BUILDING INFORMATION MODELING AND LEAN CONSTRUCTION: TECHNOLOGY, METHODOLOGY AND ADVANCES FROM PRACTICE

David J. Gerber[1], Burcin Becerik-Gerber[2], and Alex Kunz[3]

ABSTRACT

Building Information Modeling (BIM) is seen as an emerging approach that will help the construction industry in achieving lean construction principles by eliminating waste; cutting costs, improving team productivity and creating positive project outcomes. While BIM is a building-modeling tool, it is also seen as a process and BIM is quickly converging to demand one integrated, collaborative process involving all disciplines throughout the entire building lifecycle. By analyzing three case studies, this paper explores the relation of BIM and Lean Construction. Specifically, this paper provides insights into how BIM can facilitate lean measures through design to construction to occupancy. Some of the examples include BIM – enabled automated work package creation, resource leveling, value planning, prefabrication, and the benefits of coordination through the use of BIM methodology. It also examines BIM and Lean Construction pre-existence, and value of BIM in terms of improvement in project cost, schedule, quality and reduction of waste.

KEY WORDS

BIM, Lean Construction, Design technology, Design and construction process

INTRODUCTION

Building Information Modeling (BIM) can be used effectively to address the conceptual design, product and process design elements of the Lean Construction principles (Khanzode et al, 2005). While we acknowledge Lean Construction has been developed and performed irrespective of BIM technologies, our focus is on their existing and potential conjoining and on the reciprocal improvements each disparate research will have for the other. Critical to the approach for presenting the research is the hypothesis that *BIM in fact will become increasingly essential and an inextricably linked component to a Lean Construction process, especially within the context of abundant project information, geometric and semantic.* BIM as defined by Eastman et al. is a modeling technology and associated set of processes to produce, communicate,

[1] Assistant Professor, School of Architecture, Watt Hall 204, University of Southern California, CA 90089-0291, USA, Phone 1 617 794 7367, Fax 1 213 740 8884, dgerber@usc.edu

[2] Assistant Professor, Viterbi School of Engineering, Sonny Astani Department of Civil and Environmental Engineering, University of Southern California, 3620 S. Vermont Avenue, KAP 224C, Los Angeles, CA 90089-2531, Phone: 1 213 740 4383, Fax: 1 213 744 1426, becerik@usc.edu

[3] Director, Gehry Technologies Inc., Europe; 17 Rue Paul Lelong, Paris 75002, France, Phone: +33 9 81 76 96 94, akunz@gt-global.com

and analyze building models. BIM is seen as a tool within the Lean Construction community; however, this paper aims to illustrate that BIM based leveraging of project data is in fact aligned with Lean Construction. Our hypothesis furthermore states that through BIM technologies and more critically methodologies, a set of Lean activities can be achieved and enhanced. The hypothesis is validated through the project documentation and practice testimonial in the form of time-savings, waste reduction, and enhanced collaboration. Building information modelling provides a powerful platform for visualizing workflow in control systems that also enable pull flow and deeper collaboration between teams on and off site (Sacks et al, 2010b). Through the enumeration of interactions (Sacks et al, 2010a) between the two paradigms of BIM and Lean, the choosing of case based methods has been employed. Once projects were analyzed for their potential interactions, a large array of BIM activities and products that are directly related to Lean were found. The paper examines three case studies, where waste has been eradicated or significantly impacted. The paper provides examples of Lean through the implementation of BIM based methods primarily, and secondarily, incremental inclusion of Lean definitions. As a general understanding for the described cases that follow, the project teams are not Lean Construction professionals, nor were targeting explicitly Lean Construction outcomes. However, the paper suggests that there is strong implicit overlap furthering the argument of convergence and aligning of BIM and Lean principles.

METHODOLOGY

Our methodology includes the analysis of projects and practices and their effect upon Lean Construction outcomes. The methodology has been to describe three case studies from practice through the BIM based objectives and outcomes and to map these outcomes to the taxonomy of interactions described by (Sacks et al. 2010a). Through this method, we have enumerated a large body of undocumented interaction and convergences, which will instigate further research. As a starting point the team reviewed the body of projects from the Gehry Technologies, Inc, (GT) a global BIM and integrated project delivery (IPD) consultancy. A subset of projects were selected based on the following criteria; (1) cataloguing different Lean and BIM interactions, (2) where possible, enumerating outcomes, and (3) contributing to a larger research that is suggestive of a holistic approach to Lean and BIM integration. Once the projects were selected, a case based structure was followed to describe project vital statistics to provide context and then a focus on outcomes and process improvements. In some cases project materials were anonymized to sensitive project data and figures. To highlight the multiple interactions, we focus on different advances from practice in each project including value planning and schedule based risk mitigation, resource levelling and coordination, and organizational optimization and project collaboration and latency improvement.

