construction addressed as a discipline inspired by, not copied from, lean production (Koskela et al., 2002). Similar to the diffusion of lean thinking within the manufacturing sector (Hines et al., 2004), the interest in value started to gain momentum much later than the issues concerning production rationalisation; although this development in construction appears to be slower compared to other sectors. Figure 1 summarises the transfer of lean from manufacturing to construction.

Customer value
An important implication of applying the lean philosophy to construction is the understanding of waste and value. In the lean terminology (as originally suggested by Ohno, 1988) value is understood very narrowly as consisting only of what the end customer perceives as representing value to him/her. Anything that does not directly add to this value is regarded waste. Consequently any process is wasteful, so it is appropriate to distinguish between waste that cannot be avoided but should be reduced as much as possible (type 1), and waste that in principle is not required for delivering the value requested (type 2) which should be eliminated. In the lean construction literature value is either unaddressed, or it is largely discussed in the context of the construction project (the process), not the resultant building (the product).
The concept of customer value poses a number of challenges when applied to the construction of a built artefact representing a long-term investment which may be in function for one hundred years or more and have a number of different owners and users. The lean philosophy is only meaningful in construction if value and waste are defined with reference to a whole-life perspective. From a practical perspective, questions of systematically enhancing value and eliminating waste become increasingly more complex the further one moves from production activities into the field of architectural design. Detailed discussion of customer value is outside the scope of this paper, however, it is important to highlight the fact that this does need to be addressed.

The concept of customer value poses a number of challenges when applied to the construction of a built artefact representing a long-term investment which may be in function for one hundred years or more and have a number of different owners and users. The lean philosophy is only meaningful in construction if value and waste are defined with reference to a whole-life perspective. From a practical perspective, questions of systematically enhancing value and eliminating waste become increasingly more complex the further one moves from production activities into the field of architectural design. Detailed discussion of customer value is outside the scope of this paper, however, it is important to highlight the fact that this does need to be addressed.

Figure 1. Schematic overview of the diffusion of lean production – schematic overview, only main ways (arrows) shown
Lean construction – the lack of a common definition

A distinctive feature of the lean construction literature is the lack of commonly used definitions. In an extensive review of the lean construction terminology and definitions, Jørgensen (2006) found a wide range of interpretations; concluding that few authors had posited explicit and concise definitions, making it difficult to establish exactly what the term lean construction means. Jørgensen (2006) also found that the term “lean design” was increasingly being applied (e.g. Koskela et al., 1997; Freire and Alarcón, 2002), although it too had a variety of meanings. The lack of a common definition for lean construction and “leanness”, has also been discussed by Green and May (2005) who found that lean construction and lean production are “variously understood as a set of techniques, a discourse, a ‘socio-technical paradigm’ or even a ‘cultural commodity’”. Based on an empirical study from the UK construction industry and interviews with authors of the Egan Report (DETR, 1998), Green and May suggest that three models represent the practical adoption of lean in construction: a lean model of waste elimination, partnering, and structuring the context. Their findings support the view that lean construction, while highly diverse in interpretation and application, is inspired by lean production rather than just a modified copy of it (as previously discussed by Koskela et al., 2002). Whether lean construction techniques are an extension of lean manufacturing or a diversion from it is, according to Paez et al. (2005, p. 234), still an open question. A question that is difficult to answer given the wide range of meanings found in the literature. Green and May conclude that the meaning of lean construction is continuously renegotiated within localised contexts. Of course, this observation could also be made of other approaches such as project partnering and supply chain management in construction (e.g. Fernie and Thorpe, 2007).

The importance of clear terminology, or rather the lack of it, is illustrated in an exchange of views following publication of a report by Thomas et al. (CIB, 2002). In the report and two associated articles based on empirical studies (Thomas et al., 2002, 2003) it is argued that in construction the production throughput variability should be reduced to “acceptable levels” and the remaining variability absorbed by flexible workforce management strategies. Flexible workforce strategies were found to be a more efficient alternative to reducing the variability of workflow, which according to (Thomas et al., 2002, 2003) has been overemphasised in lean construction. They concluded that lean construction should focus more on labour flow and workforce management strategies to achieve better labour performance.

The arguments and conclusion have been disputed by Howell et al. (2004) and Ballard et al., 2005), and the critique subsequently rejected by Thomas et al. (2004, 2005). The exchange of views is marked by lengthy clarifications and obvious disagreement regarding what is meant by terms and definitions through which the arguments are presented. The very perception of labour resource is an issue of fundamental importance to discussions on the application of lean techniques, methods and approaches to construction management. If understanding production processes as involving a set of different flows, (according to the TFV theory (Koskela, 2000) on which much of the discussion builds), it follows that the flow of labour cannot be considered a simple production parameter, like, e.g. the flow of materials. This aspect is brought up by Ballard et al. (2005), emphasising that labour is not a commodity and should not be treated as such; thus they do not find the recommendation of applying flexible workforce capacity strategies ethically justifiable. The discussion has raised
phenomenon and that the adoption of lean in construction does not necessarily lead to negative issues. Interestingly, they fail to address Green’s concern about the reluctance of the lean construction community to embrace the critical research literature. It is, however, not proven that negative impacts of lean production necessarily transfer to construction. Some studies have revealed how the application of lean practices had a deteriorating effect on workers’ conditions in manufacturing, but context must be considered before concluding that outcomes of lean implementation, positive or negative, can be generalised across all business sectors. Research into the possibilities for construction to benefit from lean approaches while avoiding negative impacts, as called for by Howell and Ballard (1999), is still to be addressed.

The question about an appropriate fundamental approach for the development of a production management theory has been addressed in a number of publications (e.g. Koskela, 2000; Koskela et al., 2004; Koskela and Ballard, 2006). Economics-based approaches to managing projects through decomposition of elements, cost and transactions are criticised for offering an inappropriate basis for theory development since they do not address directly the transformation, flow and value perspectives of production which Koskela (2000) argued to be central for understanding the production phenomenon. It is argued that a theory of project management should instead be based primarily on theories of production. Responding to a call from Koskela et al. (2004) and Koskela and Ballard (2006) to engage in a discussion on these issues Winch (2005; 2006) argues that, on its own, a production-based management approach will be insufficient since it does not address vital contextual issues of transaction costs, market functions and intra- and inter-organisational business processes of the supply chain. Winch (2006) also argues that lean construction builds on a unitary concept of value deriving from quality management, which he concludes is inadequate for developing methods for ensuring that incentives are aligned both within the project coalition of interests and between the project coalition and external interests. While acknowledging that the work on lean construction has contributed to the understanding of the project management field Winch (2006) concludes that the proposed dichotomy between theories of economics and theories of production is not meaningful.

An important observation is that implicitly Winch argues from a position of lean construction narrowly understood as building on a theoretical element constituted by the TFV model (Koskela, 2000) and practical application through the framework of the Lean Project Delivery System (Ballard et al., 2002). Such limitation is arguably regrettable, but understandable within the confines of a journal article when considering the absence of a shared definition/understanding of lean construction.

**Conclusions and recommendations**

Comparing the lean manufacturing and the lean construction research literature it is evident that that first field is considerably more developed than the second. The literature relating to lean production and manufacturing has a certain maturity, in that there is evidence of informed and critical debate within the peer reviewed journals. In particular, it is the critical and informed debate that appears to have been slow to develop within the lean construction literature. Similarly, a coherent philosophy for lean construction has not yet been developed. This may simply reflect a slower development of the construction literature compared with lean production and manufacturing (one could argue that it is difficult to enter into informed debate when...
so little research has been published in the peer reviewed journals; or it could be indicative of a reluctance to tackle some of the underlying weaknesses of the lean production approach. Similarly, the difference between the bodies of literature could be related to the fact that some of the most critical arguments are not relevant to a construction context; however, this cannot be taken for granted and needs to be confirmed or refuted through research.

In the transition of lean from manufacturing to construction the process losses appear to be related mainly to the critical aspects and the challenges surrounding the practical application to a different context. The picture is blurred by diverse interpretations of ideas and concepts (similar to the lean manufacturing literature) and the absence of a generally shared/accepted system of terminology is an obstacle for focussed debate. The original concept of delivering value to a specific single end customer is also highly problematic when considering the built product in a whole-life context.

