LEAN AND GREEN CONSTRUCTION: LESSONS LEARNED FROM DESIGN AND CONSTRUCTION OF A MODULAR LEED® GOLD BUILDING

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ABSTRACT

This paper presents the collaboration efforts of a design-build project team that designed and constructed a modular LEED® Gold office building in Long Beach, California. A fixed budget, and requirements for modular construction, LEED® Gold, and design-build project delivery required the project team be innovative to meet the imposed constraints. The team was formed to design and build this project, which presented challenges for work structuring and building shared understanding. Despite challenges, the owner hopes this building will serve as a model for "lean and green" design and construction of municipal buildings in Southern California.

The design-build team, led by the architect and the modular construction contractor, proposed various design concepts that fulfilled the modular and LEED® Gold requirements but were infeasible from a cost perspective. Leveraging technical assistance provided through a partnership with the United States Department of Energy (U.S. DOE), the team was able to refine their original concepts to more economically meet the energy efficiency requirements. Further, a partnership with the local utility provider, Southern California Edison (SCE), provided additional funding for low-energy building features. These partnerships proved instrumental for achieving green goals while meeting modular requirements.

This paper describes the team's efforts to design a modular building that is energy efficient and meets a stringent cost requirement. It discusses how the requirements for modularity and LEED® Gold defined the design, construction, and operations processes. This paper documents the team's successes in achieving lean and green practices as well as challenges they faced in the design-build environment.

KEY WORDS

Lean construction, manufacturing, customisation, flexible, work structuring, sustainability

INTRODUCTION

Modular construction offers first-cost savings, a fast-tracked design and construction process, and safer construction methods. Despite these benefits, modular construction is not the status quo in the U.S., potentially due to a perceived lack of flexibility in the final modular product—building owners typically do not want a "cookie cutter"

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building. This paper examines two research questions using a case study approach. First, can modular construction offer sufficient flexibility to be attractive to owners? Second, does LEED® impose constraints to modular construction beyond those LEED® imposes on traditional construction? To address these questions, this paper presents a modular construction case study from the city of Long Beach, California. It also describes the importance of work structuring and clear communication for delivering sufficiently-flexible modular construction projects and the need for new cost analyses in low-energy projects.

The owner of the building presented in this study, Long Beach Gas and Oil (LBGO) (a division of the City of Long Beach), was attracted to modular construction that also offered flexibility (e.g., Jensen et al. 2009) and a lean approach *without* appearing “cookie cutter” (e.g., Bertelsen 2005). LBGO opted to pursue a modular approach from the project outset and sought design-build teams that would be able to deliver a low-energy modular building within their US$4 million first-cost constraint.

DOCUMENTED ADVANTAGES AND CHALLENGES OF MODULAR CONSTRUCTION

Bertelsen (2005) highlights the shift in thinking and doing that modularization requires. He cites the need to think in terms of systems, rather than in terms of components and explains the work structuring implication, “a module is almost never the output of a single trade but must be seen as a product designed and manufactured by a number of different trade experts and most often installed at the site by the manufactures’ own, specially trained crews.” He elaborates that to effectively design and deliver modularized buildings, work structuring efforts must align team members to deliver systems as modules rather than perform the parade of trades (e.g., Tommelein et al. 1999) onsite. Bertelsen states the best way to support this work structuring is to “make sure that the ‘module owner’ encompasses design, manufacturing and installation of the product…” Indeed, this was observed on the case study project at LBGO. Bertelsen also documents challenges of modularization; of particular note is the danger of losing the ability to customize the building.

Blismas et al. (2006) enumerate many advantages of prefabrication, a typical production method for modules. For municipal owners, these may be most important:

- Prefabrication is known to be safer than onsite construction (Rwamamara et al. 2010; Simonsson and Rwamamara 2007). This is intuitive in the lean construction community, as offsite work generally has less variability than onsite work, and thus, contractors can more easily identify and manage risks.
- More prefabricated work often reduces insurance rates, and the difference in insurance rates can often be the difference between winning or not winning a job (Brosnan 2012). Thus, prefabrication may be attractive for public owners that are first-cost constrained.
- Reduced variability increases the certainty of project completion dates (Blismas et al. 2006). This provides an advantage for all owners, though municipal owners may find this advantage more important than private owners.

CASE STUDY: NEW MODULAR OFFICE BUILDING FOR LBGO

BACKGROUND

The City of Long Beach adopted a Green Building ordinance (2009) that requires that all municipally-owned buildings are LEED® Gold certified or equivalent. This requirement effectively acts as a constraint to the design space for City buildings. The new modular office building on the LBGO campus in Long Beach, CA is a two-story, 1,400 m^2 [15,000ft^2] building containing private offices, open-plan cubicle offices, and a conference room and call centre on the second floor. This building serves as a pilot for the City of Long Beach, who is interested in deeply energy-efficient buildings that are also cost-effective. The modular nature of this building allows LBGO to realize the cost benefits of fast-tracked, safer construction while achieving deep energy savings, which also saves operational costs.