CASE STUDY 1

At the Lower Manhattan Construction Command Center (LMCCC), Gehry Technologies, Inc., (GT) a consultancy, has acted as the BIM support team to aid in the deployed risk mitigation practices through the integration of scheduling, expert workshops, and BIMs. The project as a whole involves the oversight and logistics

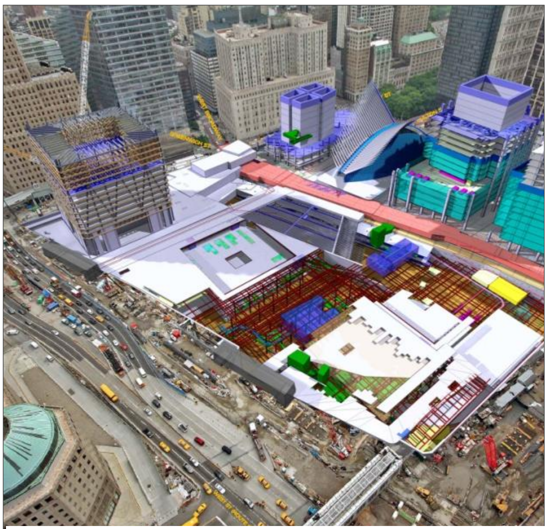

Figure 1: View of World Trade Center BIM model mapped to existing state. Courtesy of the LMCCC and Gehry Technologies, Inc.

planning for the entire World Trade Center site (WTC) reconstruction. A major project challenge is to aggregate available project data, spatially represent the projects, simulate the proposed construction sequencing, and represent the systems interdependencies. Given the dynamic and dispersed physical environments and the fractured contracting arrangements typical of construction, BIM-based visualization interfaces are important tools for providing process transparency (Sacks et al, 2009a). The core activity was to create 4D simulation for each master schedule of the reconstruction of the site and to create comparison simulation for the combinations of the master schedules in and around the WTC site and the need to mitigate the problems arising from competing project schedules and logistical needs. The team has modelled all of the construction projects as geometric objects but more importantly has continually mapped these geometries to the time based construction activities.

The challenges included the managing of the schedule activities and their related geometries, achieved through the constant modelling, associating, and testing of project geometries, permanent and temporary, and project schedules. Another challenge was to devise a method for managing the sheer number of activities and parts and to then create comparative analysis between simulations and schedules. The project exemplifies how BIM and schedule integration are essential to improving upstream flow variability through visualizing construction methods and processes (Sacks et al. 2010a). Interaction; optimization through 4D scheduling for improving efficiency and safety can help identify bottlenecks and improve flow, and interaction; visualization of proposed schedules and visualization of ongoing processes to verify and validate process information (Sacks et al. 2010a) could be seen in this example.

In the most general, all the projects south of Canal Street for lower Manhattan were modelled, in conjunction all of the model objects are mapped to differing level of detail schedules in order to support a risk mitigation process and large multi-disciplinary client, consultant and advisory collaboration. This is an example of interaction between the online communication of product and process information to reduction of variability (Sacks et al. 2010a). In specific terms, the LMCCC model process has enabled a reoccurring risk management method where there are scheduled expert workshops to provide look ahead planning and coordination solutions which has been described as proactive value planning in direct opposition to reactive value engineering. This has been achieved not only through the technological means but also equally through the organizational and methodological. The project consultation has resulted in a reduction in time through the early discovery of coordination errors that would have required costly and time consuming re-work. At the core of the process is the simple method of modelling geometries of the entire sequence of construction providing a high fidelity model of 3D, and 4D outcomes. In terms of innovation the project team optimized schedules using a risk analysis approach which includes the use of Monte Carlo Simulation; the random generation of activity durations; the calculation of schedules with each randomization allowing for 1000 iterations which in turn generate probability distribution curves for the entire schedule and for each activity and milestone (Harvey et al, 2009).