Some “back to basics” discussion on what is meant and implied by the terms “lean construction” and “customer value” would be helpful in establishing greater clarity. In particular the role of designers and the effect of early design decisions on construction activities requires further research. The lack of empirical research findings in the peer-reviewed journals is currently a weakness of the lean construction field. So too is the failure to recognise the empirical research findings from the lean manufacturing and production literature, especially the findings that are not supportive of lean superiority. Confronting and learning from known weaknesses and the potential disadvantages of lean manufacturing should help, rather than hinder, the future development of lean construction. Critical discussion on the preconditions for, and limits of, lean application to construction would greatly help to advance the body of knowledge concerning practical application of lean to the built environment. Present industry attention illustrates the need for a better basis from which to offer impartial advice to practitioners based on empirical research findings, clear constructs, informed debate and constructive criticism.

References


Factors Influencing the Construction Industry’s Shift to Modular Construction

Namhun Lee Ph.D.
Central Connecticut State University
New Britain, Connecticut

Seong Jin Kim Ph.D.
Minnesota State University Mankato
Mankato, Minnesota

Current practices in the construction industry emphasize on increasing productivity through several approaches. Building Information Modeling (BIM) technology is one of the approaches to improving work productivity. It opens up a channel to the increased use of prefabrication and modularization. Model-driven prefabrication becomes a way to design and construct prefabricated modular buildings. Furthermore, current influential construction trends such as Lean Construction and Green Building have caused many construction professionals to bring prefabrication and modularization back into the spotlight. Modular prefabricated construction can reduce on-site activities, site disturbance, and waste or pollution through more efficient processes. Consequently, modular prefabricated construction has become more prominent in the construction industry. The primary benefit of modular construction is the increased productivity, especially when schedule is tight, there is a weather concern, and skilled labor is not available. The main objective of this study is to identify factors influencing the construction industry’s shift to modular construction and make some suggestions for its application to future vertical-extension projects. To achieve this objective, this paper reviews modular construction processes and building codes and permit requirements for modular prefabricated buildings. Also, the paper investigates current methods of modular construction through an industry survey and discusses possible benefits from modular construction methods and potential barriers in utilizing them.

Key Words: Modular Construction, Prefabrication, Building Codes, Construction Methods

Introduction

Construction projects are labor-intensive and embraced by various risks inherent in the project. Current practices in the construction industry emphasize on increasing productivity through several approaches. One approach to increase productivity is prefabrication and modularization. Modern prefabrication and modularization actually started in the early 1900s. Europe and Japan have adopted these methods for a long time. Also, in the United States, modular construction has been widely used in military and commercial buildings.

Current influential construction trends such as Lean Construction, Building Information Modeling (BIM), and Green Building have caused many construction professionals to bring prefabrication and modularization back into the spotlight. The National Research Council (2009) recommended prefabrication and modularization as an “opportunity for breakthrough achievement” to improve productivity in the construction industry. There are some factors influencing the construction industry’s shift to modular construction. Consequently, modular prefabricated construction has become more prominent in the construction industry due to its ability to combine all the current construction trends.

Modular Prefabricated Construction

Modular construction is a process in which building units are prefabricated in a safe and controlled setting at a manufacturing facility, transported to a construction site, and erected into their final position on site (Gassel & Roders, 2006). This process has been utilized when onsite construction is limited by constraints such as space limitations, tight schedules, and adverse weather conditions. Especially for mechanical, electrical, and plumbing
(MEP) components, factory-built units have been used often (Lu & Korman, 2010). These modular units are constructed in an enclosed facility where constraints hindering the construction timeline can be controlled.

With advancing Building Information Modeling (BIM) technology, model-driven prefabrication becomes a way to design and construct modular buildings (Bernstein et al., 2011). It has been used for a wide variety of building types, ranging from apartment buildings to healthcare facilities. This building method can provide a project with several benefits, compared to conventional construction practices.

The primary benefit of prefabricated modular construction is the increased productivity, especially when a schedule is tight, there are weather concerns, or skilled labor is not available. Other benefits include enhanced and simplified site logistics, a lower risk of theft or vandalism, and better protection from weather damage. Prefabricated modular construction helps to decrease material waste and create less disruption to the surrounding environment (Bernstein et al., 2011).

Shelley (1990) argues that five to ten percent of the total cost for most projects can be saved using modular construction. Typically, labor rates in the fabrication shop are less expensive than ones on the jobsite (Hesler, 1990). In addition, required equipment and tools remain in the fabrication shop. Therefore, equipment cost can be saved through the transfer of field works into shop works. This results in overall cost and time savings especially when work is repetitive (e.g. 90 modular units of the same bathroom).

Most benefits to modular construction result from working in a controlled indoor environment. Modular buildings can be constructed with a faster schedule and in a safe environment. The quality of production can be increased because prefabricated modules are constructed in a better work environment and are inspected by third parties. Safety can be also improved through modular construction because the majority of work is performed in a controlled factory setting. Construction time can be reduced by carrying out several tasks independently. For instance, the schedule can be accelerated by working the module assembly and site development concurrently. In modular building projects, several activities can go on in parallel that would typically be performed in series. This results in earlier completion of a project. Therefore, financing expenses and associated costs can be reduced (Shelley, 1990).

On the contrary, cost increases emerge from the extra design and engineering and transportation and handling effort. This extra activity is required to avoid later design changes and withstand transportation and handling loads. In addition, more detailed planning and scheduling are required for a modular construction project than a conventional construction project since greater interdependence of construction activities associated with site logistics should be given. Therefore, the actual planning phase of a modular construction project is typically longer than in a conventional construction project (Mullet, 1984).

In modular construction, building units are prefabricated and assembled at various locations. Hence, it is not a simple process to communicate among fabricators for seamless coordination due to the increased interdependence of construction activities. Changes in a design can disrupt various inter-related activities. Thus, modular construction is not easily adaptable to design changes. Furthermore, transportation studies including route investigations are required early in the project not only to determine the size of factory-built units and equipment requirements with adequate lifting capacity but also to thoroughly analyze the possible transportation methods meeting transportation, handling, and erection requirements (Stubbs & Emes, 1990).

**Building Codes and Permit Requirements**

Building codes are the rules and regulations that specify the standards for constructed objects to protect public health, safety, and general welfare. Modular buildings are constructed according to the same state, local or regional building codes as site-built buildings. For example, the state building code of Connecticut (2017) specifies that “A certificate of approval by an approved agency shall be furnished with every prefabricated assembly, including modular housing, except where all elements of the assembly are readily accessible for inspection at the site. The building official shall inspect placement of prefabricated assemblies and the connections to public utilities and private water and septic systems at the building site, as well as any site built or installed components or equipment to determine compliance with this code. A final inspection shall be provided in accordance with Section R109.1.6.”
Local authorities may require that all foundations to be used in conjunction with the modular buildings meet either permanent or temporary standards. All site related works are subject to local permitting and inspections. For instance, the Florida state building code (2017) - Section 553.80(1)(d) articulates that “Erection, assembly and construction at the site are subject to local permitting and inspections.” Furthermore, local building agencies may have standards for handicapped access and aesthetic elements.

Table 1

Currently adopted model codes

<table>
<thead>
<tr>
<th>Code Type</th>
<th>Code Model</th>
</tr>
</thead>
<tbody>
<tr>
<td>Building/Dwelling Code</td>
<td>International Building Code</td>
</tr>
<tr>
<td>Structural Code</td>
<td>International Residential Code</td>
</tr>
<tr>
<td>Mechanical Code</td>
<td>International Mechanical Code</td>
</tr>
<tr>
<td>Plumbing Code</td>
<td>International Plumbing Code</td>
</tr>
<tr>
<td>Electrical Code</td>
<td>National Electrical Code</td>
</tr>
</tbody>
</table>

Modular building contractors should know the regulations that apply to their own project based on the physical building site and the agencies that have jurisdiction over that area. They should check with the state and local agencies to ensure that their projects will meet or exceed the required building codes. Most states have commonly adopted the model codes presented in Table 1. These codes must be uniformly applied and enforced without any distinction as to whether building is conventionally constructed or manufactured. Onsite modifications to existing modular buildings must be also permitted and inspected by local authorities.

Building plans approved by the local building authority must be submitted with the building permit application. Under the jurisdiction of the local building department, a building permit application usually requires:

- **Site plan** which shows building onsite location, parking, landscaping, all rights of way, and all utilities serving modular building and on-site construction.
- **Foundation plan and installation details** which include fastening schedules and utility hook-ups.
- **Geotechnical report**
- **On-site construction details** for all stairs, ramps, handrails, carports, covered entries, and any other structures.

Local authorities are responsible for inspection of the on-site assembly and construction of modular buildings as well as all other site related issues including foundations and utility hook-ups. Therefore, modular buildings must meet the same building codes and permits as those required of conventionally constructed buildings.