Since 2010, this building has been the focus of a collaborative effort between LBGO, their design-build team, the Lawrence Berkeley National Laboratory (Berkeley Lab), and their subcontractors, Stantec (formerly Burt Hill) and LHB Inc. to meet aggressive energy targets as part of the Commercial Building Partnerships Program (U.S. DOE 2010a; 2011). Working together, the group proposed a building design that consumed 50% less energy versus ASHRAE 90.1-2007 (ANSI/ASHRAE 2007), an aggressive energy target, even considering the City's Green Building Ordinance (City of Long Beach 2009). This achievement allowed LBGO to participate in the SCE (the local electricity utility) Savings By Design program (http://www.savingsbydesign.com) that offers approximately US$40,000 in incentives for low-energy design.

Commercial Building Partnerships Program

The Request for Proposals for technical expertise for the Commercial Building Partnerships (CBP) program (U.S. DOE 2010b) explains the American-Reinvestment-and-Recovery-Act-funded CBP program:

> CBP works with commercial building owners to create, test, validate, and deploy low-energy building designs. CBP allows companies to explore energy-saving design alternatives that may be too technologically challenging or expensive to consider without the DOE-funded technical expertise ... The CBP objective is to develop a set of energy-efficient, market-ready building solutions that will be widely deployable throughout the commercial building sector.

This program, along with the Savings By Design program, provides support for additional technical analysis during design, construction, and early operations that would otherwise be too costly. The CBP program also offers an educational opportunity for building owners, as their design teams learn from the experts at national laboratories and their subcontractors. On this project, the CBP team developed design alternatives and provided additional information that aided in the evaluation of these alternatives. These alternatives were considered for inclusion on this project and will be considered for inclusion on other municipal buildings in Long Beach, thus providing value to LBGO beyond this project. Moreover, the information about these alternatives, especially the cost analysis, cultivated shared understanding of these alternatives and can be used as a basis for target value design in the future.

DESIGN DECISIONS

Figure 1 illustrates the energy use breakdown in the building from the baseline model. Note lighting, ventilation, and cooling consume most of the building's energy. Energy efficiency measures (EEMs) thus primarily targeted these end uses (Stantec 2011). Promising EEMs were modelled to estimate their energy performance in the project. Each EEM suggested was assessed to ensure it was economically feasible given the first-cost constraint and to ensure it contributed to LEED® credits (EEMs offering more LEED® credits per dollar were preferred).

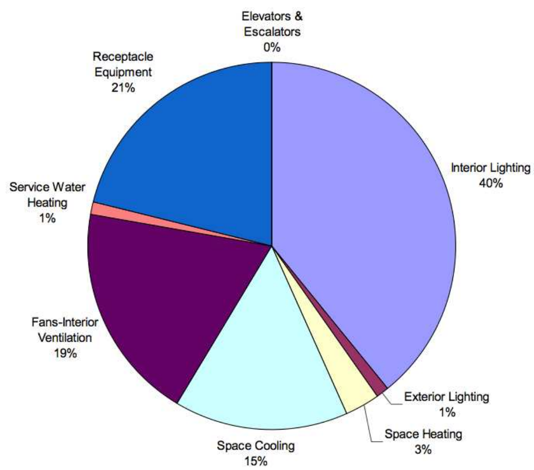

Figure 1: Modelled Energy Use Breakdown of the Baseline LBGO Building

Figure 2 shows the design the project team developed. EEMs include the sawtooth roof monitors that allow daylight to illuminate the call centre within the building, the shading elements that reduce the thermal loads in the building, and the thermal breaks (not clearly visible) that also reduce the thermal loads in the building. Figure 3 shows a photograph of the constructed building, with shading elements visible. The finished product showcases the flexibility built in to the modular construction process—the shading elements and the asymmetric glazing show customization in the modules.

The project team developed many design alternatives that supported modularization while achieving deep energy savings. Though a detailed discussion of the many design alternatives considered and how selections were made among these alternatives is outside the scope of this paper, some of the decision-making criteria bear mention. Design decisions were made based on first-cost constraints, which meant that some alternatives with operational cost and energy consumption benefits were not selected due to higher first costs. Operational considerations also impacted design decisions. For example, LBGO uses standard lamps in their buildings, so light fixtures were selected that accommodated these lamps. The project site is close to a well-travelled highway and an airport, which eliminated those design alternatives that included operable windows or other so-called natural ventilation schemes due to pollution and noise concerns.