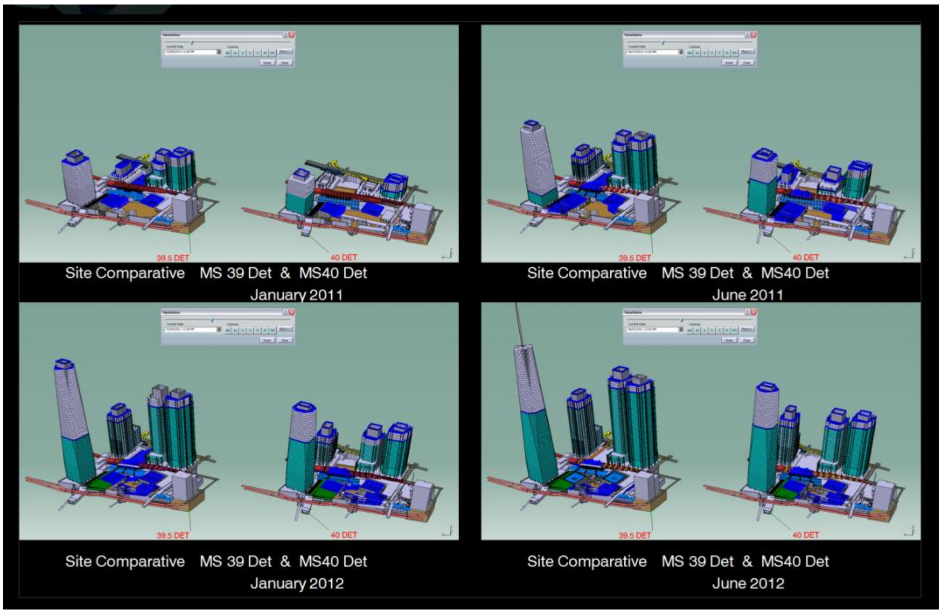

Figure 2: An example of side-by-side comparison of simulated schedule and risk-adjusted schedules. Courtesy of the LMCCC and Gehry Technologies, Inc.

The LMCCC case demonstrates the use of BIM and the synchronizing with scheduling software solutions and experts to reduce the waste caused by poor coordination, and to maximize value for the entire project constituency by ensuring look-ahead collaboration. While the project has begun to be published with no specific reference to Lean the project is an exemplary case where BIM and the organizational innovation demonstrates an essential characteristic of Lean to support a very complex team, waste reduction, value planning, and continual improvements.

CASE STUDY 2

At Yas Island, Abu Dhabi UAE, the client Al-Futtain Carrillion, commissioned Asymptote Architects to design a hotel complex, which includes the world's largest grid-shell. GT had previously worked with Asymptote architects in design assist roles focused on the delivery of project rationalization and automation through parametric design technologies and methods. In the case of the Yas Island Formula One Hotel project (Yas), GT continued to support the project more significantly as the model transitioned from design to construction phases. The model initially was used to aid in the description of the design complexity, then used to aid in the description of construction sequence, leading to the reduction of coordination problems during construction. Here it must be noted that this following through is an example of Lean via the design the production system for flow and value interaction (Sacks et al. 2010a).

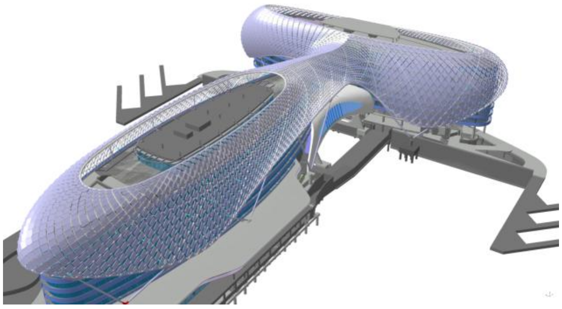

Figure 3: Yas Island Formula One Hotel BIM. Courtesy of Gehry Technologies, Inc.