The transportation method limits the size of modules since they need to be transported to the jobsite. This limitation is mostly based on state and federal highway restrictions. Thus, the size of modules depends on the variance allowed the local state transportation board and the condition of the local roadway from the prefabrication shop to the jobsite. Typically, the width of modules ranges between 10 and 15 feet; the length of modules is limited by the turns on the route (about 60 feet); and the height of modules is dictated mostly by highway overpasses or tunnels on the route (under 14 feet). For instance, the Connecticut guidelines and policies (2017) for transporting mobile, modular or sectional housing require the following restrictions:

“Maximum width (14’) fourteen feet including all roof overhangs, sills, knobs, and siding; maximum height (13’6”) thirteen feet six inches; maximum length (85’) eighty-five feet, except that (90’) ninety feet is permitted when the towed unit does not exceed (66’) sixty-six feet in length excluding the hitch; maximum
gross vehicle weight of 80,000 pounds which is allowed when all the requirements of the Federal Bridge Formula are met.”

**Current Methods of Prefabrication and Modularization**

Transportation, handling, and erection activities are performed at the end of the modular construction process. However, it is critical to prearrange special support for transportation and handling equipment depending on the modules’ dimensions and transportation methods. Once building modules arrive at the jobsite, they will be erected into their final positions. The process of modular construction is illustrated in Figure 1.

After the module design is approved and other interdependent activities are undertaken, the design should not be changed. Typically in modular construction, there is little flexibility in changes of module design. Hence, modular construction requires more time to complete design and engineering prior to commencing construction than conventional construction practices do. This may result in a tight schedule with little float time. To overcome this challenge, technology needs to support an effective modular construction process. Nowadays, technology has advanced enough to generate shop drawings and allow the fabrication of modules directly from BIM models. This enables just-in-time delivery for field installation on the jobsite. Just-in-time delivery is essential in modular construction projects. Otherwise, storage space may be required additionally to avoid onsite congestion.

![Figure 1: Modular construction process](image)

With BIM, it is possible to identify interferences and resolve any issues during a coordination session. This has evolved into an effective way for completing field installation with few errors, if any. Furthermore, it has become possible to drive cutting machines directly from the 3D model. Using BIM, it is possible to have full collaboration throughout the entire modular construction process. This collaboration reduces design errors and eliminates conflicts caused by uncoordinated drawings.

BIM provides not only the ability to validate the design and verify compliance but also the quality of the modules against an established set of standards or guidelines (e.g., code compliance, structural integrity, stability, tolerances and connections, etc.). In addition, BIM can be used to create shop drawing and support the coordination process among specialty contractors. BIM can be integrated with fabrication machinery and supply chain management systems to facilitate the specialty contractor’s fabrication process. The following information can be possibly added on BIM models:

- Material quantities and ordering
- Work planning and labor codes associated with fabrication
- Field installation and assembly codes of modules

To create BIM models that support the shop drawing and coordination process, there are two key factors that should be considered: (1) design intents and (2) engineering knowledge of the fabrication and installation processes in modular construction. Figure 2 illustrates how the two factors are embedded in the iterative BIM-based coordination process.

There are other uses for BIM in modular construction projects such as visualization of design intents and site logistics plans, analysis and evaluation of alternative materials, and simulation of intended construction sequencing and installation. The use of BIM is a way for all project team members to accomplish their common goals by providing them with the benefit of improved visualization of a construction project through a shared 3D virtual model of that project.
Industry Surveys on Modular Construction

Individuals from fifty companies were contacted to verify if they have currently had projects using modular construction. Of the fifty companies, seventeen individuals explained their recent modular building projects. Based on the project information described by them, the projects were grouped by the type of building. Table 2 lists the number of projects by the type of building.

Table 2

<table>
<thead>
<tr>
<th>Type of Building</th>
<th>No. of Projects</th>
</tr>
</thead>
<tbody>
<tr>
<td>Commercial Housing</td>
<td>7</td>
</tr>
<tr>
<td>Healthcare</td>
<td>4</td>
</tr>
<tr>
<td>Education</td>
<td>6</td>
</tr>
<tr>
<td>Retail</td>
<td>2</td>
</tr>
<tr>
<td>Office</td>
<td>2</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td>*<em>21</em></td>
</tr>
</tbody>
</table>

Note: *This number is greater than the total number of the respondents which is 17 because some respondents mentioned more than one project.

The seventeen individuals were asked again to participate in a survey on modular construction. All seventeen individuals responded. The respondents’ roles in their modular building projects are presented in Table 3. This survey focuses on the following information: (1) general information on modular construction practices and (2) specific examples of benefits from modular construction methods. The findings that have been derived from this survey are described below.

One of the questions was “what percent of work is done typically in the manufacturing factory?” Most of the respondents answered that 60-80% of work is completed in the manufacturing factory. Another question was “how much cost savings occur from prefabrication and modularization?”. Five respondents mentioned an average of 6-10% cost can be saved compared to on-site construction. However, most of the respondents stated that the cost is not necessarily less all the time. The next question was “How much time can be saved from modular construction?” Fifteen respondents mentioned that the project schedule can be reduced by about 1-2 months. Three respondents indicated that the schedule can be decreased by 5 months or more, compared to conventional construction methods.

This survey also tried to identify if there was a common reason for using modular construction methods in building projects in which the respondents were involved. Most of the buildings had to be functional much faster than was

---

Figure 2: BIM-based coordination process
possible with conventional construction methods. This was the most common answer to the question, “why was modular construction chosen?” Also, this survey found that only three respondents stated they used BIM for modular construction projects.

Table 3

Roles of respondents

<table>
<thead>
<tr>
<th>Role</th>
<th>No. of Respondents</th>
</tr>
</thead>
<tbody>
<tr>
<td>Owner</td>
<td>2</td>
</tr>
<tr>
<td>Designer</td>
<td>3</td>
</tr>
<tr>
<td>General Contractor</td>
<td>5</td>
</tr>
<tr>
<td>Modular Manufacturer</td>
<td>7</td>
</tr>
<tr>
<td>Total</td>
<td>17</td>
</tr>
</tbody>
</table>

From this survey, several specific benefits and barriers in utilizing modular construction methods were also identified. The benefits and barriers identified by the respondents are summarized in Figure 3.

Figure 3: Current benefits and barriers in utilizing modular construction

As shown in Figure 3, 71% of the respondents mentioned faster project delivery as the main benefit from modular construction. 59% of the respondents explained safer working conditions and improved quality and material management as the benefits from modular construction methods. Also, 47% of the respondents indicated a lack of cooperation between design and construction as well as between off-site work and on-site work as the main barrier in modular construction projects. 41% of the respondents mentioned that transportation and logistics issues should be managed carefully.
Discussions

Modular buildings use the same materials and must comply with the same building codes and standards as site-built facilities. Furthermore, each module is engineered to independently withstand the rigors of transportation and hoisting. Once all modules are assembled and sealed, they reflect the identical design intent and specifications of their site-built counterparts. Modular construction can reduce the number of change orders due to inflexibility in design changes as well as controlled factory settings. The design should be completed before the module unit is produced and should not be changed during production of modular units. In this way, the cost of modular construction can be managed and controlled. This would be one of the reasons why modular construction is cost-efficient compared to conventional construction.

Modular construction projects can be completed faster than conventional construction projects. This is possible because modular units can be built in a factory simultaneously with site and foundation works. For this reason, modular construction reduces construction time and mitigates the risk of weather delays during construction. It is a key factor as to why modular construction is used in building projects. Moreover, modular construction ensures improved quality and material management. Materials are delivered and stored at the manufacturing plant safely and securely, which prevents them from damage or quality deterioration. Also, it is possible for contractors to minimize the storage of hazardous materials on jobsite. Manufacturing plants can have stringent quality assurance and control programs with independent inspection and testing protocols, which promotes superior quality of construction.

Modular construction removes significant numbers of on-site job activities and decreases a significant amount of disturbance resulting from labor, equipment, and suppliers, thereby improving overall jobsite safety and security. Laborers work in controlled environments, which significantly reduces safety incidents. Modular construction also promotes sustainability by reducing on-site operation, waste, or pollution through more efficient processes. Modular buildings can be disassembled and the modules can be relocated or refurbished for another use.

As described above, there are perceived benefits from modular construction. On the other hand, there are realized barriers in modular construction. First, there may be permit and code issues because building officials may not be knowledgeable about modular prefabricated construction. In addition, there may be transportation issues when the manufacturing site is in a different state. Late design changes, an adversarial climate between designer and contractor, and a lack of cooperation could be potential issues on utilizing modular construction.