Figure 2: Rendering of the Modular LBGO Office Building

Figure 3: Photo of the Completed Modular LBGO Office Building (taken by Craig Beck on April 6, 2012)

Two specific decisions bear mention in this paper, as they have implications for lean project delivery: 1) the mechanical system selection was governed by the first cost and 2) the sawtooth monitors were installed facing south, rather than north. Each of these decisions reflects a breakdown in communication and a lack of transparency that must be addressed on future projects for energy-efficiency goals to be fully realized. Lean theory offers solutions to these breakdowns.

Selecting a mechanical system was a long process on this project. The energy and operational savings from one system (a variable refrigerant system) exceeded the performance of a rooftop unit-type system that was originally included in the modular contractor's cost estimate. When the CBP team suggested that this system be upgraded, they were aware that costs would also be "upgraded." However, the CBP team expected the additional costs to be about a 30% increase, and the contractor's estimate had the mechanical system upgrade as a 100% increase in cost. The specific cost increase is important, to be sure, but ultimately, the two estimates could not be reconciled, so the less expensive system was selected. This highlights the need for trust between team members that real collaboration and transparency in communications with other project team members can facilitate (Howell and Koskela 2000; Lichtig 2005; Matthews and Howell 2005). Had the team members communicated directly, and trusted each other enough to share their assumptions and costs, the estimates likely would have been reconciled, thus supporting informed decision-making.

The design team and the CBP team intended for the sawtooth monitors to face north to avoid glare and heat gain concerns from south-facing glass. However, when the monitors were first sketched, they were south facing. Despite clear agreement within the design team that these monitors should face north, they were installed facing south, as the drawings were not updated and the builder was not part of the conversation about reversing their orientation. This situation underscores the importance of the language action cycle (Macomber and Howell 2003): though the design team discussed the monitors' orientation, and even agreed that it should be north-facing, a clear request to change the drawings was either not made or not acted upon. Had an assessment been requested, the fact that the drawings had not been changed may have been illuminated and subsequently addressed. This situation also reinforces the need for collaboration: had the modular contractor been present during the discussions of the roof monitor orientation, perhaps the contractor could have clarified the orientation before fabricating the monitors according to the drawings.

CONSTRUCTION METHODS

As previously mentioned, LBGO committed early to lean construction, especially as it relates to design-build delivery and modularization. They worked with their modular contractor early on to determine a size and shape for the modules that allowed for efficient transport and erection.

LBGO also worked with the modular contractor to maintain flexibility within the modular systems until the last responsible moment. LBGO postponed committing to a specific lighting layout or duct layout until the electrical and mechanical systems, respectively, were developed and evaluated for their energy performance. When these systems were selected, poka yokes (e.g., Tommelein 2008) were incorporated into the modules to ensure that installation onsite went smoothly. Specifically, wires were colour coded to ensure proper electrical connections across modules and holes were pre-cut in the drywall to facilitate duct and pipe runs across modules.

BUILDING OPERATIONS

Most of the EEMs selected for the building required enhanced commissioning to ensure they were operating as efficiently as possible. For example, the call centre requires daylight control to ensure that artificial lights are not on when the centre has adequate natural light. Traditional commissioning would ensure that the artificial lights were operational, but would not necessarily ensure that the lights turn off when adequate natural light is available. Moreover, enhanced commissioning offers additional LEED® credit (USGBC 2009).

The design team and their external partners also wanted to maintain energy performance over time. Thus, they planned for measurement and verification (M&V), a process that involves monitoring energy consumption in the building with system-level resolution. That is, monitoring the energy consumption of each building system to track energy performance and inform operations and maintenance decisions. M&V also offered a LEED® credit and earned a larger incentive payment from SCE.

DISCUSSION

LBGO expects their new modular office building will be LEED® Gold certified and from an energy efficiency perspective, this project has far exceeded the LEED® standard. The energy model for the building predicts that the building will consume ~45% less energy than a building designed and constructed to minimum code standards (Stantec 2011). LBGO anticipates capturing all possible energy efficiency LEED® credits with this level of energy savings. This project will serve as the model for future modular buildings in the City of Long Beach. Further, EEMs on this project—including thermal breaks, glass that maintains light transmittance while minimizing heat gain, shading elements, and others—can be incorporated into modules on the modular contractor's future projects. This is a significant achievement enabled by the CBP and SCE partnerships. As in any project, the final constructed product does not reflect all of the design alternatives. However, the owner and the design-build team have added the full set of design alternatives to their collective institutional knowledge, and should therefore be able to consider these alternatives on future projects. For instance, the design-build team may consider implementing natural ventilation at Long Beach sites where pollution concerns from the highway and airport are reduced. Finally, lessons learned on this pilot project will inform future lean implementation for City projects.