For the Yas project, a BIM method was implemented where coordination and management of project complexity was the primary thrust. The project requirements included the managing of the incrementally increasing level of geometric detail as the project moved from design BIM to construction BIM. The team then developed the 4D program by continually updating the model to reflect the existing and projected schedules to visualize site progress and look ahead coordination issues. By utilizing the parametric capabilities of the BIM software, Digital Project™, the team was able to rapidly update to provide rapid turn around of chosen coordination solutions. One example was the discovery that the prefabricated bathroom pod installation was in fact not possible as projected given clashes with temporary grid shell works. The team developed what was called a “nearly warning system” based on the visualizing of coordination issues extending the time horizon significantly as in the previous case. Through the simple method of modelling the geometries, permanent, temporary and activities the overall project complexity was discernible and controlled through the breaking down of the project into solvable parts and sub-systems. This is an example of interaction 46, “clash checking and solving other integration issues to verify and validate product information” (Sacks et al 2010a).

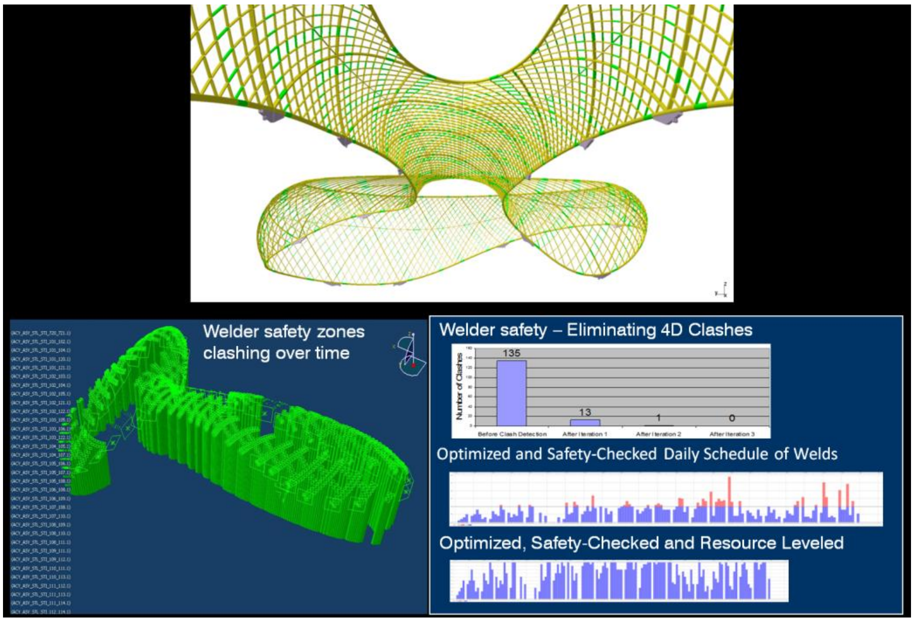

Figure 4: BIM model illustrating grid shell geometry, welding clash analysis and optimized resource levelling. Courtesy of Gehry Technologies, Inc.

Through the continual development of the model, the team innovated in its own use and leveraging of the data of the model and discovered a means to add significant value to the project through the 4D process optimization and grid shell resource levelling. A challenge was the sequencing of the erection of the steel structure and the welding of primary ladders, where welding teams could not work above others due to safety reasons, and where the complex geometry required thorough look ahead planning with respect to temporary works and erection requirements structurally. By modelling the welding team clashes, the team not only eradicated unforeseen delays but more significantly enabled an optimization of welding resources on site and the levelling, i.e. more efficient use of the teams while on site. Through the use of BIM, analysis of construction activities and their related hazards could be identified and some of these risks could be mitigated (Sacks et al, 2009b). The result was the shortening of the construction schedule and the increased value of the welding teams via reduction of idle time necessary to avoid dangerous conflicts. This leveraging can be seen as an example of multiple interaction types: levelling the production through discrete event simulation and ensuring requirement flow down through multi-user viewing of merged or separate multi-discipline models. In addition, this leveraging can be seen as an interaction, according to Sacks et al. (2010a) no documented evidence has been found for “animations of production or installation sequences prepared to guide workers in how to perform work in specific contexts.”

CASE STUDY 3

The two projects presented in case study three include precast concrete facades and structures for the Convention Center of Jeddah (CCJ) in Saudi Arabia, where OGER International and GT collaborated to deliver the construction methods and a second project supporting the King Abdullah University of Science and Technology (KAUST) solar chimney construction, where the team modelled the project for fabrication and construction sequencing. These two projects have been chosen as incremental examples of BIM and Lean Construction interaction, where the focus is on the integration of fabrication processes into the design and construction methods and on the development of work packaging and look ahead planning for construction coordination. Here as before, there is an acknowledgement that Lean principles were not explicitly cited as part of project scope and the focus has in large part been to address product problems, however, there has been an intentional introduction of the vocabulary of Lean into the projects and instances, where process, system, and organizational improvements have in fact occurred.