This study identified that the primary factors influencing the use of modular construction methods include “faster delivery” and “cost savings” from the owner’s perspective and “safer working environments” and “better quality of construction” from the contractor’s viewpoint.

Conclusions

From this study, it can be concluded that several potential benefits can be achieved if modular construction is used under appropriate conditions. It should be also emphasized that modular construction is not for every project. Therefore, influence factors for modular construction must be identified before this method is adapted for vertical-extension projects. Modular construction can be a cost-cutting, time-saving option. Also, it can be a venue for exceptional safe records and quality project delivery.

In conjunction with BIM, model-driven prefabrication process can be efficiently and effective for modular construction. However, it need to be more involved in modular construction projects. Again, the key to success with prefabrication and modularization is strategy in selecting which projects are most appropriate for modular construction. One of the most critical criteria is to evaluate if buildings have a repetitive piece of work. This would be the reason why modular construction methods have been used commonly for housing, healthcare centers, schools, hotels, and dormitories.

Modular construction also requires a higher level of collaboration between project stakeholders. An integrated approach to project delivery increases the possibility for project success as well as collaboration. Therefore, it is
beneficial for stakeholders to choose modular construction early in the project development process. In addition, it is essential for modular manufactures to get involved early in the design phase so that the benefits from utilizing prefabrication and modularization can be maximized.

**Limitations of This Study**

The authors were not able to obtain specific data such as actual costs and schedules of modular construction projects because the data is either proprietary or confidential. Hence, this study was not able to do comparative analysis with actual data of off-site vs. on-site construction. Nevertheless, the survey questions focused on comparing the two different construction methods since the respondents already know the difference between the two methods even though the data cannot be shared to third parties. Therefore, the authors believe that this study probed the difference of the two construction methods descriptively.

**References**


SUCCESSFUL PATHS TO BECOMING A LEAN ORGANIZATION IN THE
CONSTRUCTION INDUSTRY

by

Robert Warcup

A dissertation submitted in partial fulfillment
of the requirements for the degree

of

DOCTOR OF PHILOSOPHY

in

Education
(Curriculum and Instruction)

Approved:

Dr. Edward Reeve
Major Professor

Dr. Gary Stewardson
Committee Member

Dr. David Williams
Committee Member

Dr. Karina Hauser
Committee Member

Dr. Wade Goodridge
Committee Member

Dr. Mark R. McLellan
Vice President for Research and
Dean of the School of Graduate Studies

UTAH STATE UNIVERSITY
Logan, Utah

2015
CHAPTER I
INTRODUCTION

Over the past 50 years, the productivity of the U.S. construction industry has steadily declined, while general business productivity in the U.S. has steadily improved. This trend is confirmed by research from several studies. Using numbers from the Bureau of Labor Statistics (BLS), Dr. Paul Teicholz (2004) reported that construction productivity has steadily fallen 0.32% each year while nonconstruction productivity has risen 3.06% each year since 1964, as illustrated in Figure 1. Productivity is measured by dividing industry revenues by total industry work hours.

In addition, Forbes and Ahmed (2010) reported an increase of only 0.78% per year in U.S. construction productivity from 1966 to 2007; in comparison, nonfarm productivity grew 1.75% per year over the same time period. They pointed out that the modest growth of construction productivity equates to less than half the gains of nonagricultural productivity, and add that the productivity of the construction industry still lags far behind all other industries (p. 25).

Finally, a study by the Construction Industry Institute (2004) discovered that, on average, 75% of all construction activities are considered nonvalue adding (Diekmann, Krewedl, Balonick, Stewart, & Won, 2004). The remaining amount is divided into two categories; 15% is considered essential, nonvalue added work, while only 10% is considered value adding. Therefore, the vast majority of all construction work is considered waste by lean standards. The poor results from each of these studies reveal a significant need for improvement in the construction industry.
Figure 1. Construction and nonfarm productivity index. The graph compares variations of construction productivity calculations with all nonfarm businesses and illustrates the decline in construction productivity since 1964. Graph by Dr. Paul Teicholz, 2013, found at http://www.aecbytes.com/viewpoint/2013/issue_67.html
determination to continuously improve based on lean principles, which results from deliberate leadership and planning. Kinnie and colleagues suggested that very few organizations actually achieve this stage because of the intense focus that it requires. They further stated that Stage Three organizations focus their efforts on cultural programs, teamwork, and continuous improvement efforts to instill “a capacity for change” within the firm (Kinnie et al., 1996, p. 20).

The researcher’s interpretation of this definition suggests that a company that is at Stage Three is practicing lean in large measure throughout the entire company and that most employees have some knowledge of the concepts and the tools. Such companies are very methodical and intentional in their lean initiatives. As stated previously, the three construction firms participating in this study have all achieved Stage Three. However, in addition to meeting the criteria for Stage Three, the companies also meet other objective criteria to be described in chapter three. These criteria help separate the most successful lean companies from Stage Two firms and from other construction firms that may have also entered Stage Three.

**Challenges to Implementing Lean**

Literature points to several cultural barriers that inhibit successful implementation of lean. Johansen, Porter, and Greenwood (2004) summarized these barriers as (a) historic problems inherent within the industry and (b) industry fragmentation. Historic problems referred to the “basis of commercial engagement” that “results in barriers caused by power imbalances, diversity of allegiance, interests, and commitments” (p. 5).
All three companies were searching for solutions to the crisis before lean was introduced.

LCI founder-consultants played a key role in the adoption of lean at each company.

Theme 2: People

In what way did people contribute or hinder the success of lean? Who were the key leaders?

Participant 1, group president and champion, said that the organization was continually searching for ways to improve the business well before employees heard of lean. Key leaders played a role in this effort. Regarding the importance of upper management in the adoption process, Participant 1 exclaimed:

Absolutely critical! If it wasn’t supported at the upper levels of the company, it wouldn’t have given us the comfort of knowing that trying to find a different way of doing something was okay. That [culture] still remains prevalent today.

He continued:

There is not a textbook you can open up that [explains] “Here’s how you do [lean].” There has to be a lot of faith and trust by upper management that the current way of doing things is not going to produce the types of results we want to achieve. So in order to get a different outcome, we have to have a different process.

Continuing further on the importance of the executive role, Participant 1 shared that “much of what is asked of project managers is uncomfortable to them, so if there is no support from upper management, this only confirms that it is okay to not use lean” (emphasis added). He described the need for executive support as “unwavering.”

Participant 2, BIM manager and lean trainer, also emphasized the importance of
Regarding the minimal number of firms for this study, Stake (2013, p. 22), one of the pioneers of qualitative case study research, suggested that if a multi-case study has fewer than four cases, the benefits may be limited. In order to mitigate this issue, in addition to the three organizations selected, three individuals from each firm were interviewed to add variety and to minimize bias. The criteria for selecting each participant were as follows.

1. Each individual must have been employed by the organization before the term “lean” entered the company’s vocabulary.

2. Each individual should occupy a different organizational position within his or her company to maintain variety within the sample.

Possible individuals to interview included project managers, superintendents, seasoned lean experts, and company executives. Because of the rising popularity of lean construction, lean enthusiasts are commonly willing to share their knowledge with others. Therefore, the researcher expected continued support from each of his contacts in arranging interviews and company visits.

**Instrumentation**

The researcher was considered the interpretation instrument in qualitative studies. Merriam (1988) stated that qualitative research “requires a data collection instrument sensitive to underlying meaning when gathering and interpreting data. Humans are best suited for this task—and best when using methods that make use of human sensibilities such as interviewing, observing, and analyzing” (p. 3). It is the researcher who develops
largest barrier to lean is often people. “Change is tough. Change requires work and people aren’t typically looking for more work.” He explained that many will raise their hand to indicate that they want to learn lean “but nobody really wants to do the lifting. My theory is that at least 40% of the industry today cannot make the change.” He then explained that the industry will need to shift. The challenge is that the change to lean “is not small. [It is] not tweaking the old process. [It] is throwing away the old process…. It takes a lot of work, and it takes a lot of ‘brain-matter work.’” He continued:

It all goes well until the lifting really starts. And when we go into crisis, our latent behaviors come out. Those behaviors are based on the way we have done it our entire career, the way we were taught, the way the industry has done it the last 100 years.

He also shared that one of the biggest problems is academia. He feels they have been “too slow to change.” As a member of the LCI board, he petitioned the group to influence the construction management accrediting bodies to address the problem. “My perception is that academics is at least 10 to 20 years behind in what we’re teaching when it comes to delivery process and current technology.” He was very pleased to see an academic researcher studying and promoting lean at the university level.