LESSONS LEARNED

This project serves as a proof of concept for the City of Long Beach, California, who seeks to build more modular, low-energy buildings. With this project, LBGO has learned many valuable lessons that will influence how work proceeds in the future. This section highlights those of relevance to lean design and construction.

MODULAR CONSTRUCTION REQUIRES A RIGOROUS WORK STRUCTURING EFFORT

At the outset, LBGO was interested in a modular building to capture the advantages of accelerated project delivery and associated cost savings. However, they were not accustomed to new working relationships that design-build, especially for modular construction, warrants. In future projects, the City of Long Beach plans to engage the larger design-build team frequently in the design process. This team includes not only the traditional design team; it also includes the specialty contractors who are part of the modular building team. The City may even consider including explicit expectations about meeting attendance in future contracts with design-build teams. This project illustrates the different roles that project stakeholders may take on during design-build projects (e.g., the contractor assuming some level of design responsibility) and in particular, the role of contractors in modular construction, where design and construction teams must collaborate early to deliver prefabricated *systems* rather than prefabricated *components*. In future projects, LBGO advises the City of Long Beach work with the entire modular design and construction team as early as possible, and engage them often, to ensure that the final design satisfies the constraints from the design team as well as those from the modular contractor. Moreover, this ensures that all stakeholders are aware of design decisions.

THE LANGUAGE-ACTION CYCLE IS CRITICAL ON DESIGN-BUILD TEAMS

When the project team decided to pursue a daylighting strategy for the building, roof monitors were added to the building atop the call centre. As previously described, these monitors were installed facing south rather than north. The failure to make or act on a clear request required a post-construction solution be found to mitigate glare concerns in the building. Implementing the language-action cycle becomes even more important in new work structures, since stakeholders may be unaware or unsure of expectations that may be implicit in their new role. All project teams should consider implementing a system to clearly assign responsibilities and ensure that tasks are recorded and completed (e.g., Last Planner^{TM}).

LEAN AND GREEN PROJECTS REQUIRE NEW COST PARADIGMS

Koskela and Tommelein (2009) discuss the deficiencies of the economic theory of production when assessing sustainability. This project supports their findings and suggests that new cost paradigms need to be developed and implemented when evaluating sustainability. Koskela and Tommelein challenge the economic theory of production's assertion that ends are given. The LBGO project emphasizes and extends that point. Not only does the economic theory of production fail to account for differences in *installation* time and quality, it also fails to consider differences in *operational* time and quality. Even with a strong commitment to sustainable practices, as exemplified by LBGO on this case study project, the economic theory of production is still the status quo for cost analyses, and thus, advantageous alternatives may be rejected. New cost paradigms (e.g., life cycle cost analysis) show promise for more accurately valuing sustainability (among other factors), but a challenge of good data for these analyses still exists.

The LEED® rating system introduces a new element of cost analysis as well, as project teams often set a LEED® target (e.g., Gold in this case), and then seek the least expensive means to earn enough LEED® credits to achieve their target. (It is worth noting that teams often aim for 10% more credits than required for a given level of certification to ensure they hit their LEED® target). This "cherry picking" process often leads to selecting the least expensive credits, rather than pursuing those that contribute most to a whole-building sustainability strategy. For instance, it may be less expensive to install a bicycle rack than to install a more-efficient mechanical system. However, if building users do not ride their bicycles to work, then money spent does not contribute to a more sustainable workplace. This reinforces the need for new cost paradigms that consider *value*, rather than simply costs.

CONCLUSIONS

LBGO and the City of Long Beach were both attracted to the modular building concept because it supported shorter construction duration and a streamlined delivery method. Moreover, it was cost-effective for the municipality. This project is a proof-of-concept illustrating that modular municipal can achieve LEED® Gold or better and also be attractive, both from an architectural and energy perspective. Regarding the first research question, this project illustrates that modular construction can offer flexibility: the final product does not look "like a trailer", it looks like a custom building with unique features that provide a distinctive visual character and cost-effectively drive energy consumption down. Concerning the second research question, this case study shows that LEED® does not impose additional constraints on modular construction compared to those imposed on traditional construction.

The design-build team will need to transfer the knowledge they've learned on this project to future work (when the CBP team will not be available as a "free" resource). Further, the owners will need to adjust their approach to modular construction, in terms of work structuring and cost analysis, based on their lessons learned on this project. The lean construction community may also consider the lessons learned as motivation for future work on work structuring for modular construction, tools or methods for improving the implementation and transparency of the language-action cycle, and developing new cost paradigms.

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