Participant 8, emeritus executive and architect, like several others, suggested that people were often a barrier to lean. “Older successful employees have a way of working and are sometimes hesitant to give up what they know has worked in the past [just] to do something new. Those with less experience are often easier to convert.” He shared that it took time for younger employees at Company C to move up and to seize the opportunity to pursue lean.

Participant 9, current CEO at Company C, like the others, shared that people are
jobs. There’s nobody better to drive the industry than owners. We are going to put a stamp…on our business cards” that showcases the credential. He then concluded, “We want all our trade partners to get [certified] so that when owners start asking, we can deliver. It’s a win-win.”

A brief, itemized summary of the merged findings for Theme 5: Training, is found below.

- Consultants were used by all three companies for multiple years (5-8 years).
- Hands-on training with some theory was a preferred teaching strategy at each.
- Mentoring was favored over lecturing at each company.
- Training trade contractors was challenging at each company, but necessary.

Theme 6: Culture

What role did the organization’s culture play in lean initiatives?

Participant 1, group president and champion, said:

The construction industry is not a whole lot different than it was 50 years ago. It hasn’t innovated a great deal. Everyone has a tendency to fall back on what they used on the last job as the latest innovation. But [here at Company A], it’s important to make a safe environment where it’s okay for our people to innovate and potentially fail.

Concerning the culture of the executive leadership team supporting lean, he stated:

They don’t have to necessarily understand it all, but they have to make sure that it’s a safe environment for the employees to be practicing a new delivery process and working on innovating.

The cultural expectation of Company A is represented in a slogan often repeated among management: “You’ve got a voice, but you don’t have a choice.” He explained the slogan by emphasizing that individuals should put their energy into showing management
A Critical Review of Lean Construction for Cost Reduction in Complex Projects

Leong Sing Wong 1)* and Mohammed Elhaj Alsoufi Mohammed Ahmed 2)

1) Doctor, Universiti Tenaga Nasional, Malaysia.
* Corresponding Author. E-Mail: wongls@uniten.edu.my
2) PhD Candidate, Universiti Tenaga Nasional, Malaysia. E-Mail: mohammedelsofi@yahoo.com

ABSTRACT

Many countries started to apply lean construction and get benefits of lean construction techniques that can reduce project cost in construction industry, particularly for complex projects. In addition, last planner lean construction techniques started to be widely used instead of current traditional planning techniques for the purpose of decreasing the variation in the processes. Importantly, reducing variation in the project processes can help improve performance and make significant cost savings. Moreover, processes should optimize predictability and facilitate teamwork and effective communication among participants. In the current scenario, lean construction techniques are not reviewed for complex projects. This paper aims to perform a critical review of lean construction for complex projects.

KEYWORDS: Lean construction, Project cost, Traditional planning techniques, Cost savings, Team work.

INTRODUCTION

Conventional construction project management is constantly facing problems in terms of cost, time, quality and safety. These problems are fueled by the segregation between design and construction works (Ballard, 2000). For this reason, construction industry needs a radical change rather than a step-by-step change to overcome the problems and challenges it is facing. Project management is often defined as the process of ensuring that projects are completed within a predetermined budget and duration and with the specified quality. Project managers control duration and take necessary action when progress deviates from the overall project plan (schedule) (Kerzner, 2006). Whilst this approach seems logical, it is often a cause of waste and inefficient performance as a result of applying the traditional approach. Projects are becoming more complex and the need to finish projects more quickly makes the task of controlling progress very hard. As building construction becomes more complex (level of services, information technology, building technology), the construction process becomes more demanding and the number of suppliers becomes more extensive. The need for fast track projects means that more building components are produced off-site and on-site, followed by construction activities (site-based assembling activities). As the number of overlapping activities becomes significant, the effect of delay (or slower than anticipated production rate) in one activity is likely to result in others being slowed down or suspended (waste). This is a problem that is well understood and addressed in the manufacturing industry, where physical or time buffers are placed between activities with variable production rates. Alternatively, “planning buffers” could be introduced where short-term plans allocate work only to activities of the necessary
reducing unnecessary cost (waste) throughout the whole life of the project in order to reduce production time, enhance quality, improve wages, enhance safety environment for workers and increase customer satisfaction.

Figure (1): Value maximization according to lean construction (Marhani et al., 2012)

Current Planning Method (Conventional Method) for Construction Projects

The project management profession is becoming increasingly necessary as construction industry moves to more integrated and concurrent procurement systems for various reasons (Cleland and Ireland, 2007). The main focus was on setting cost, time and quality targets and then meeting these targets. Construction is unique and hence management concepts and tools have to come from within. Project manager has to do mainly with maximizing efficiency and predictability given the scenario. Roberts and Wallace (2004) illustrated that boundaries and “rules of the game” were assumed to be fixed, which implies the use of standard forms of contracts. Project managers along with others would turn their attention to bringing progress back in line with the pre-set schedule (PMBOK Guide, 2011). This is often done by adding more resources by various ways, such as increasing number of workers, materials and hours of work at the expense of meeting cost targets.

Ballard and Howell (1997) clarified that non-critical paths have relatively small delays that do not influence the project overall duration. As discussed before, the project manager’s role is to control duration by taking necessary action when progress deviates from the overall project plan (schedule). Cleland and Ireland (2007) discussed that whilst this approach seems logical, it often causes waste and inefficient performance. In addition, projects are becoming more complex and the need to finish projects more quickly makes the task of controlling progress very hard and firefighting often results in higher cost or short cuts (Ballard, 2000).

Effective Construction Production Planning Method (Buffers)

Ballard (2000) elucidated that in manufacturing, the term buffer often refers to physical stock of raw materials and work in process, which implies incomplete product waiting to be developed further by the remaining sub-processes or inventories (finished goods). In the case of construction projects, a buffer can also be represented by the time allocated between the
Table 1. Differences between traditional planning method and last planner system based on several published works

<table>
<thead>
<tr>
<th>Key characteristics</th>
<th>Traditional planning method</th>
<th>Lean last planner system</th>
</tr>
</thead>
<tbody>
<tr>
<td>Method of production (Ballard, 2000)</td>
<td>Push</td>
<td>Pull</td>
</tr>
<tr>
<td>Planning tool (Lean Construction Institute, 2001)</td>
<td>CPM</td>
<td>LK</td>
</tr>
<tr>
<td>Work planning (Winch, 2007)</td>
<td>Making planning for the whole work.</td>
<td>The concept puts emphasis on the work that actually has to be done to recognize the desirable outcomes.</td>
</tr>
<tr>
<td>Activities identification (Winch, 2003)</td>
<td>When it will be done and how long it will take.</td>
<td>It is focused on how an activity can be done and whether it can be completed within time by the judgment of an expert who may be the contractor or the foreman.</td>
</tr>
</tbody>
</table>

**Last Planner System for Lean Construction**

The last planner is a planning system developed by Lean Construction Institute to address some of the problems of the traditional planning system (Ballard, 2000). This also draws on the same idea of shielding production from upstream variation and uncertainty and introduces upstream variation and uncertainty as well as promoting practices that are closely related to the lean construction principles originally conceived by Toyota (Ballard, 2000). Shange and Sui Pheng (2014) stated that it is notable that the principle of the last planner system is to pull production down from the master program as opposed to the use of the master program to push production forward. In addition, the system encourages the application of pull instead of push. In other words, downstream activities determine the size of workable backlog. The resources, such as materials to be delivered or progress required from upstream activities, are determined by the progress of downstream activities, which means that activities are dependent on these resources (Nesteby et al., 2016). This pull type of system ensures that only the necessary resources and work are being delivered, hence reducing the need for physical buffers (storage space or time) (Ballard, 2000). Managers applying this concept must ensure that the system allows for true inflow variation of each activity or process, otherwise the risk of disruption and stoppage becomes high. Ballard (2000) stated that the system emphasizes the need for a mean of assessing the performance of the various levels of the plans. The system should determine where to intervene. Brioso et al. (2017) illustrated that the match between output and directive at each level should be measured and causes for mismatch must be understood. For instance, the match between ‘will’ and ‘did’ is measured by percent plan completed (PPC). In case of a mismatch, the last planner must investigate the sources of the problem and, in particular, these mismatches could not have been caused by the unavailability of resources or work in progress. Similarly, project level plans can be based on true activity durations. Future mismatches between progress and these plans must be thoroughly assessed. The system therefore emphasizes measurement of performance and continuous improvement.

Brioso et al. (2017) described that last planner can be identified as a person with the expert or specific knowledge of how to actually produce the output that is required by the specific project task and the person can be a sub-contractor, a manager or a foreman. Shange and Sui Pheng (2014) stated that the system requires the last
planner to decompose larger tasks into specific work assignments that can be given to individual construction operatives or teams to be completed in a relatively small time window such as 1-2 weeks. The assignment concept puts emphasis on the work that actually has to be done instead of creating a further plan that simply recognizes the outcome that is desired (Ballard, 2000). Nesteby et al. (2016) provided that as work progress and experience increase, the last planner is able to generate a better assignment through a process of reflection, learning and corrective actions. Table 1 describes differences between the tradition planning method and the last planner system.

**Evaluation of Lean Construction Techniques**

Lean construction principle can only be applied fully and effectively in construction by methods focusing on improving the whole process. This means that all parties must be committed, involved and work to overcome obstacles that may arise from traditional contractual arrangements. In addition, data collection must be carried out before evaluating lean techniques. Li et al. (2017) used both interview and questionnaire in various case studies for their evaluation. Accordingly, evaluation of lean construction has been conducted utilizing both methods.

**Value Management (VM) for Eliminating Unnecessary Cost through the Whole Life Cycle Cost of the Project**

Rashwan et al. (2016) illustrated that value management in construction is a proactive, creative and problem-solving service. It involves using a structured, multi-disciplinary, team-oriented approach to make explicitly the client’s value system using functional analysis to expose the relationship between time, cost and quality. Kelly et al. (2004) claimed that strategic and tactical decisions taken by the client and the design team are audited against the client’s value system at targeted stages throughout the development of a project and/or the life of a facility. This is comprised of manufactured components, where components form elements, elements form spaces, spaces reflect corporate organization and client strategy as shown in Fig. 3. Kelly et al. (2004) described that value engineering (technical level) is an organized approach to provide the necessary functions at the lowest cost without compromising quality and it is concerned with both client and contractor and applicable at technical level to improve design solutions. Kelly et al. (2004) stated that both value management and value engineering are conducted through a workshop at an early stage of the project. Major stakeholders must attend the workshop to recognize the client objectives, participate in making the client value system and keep monitoring the implementation of the client value system through the whole life cycle of the project. However, VM is more likely to be found as rigid application of set tools and techniques to engineer out excess cost without due consideration of value or process (Rashwan et al., 2016). It is frequently viewed as extra to the construction process rather than an integral part of it and it is often called value engineering or sometimes value analysis (Marhani et al., 2013). Rashwan et al. (2016) stated that VE can be carried out by providing sustainable design in construction industry through improving thermal insulation by 55% as well as reducing the cost for each activity (item) at the construction stage by 40%. Fig. 4 shows the relation between cost and time according to VE. It mainly shows the cost savings through the application of VE even before the design phase without compromising quality through the design phase.
Applying lean construction can be done at different stages according to the project phases in construction industry (Marhani et al., 2013). However, there is considerable scope for the application of lean thinking to remove waste from the design process. Ballard and Howell (1997) found that system building techniques involve reliance upon standardization of components and prefabrication of building sub-assemblies. System building techniques are now generally viewed as failure, since many of the buildings they delivered were deemed socially unacceptable. Koskela and Huovila (2000) provided that standardization and prefabrication, together with dimensional coordination, remain key features of almost all modern construction works. The production engineering function which can be seen in conventional manufacturing industries assumes a far greater role than we are used to see in construction (Marhani et al., 2013). Moreover, this implies that the design process and even the design philosophy of building is radically transformed so that there is greater emphasis on design for production than on what may be considered as more conventional design attributes such as aesthetic form (Matti Tauriainen et al., 2016). Li et al. (2014) explained that almost all construction projects involve a high degree of mechanization and include an ‘assembly’ process that combines numerous small or large factory-produced components or sub-assemblies and integrates them to yield a ‘customized’ or unique product. Currently, construction industry is at the earlier stage of building information model (BIM).

Abanda (2017) identified Building Information Modeling (BIM) as a process of generating and managing building data during the project life cycle. Typically, it uses three-dimensional, real-time and dynamic building modeling software to increase productivity in building design and construction. Li et al. (2014), Cao et al. (2017) and Abanda (2017) explained that BIM is the most current advanced method widely used in off-site construction. Fadeyi (2017) discovered that it helps the design and construction team to collaborate on a coordinated model, thereby providing team members with better insight into how their work fits into the whole project, which ultimately helps them ensure efficiency. Mutual exchange of data between all stakeholders throughout the whole life cycle of the project is a crucial element for successful implementation of BIM. However, Tauriainen et al. (2016) clarified that BIM requires more training (for professionals and skillful people) to accept BIM technology instead of the current design methods such as CAD. Table 3 shows the advantages of adopting prefabricated buildings and building information model in construction industry based on several published works.

Chen (2016), Marhani et al. (2013) and Abd Shakur et al. (2016) illustrated that SCM is the management of upstream and downstream relationships with suppliers and customers to deliver superior customer value at least cost to the supply chain as a whole. Marhani et al. (2013) justified that supply chain management depends on the following strategies. Firstly, a high level of joint strategy development with different organizations and firms, both upstream and downstream. In addition, there is a common purpose agreement between separate firms and organizations in the supply chain. There are also jointly agreed common goals amongst the members of the supply chain as well as mutual dependence for all firms in the supply chain on the success of achieving those agreed common goals. Strategic partnerships and strategic alliances that involve separate firms (who would normally be in competition with one another) which allow resources, cost, knowledge and risks to be shared may be the keys to moving forward in these important areas. This fundamentally and radically changes the nature of competition (competitive market). Table 2 shows the successful integration in accordance with supply chain management.
Lean Construction Technology (Just In Time) (JIT)

Just In Time (JIT) is in widespread use in the industry’s supply chains in case of manufacturing of construction components and is a vital element. In order to deliver lean manufacturing, the suppliers’ network must be improved (Nowotarski et al., 2017). Zhang and Chen (2016) stated that the main reason for adopting JIT technology in construction is to fasten the flow of activities and make it move smoothly throughout the construction process. Accordingly, it eliminates waiting as well as the transportation waste between activities, because it focuses on finishing each activity in the project with its required resources in terms of personnel, materials as well as equipment (Li et al., 2017). Richard et al. (2016) mentioned that it utilizes the actual required resources (pull production) according to lean last planner system rather than forecasting resources as in traditional methods. Therefore, overproduction waste can also be eliminated. Total Quality Management (TQM) must be adopted upstream and downstream to ensure that the activities achieved are of high quality and that unnecessary processes (defects) are eliminated. Nowotarski et al. (2017) stated that huge efforts must be implemented to encourage construction industry to adopt the same lean JIT systems, often company-wide, rather than being solely concerned with that part of the suppliers’ operations that impacts the manufacturer.

Table 2. Advantages of applying prefabricated off-site assembly in construction industry using BIM based on several published works

<table>
<thead>
<tr>
<th>Research work</th>
<th>Level of implementation</th>
<th>Advantage</th>
<th>Evaluation of implementation in construction industry</th>
</tr>
</thead>
</table>
Lean Six-Sigma

Six-sigma can be described as a business improvement approach that seeks to find and eliminate causes of defects and errors in manufacturing and service processes by focussing on outputs that are critical to customers and on a clear financial return for the organization (Abd Jamil et al., 2016; Cortes et al., 2016; Li et al., 2017). Cortes et al. (2016) stated that the concept necessitates the use of basic and advanced quality improvement and control tools by teams whose members are trained to provide fact-based decision-making information according to process analysis. Cortes et al. (2016) clarified that it improves productivity, quality as well as profitability. Cortes et al. (2016) proved that using six-sigma can induce a high chance to reach zero-defect as the ultimate goal. Table 4 shows the advantages of applying total quality management and lean six-sigma in construction projects.

Continuous Improvement Key Performance Indicator (KPI) for Strategic Lean Construction

Kerzner (2006) stated that Key Performance Indicator (KPI) provided UK construction projects with a powerful tool that can be used to assess the performance of a company or a project in relation to the performance of peers. However, the produced data may not necessarily achieve continuous improvement. Obradovic et al. (2016) specified that a key aspect in the use of leading indicator performance data in securing project or industry best practice and continuous improvement is feedback. Feedback mechanisms are multiple and may be complex. Feedback is the essential component that provides information and data on how a company or a project that is presently performing at X level can actually become a company or a project that is performing at or above national or international performance levels (Kyliii et al., 2016). Kyliii et al. (2016) added that KPI includes client satisfaction in terms of service and product, predictability in terms of cost and time, profitability, productivity, safety, construction time as well as construction cost. Table 5 shows the degree of adopting lean construction techniques in construction industry based on several published research works.

<table>
<thead>
<tr>
<th>Research work</th>
<th>Level of implementation</th>
<th>Advantages</th>
<th>Evaluation of implementation in construction industry</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Nowotarski et al. (2017); Li et al. (2017); Richard et al. (2016)</td>
<td>Organizational level</td>
<td>1. Controlled production environment.</td>
<td>Almost universally accepted in mainstream construction activities.</td>
</tr>
<tr>
<td>2. Marhani et al. (2013); Richard et al. (2016)</td>
<td>Organizational level</td>
<td>2. ‘PULL’- orientated production based on actual demand instead of forecast demand.</td>
<td></td>
</tr>
</tbody>
</table>
Senior Project Proposal
SENIOR PROJECT PROGRAM - CM DEPARTMENT

SENIOR PROJECT PROPOSAL FORM

Instructions: Prior to admission to CM462 students (with junior or senior standing) student must complete this form in detail to the satisfaction of both the SPD (Senior Project Director) and self-chosen SME (Subject Matter Expert). Expect multiple renditions of this document to occur prior to final acceptance, which must be achieved before the ADD/DROP date for the quarter submitting. Failure to achieve this final acceptance in time will likely result in attempting this process again next quarter.

REQUESTING PRELIMINARY FACULTY PROJECT APPROVAL:
CM faculty approval of senior project proposal (at least one quarter prior):

STUDENT INFORMATION:

Student Name: Devin Merker
Student ID #: 009550368
Student Address: 436 Kentucky Street, San Luis Obispo, California
Student E-mail: dmerker@calpoly.edu
Student Phone: (916) 531-0123
CM461 (complete with passing grade) Fall/2017
CM462 (planned admission) Fall/2018
Graduation Date (expected) Fall/2018

Proposed SME (Subject Matter Expert) Greg Starzyk

PROJECT TYPE:

Type of Senior Project Proposed: Research Based
Type of SP (Identify Sub-Category): Case Study
Working Title of Senior Project: Implementation of LEAN Construction into Cal Poly CM Curriculum
Organization of Project: Individual

SENIOR PROJECT DETAILS (BOTH RESEARCH OR PROJECT BASED):
**Project Description:**
LEAN construction has been a focus for many companies in the recent years. With techniques and philosophies first outlined by Toyota in their car production lines, LEAN production has been tweaked slightly to incorporate the same principles into the construction industry. However, I have noticed that not all construction companies are utilizing LEAN production methods to their full potential. The purpose of LEAN production is to minimize waste, increase efficiency, and maximize resources which, in the construction industry, can lead to lower costs, streamlined schedules, and improved overall efficiency. LEAN production has also been designed to increase customer satisfaction, which is a major component of the construction industry and should therefore be applied with its full potential.

**Purpose /Objectives / Goals:**
My senior project goal is to perform a case study on LEAN construction methods utilized and identifying which areas companies are trying to optimize their LEAN practices. Construction companies often boast their LEAN practices or special programs they implement; but I am interested to see how these scenarios work in the real world, what techniques have been proven, and what new practices might be suggested.

**Student Topic Interest (why):**
After serving three internships, I have noticed that while most companies make their best effort at minimizing waste and maximizing efficiency, the construction industry is still extremely wasteful. Not only does waste pose an environmental threat, but also results in smaller profit margins. I believe that in the highly competitive construction industry, a contractor that has an established and effective LEAN construction program will prove to be both more successful and more respected. I would like to analyze different scenarios and identify the best strategies to implement so that when I enter the work force, I can hopefully demonstrate the benefits of LEAN construction to my employer.

**Benefit to Student / CM Industry:**
By conducting literature review and analyzing specific cases of LEAN construction methods, I will hopefully produce new insights pertaining to successful practices and examine how practices can be fine-tuned to best suit a company. By doing this, companies and other students can see the effects and benefits that LEAN construction exhibits and use it as a plan to implement some of the same principles into their own company.

**New Knowledge or Discovery to Achieve:**
While there are already many concepts of LEAN production practices that can be applied to construction, the adoption of these practices has only gained popularity recently. Because the topic is still relevantly new, there is not much evidence to support the success that these lean construction programs have had. By analyzing case by case examples from multiple companies
in various geographical locations, I hope to show how dynamic a LEAN construction program can be for different companies.

**Potential Project Risks and Challenges:**
I know that there may be some minor roadblocks for conducting this case study. Some companies may not want to disclose the successes that they have had with LEAN construction practices as they may feel that it gives them a competitive advantage over the other companies in the industry. To combat this, it may be best to interact with companies such as Turner Construction who pride themselves on LEAN construction practices and are more open to discussing successful techniques that have been utilized.

**Funding Needed for Project and Source:**
I do not believe that I will need any funding for this senior topic choice. However, if I do encounter that I will need funding, I have the resources available to request it.

**Professional Contacts Assisting:**
- Joshua Norris / AECOM Hunt
- Cristian Santos / Turner Construction
- Jon Khoo / Whiting-Turner

**RESEARCH BASED DETAILS:**

**Hypothesis of Research:**
Through the implementation of a dependable LEAN construction model, construction companies can effectively save time, minimize waste, and increase efficiency.

**Methodology of Research:**
I believe that my best research strategy will be to perform case studies to test the principles of lean construction that have previously been tried and tested. This type of research will grant me with quantitative data as I will have a more distant relationship with the parties that I am researching as opposed to a more direct approach with qualitative data.

I believe the best approach for data collection for my research on LEAN construction will be the fieldwork research approach as it will allow me to perform case studies, but also conduct surveys to get the best wealth of knowledge from multiple sources of information. I would like to observe the practices through research and literature review, but I think it would also be beneficial to conduct surveys to construction companies asking their opinions on what LEAN construction means to them and what they have done to implement it.

**Assurance project is realistic (time, $, etc.)**
This quarter I have a very light workload (8 units) and I am also not working my job that took up a lot of my time during my senior year. This makes my project extremely realistic as I should have ample time to research, analyze, review, and record my findings. Also, because this is a research-based case study approach, cost should be minimal and should not require any additional funding.
Preliminary Research Initial References:

- S Gao / Lean Construction Management: The Toyota Way
- L Song, D Liang / A Case Study on Applying Lean Construction to Concrete Construction Projects
- Thais Alves / Lean Principles for the Management of Construction Submittals and RFIs
- B Hyatt / A Case Study in Integrating Lean, Green, BIM into an Undergraduate Construction Management Scheduling Course

WORK PLAN (BOTH RESEARCH OR PROJECT BASED):

Work Plan Description:
Fall Quarter weeks 2-4 I will be collecting research and background knowledge of LEAN construction principles and gathering ideas for formulating my case study. I will then choose my cases that I will be studying and analyzing during week 5. Weeks 6-7 will be dedicated to conducting the case studies, taking notes, and analyzing. During weeks 8-9 I will be writing and reviewing my paper, and making final edits and reviews during week 10.

Regularly Scheduled Meetings with SME: Unknown
Project Milestones and Timeline:
- Gather Resources and Draft Questions / October 3d, 2018
- Begin Literature Review / October 10, 2018

Proposed Schedule of Completion:
- Literature Review Complete / November 14, 2018
- First Draft Complete / November 26, 2018
- Paper Completion / December 5, 2018

CONTRACT:

I, Devin Merker, hereby request consideration, acceptance, and approval of the above senior project proposal by the SPD and the SME. I am committed to complete the CM462 scope of work in the quarter registered as outlined in the senior project guidelines listed on the construction management website. If I do not complete this project in the quarter registered the SME may give me a NO PASS or INCOMPLETE grade for CM 462, as appropriate. I understand that at minimum I must re-register for the course in which I received a NO PASS in order to complete my senior project. It is further understood that a revised project proposal may also be required. As required by the University, non-completion of CM462 will result in a grade of F and a potential graduation delay.

Devin Merker
09/27/2018

Student Name (Print) Student Signature Date
CONTRACT:

I, Devin Merker, hereby request consideration, acceptance, and approval of the above senior project proposal by the SPD and the SME. I am committed to complete the CM462 scope of work in the quarter registered as outlined in the senior project guidelines listed on the construction management website. If I do not complete this project in the quarter registered the SME may give me a NO PASS or INCOMPLETE grade for CM 462, as appropriate. I understand that at minimum I must re-register for the course in which I received a NO PASS in order to complete my senior project. It is further understood that a revised project proposal may also be required. As required by the University, non-completion of CM462 will result in a grade of F and a potential graduation delay.

Devin Merker  
Student Name (Print)  
Student Signature  
Date  
09/27/2018

APPROVAL:

The SPD and SME signature on this documents indicates acceptance of this student’s senior project proposal and authorizes the student to receive a permission number for CM462 from the main office.

Greg Starzyk  
SME (Print)  
SME Signature  
Date  
9.27.18

Phil Barlow  
SPD (Print)  
SPD Signature  
Date  
9.27.18
Reflections
Reflections

I believe this research project was the most beneficial assignment from my undergraduate studies in terms of real-world applicable material. By selecting a topic that I was both interested and passionate about, it made performing the research and conducting the case study much easier. After several internships with various contractors (subcontractors, developers, and general contractors) throughout my undergraduate career, I was exposed to the massive amount of waste that was prevalent in the construction industry. When I learned about lean construction and the benefits that it can provide, I was immediately interested. The decision to select lean construction as my senior project topic choice came because I knew it was something beneficial that I would be able to bring to new employers when entering the workforce. After conducting the research, I am more passionate about and interested in lean construction now than ever before. This project has influenced me to go further into learning about lean construction implementation and how I can assist my future employers into making the transition. I truly believe that lean construction will be the future, both from personal experience and participant responses from this study, and I am excited to see more firms make the transition to lean.

Although I enjoyed the research study and topic itself, there were still some complications in the process. The first challenge presented itself when I realized my original proposal idea for the senior project was far too complicated and would take much longer than the restricted timeline I was working with. To combat this I was able to narrow down some of the expectations I was hoping for in my original proposal in order to get more realistic goals. Another challenge that I faced was not taking advantage of the resources that were readily available to me throughout the course of my research. For example, I did not take advantage of the weekly meetings with my senior project advisor which made it much more difficult for me to find direction in where I wanted to take my project and what points I wanted to get across. If I were to do this project again, I would definitely meet regularly to get advice in order to reduce the stress on myself. Although I did conduct literature review and the participant interviews early on in the process, I waited until the last two weeks to gather my ideas and provide an analysis. This procrastination hindered my ability to perfect my paper in a timely fashion and if I were to do this project again, I would definitely spread the workload out to prevent this.

Overall I am very happy with the results that I was able to conclude in my project. I hope to use the knowledge and skills that I learned throughout my research and apply them to my future career. I was also very satisfied with how the senior project class, and Cal Poly’s curriculum itself, set me up for success in my research methodology. The CM 460 class helped tremendously in how to select a topic, take relevant notes, and begin writing my paper. Cal Poly’s hands-on “Learn by Doing” approach allowed me to visualize a lot of the topics and ideas that I was researching and gave me a better understanding of them by doing so. I believe I was very well prepared for the research in this study and I am glad I was able to produce the results I was hoping for.
Cal Poly – Construction Management  
Senior Project – Student Evaluation Form

Instructions: In addition to your one page single spaced summary reflection paper, please fill out this student evaluation form so we can better format, implement, and execute the senior project goals and objectives.

Student Name: Devin Merker  
Project Type: Research – Case Study  
Project Title: Lean Construction Implementation: Case Study

1. How did you come to choose the project and project type ended-up with explained in such a way that future students could benefit?  
   a. I chose this project topic because it was something that actually interested me throughout my internships. Having it be something that really interested me made it much more enjoyable to do the project.

2. What challenges/obstacles did you have to overcome on this project that other students might learn from?  
   a. Procrastination is probably the largest obstacle. It would be recommended to spread out the workload and use as many resources as you can.

3. Approximately how many person-hours did you spend on your senior project (not including the CM461 course)?  
   a. Approximately 30 hours

4. What instructions or advice that you received did you find most helpful in navigating your senior project?  
   a. Same as before, find something that really interests or motivates you so that you stay engaged throughout the entire research.

5. What instructions or advice that you did NOT receive (or should have been emphasized more) would you have found to be helpful in navigating your senior project?  
   a. Make sure to use as many resources as you can. Meetings with your SME, previous senior project examples, and other resources are great for understanding the requirements of the project and can help get you on the right track.

6. How satisfied are you with the “Senior Project Experience” you received (1 – 10) and why?  
   a. 8; although I found many of the results that I was looking for, there is still much more research that I would have liked to do.

7. How might the content in the CM460 class be changed to better support moving forward with CM462 and the rest of your senior project?  
   a. I feel CM 460 actually did a very good job at preparing students for CM 462 and their senior projects. I referenced many of the examples and materials from 460 while conducting my research and writing my paper.

8. How might the SPD’s (Senior Project Director’s) role be improved to better support your senior project efforts?
a. Maybe one more meeting with all seniors doing their projects closer to the end would be helpful just to ensure students are on the right track and answer any questions.

9. How might the SME’s (Subject Matter Expert’s) role be improved to better support your senior project efforts?
   a. I feel like the SME’s role is fairly sufficient, to provide guidance and insight but not check multiple drafts for grammatical errors etc.

10. Any advice you would give future CM students in going through this process?
    a. Make sure to pick something that really inspires and interests you and just have fun with it. This is the last chance you get to prove something that you discovered and you should be proud of your project.
Notes/Other
Interview Questions

General Background Information
1. State your name, title, and time you have been with the company.
2. What is your previous knowledge on lean construction?
3. Have you been directly involved in any lean construction practices within your company? If so, please describe.
4. How important do you feel lean construction currently is to your company? Why?

Company Culture
5. In your honest opinion, do you feel that your company has fully adopted a lean construction culture? Why or why not?
6. What is the structure of your company? (vertical, horizontal, etc.)
   a. Do you feel the structure of your company either positively or negatively affects the ability to practice lean construction? Why or why not?
7. What steps has your company taken to enforce lean construction principles/practices?
8. What challenges do you predict with fully adopting lean construction within your company?

Lean Construction Tools
9. Have you or your company used any tools that are commonly associated with lean construction on any of its projects? (Pull-planning, BIM, modular construction, etc.)
   a. If yes, what tools were used and were they successful?
      i. Why were they successful/unsuccesful?
   b. If no, why did you decide not to implement lean construction tools?
10. What are the greatest benefits you see from the use of lean tools used on construction projects? Either within your company or other known examples.
11. What are the most recognizable barriers or challenges that you have noticed with the use of lean construction tools.

Industry Outlook
12. If the company has not already adopted lean culture [Question 5]: Do you believe your company will adopt a fully-lean construction culture within the next 5-10 years.
13. What are your opinions or observations of other firms implementing lean construction practices?
   a. Have you noticed anything that has made you question your own company’s lean construction practices?
14. How important do you feel lean construction is to future of the construction industry as a whole?

Education
15. What lean construction education or training, if any, has your company established?
   a. Has this been beneficial to the overarching lean construction culture of your company?
16. Do you feel academia is adequately educating future construction professionals in lean construction practices/culture?
   a. Have you noticed any emerging trends among college graduates entering the workforce in relation to lean construction?
17. What are your suggestions for universities and higher education in regards to lean construction?
18. How important do you value higher education in the future success of lean construction?

Other Barriers to Lean Construction/Additional Remarks
19. Do you see any additional barriers or challenges to lean construction that were not previously discussed?
20. Do you have any additional remarks, closing points, or opinions that you feel are important to the topic of this research?
Lean construction offers a collaborative approach to traditional construction practices and has the primary goal of increasing value to the client. With the proper use of lean construction tools on projects and the adoption of a lean culture, construction companies have been able to recognize real benefits in terms of cost, productivity, and schedule while increasing customer satisfaction. The construction industry has been slow however in adopting the lean construction practices that have proven to be successful. In this case study, participants from two construction companies, a leading lean contractor and a non-lean contractor, were interviewed to evaluate the different lean construction “journeys” taken by each company. The interviews and analysis in this study primarily focus on the lean culture, use of lean construction tools, common barriers, lean education, and industry outlook from each of the companies. Suggestions for the future growth of lean construction were provided based on the interview responses.

Common Tools Used in Lean Construction
- Last Planner System (Pull Planning)
- Building Information Modeling (BIM)
- Modular Construction (Prefab)
- Collaborative Contracting

Lean Culture
Establishing a lean culture within a company has proven to be necessary in order to be a successful lean contractor.

To establish a lean culture, all employees should be committed to:
1. Eliminating Waste (See Figure 3)
2. Continual Improvement

Benefits of Lean Construction
- Reduced costs or increased profitability
- Reduced project schedules
- Higher quality on projects
- Greater customer satisfaction
- Improved productivity
- Improved safety performance

New Knowledge
- Subcontractors and field crews are the most common obstacle in preventing contractors from implementing a lean culture
- Top-down approaches (from upper management down to field) for adopting a lean company culture have shown to be less effective
- Academia has failed to adequately equip students with the proper tools and concepts needed to practice lean construction