The CCJ is a new facility for hosting public events and large private gatherings. Featuring a cast-in-place concrete structure and precast façade, the design is classical architecture built with modern tools and methods. The BIM team worked with OGER International’s construction methods team to coordinate the 3D components of the precast façade in advance of fabrication. By first developing a parametric model of the complete façade assembly, the engineering team was able to determine the optimal configuration of joints in the precast panels well in advance of drawing production. By integrating cast-in-place structures into the project model, the team was able to verify the fixation details of the precast components as well. Once the optimal joint patterns were developed for the façade assembly, each precast component was modeled in production level-of-detail, including lifting hooks, inserts for fixation, and center-of-gravity as part of the component model. In addition, the required mould for production was developed in 3D, including the sheet metal base form, silicone form liner including final component details, as well as all block-outs (in foam or wood) required for production. As each component was developed in greater detail, the complete assembly was continuously reviewed to resolve coordination and construction issues in advance of both 2D production and fabrication.

Components are produced using basic sheet-metal forms with silicone mould liners reflecting the final piece geometry. Prior to drawing production, each precast component was verified, including checks to confirm mould removability, maximum concrete and silicone volume, maximum weight, and minimum clearance of silicone throughout each mould. A production control system was used to link precast detailing efforts with the actual needs of site, enabling the project model to be used for look ahead planning of both engineering and construction teams. The BIM enables the site teams to better "pull" what they need from engineering teams, rather than the classic Push system After 3D validation, each precast component was detailed in Digital Project™. Drawing production (2D) from the parametric components is approximately 80% faster than conventional processes while yielding higher quality information for fabrication and assembly. Finally, the project model was used to develop the optimal assembly sequence based on crew, equipment, and fabrication capacities.

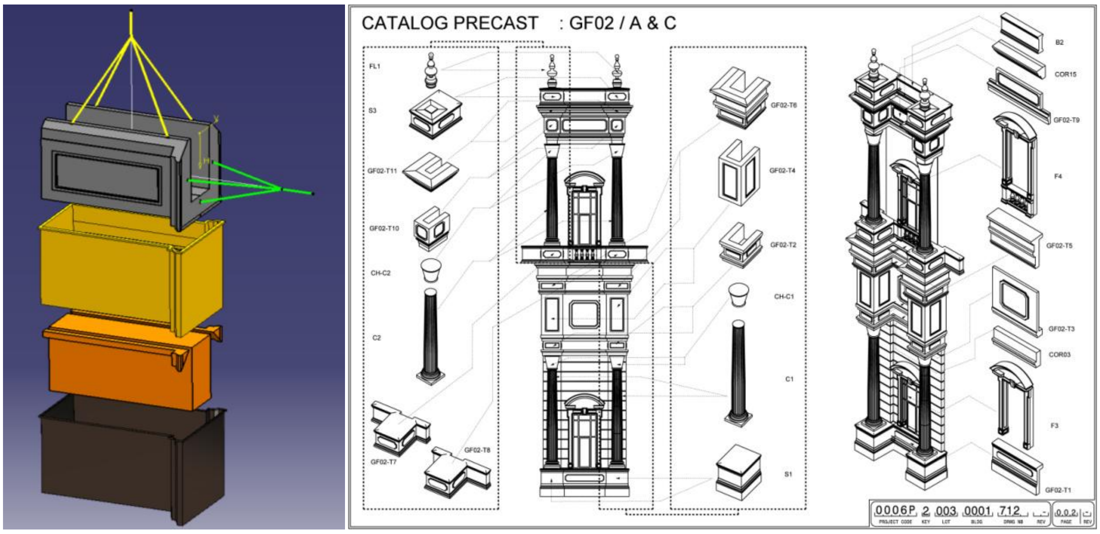

Figure 5: The CCJ project's BIM precast model and illustration of BIM based pre-cast catalogue. Courtesy of OGER International and Gehry Technologies, Inc.

The CCJ project began with a precast component-detailing rate of one component per four man-days. After optimal project systems were established, standard components are designed and detailed in less than one day, with many taking just one hour. A major component of this improvement is the implementation of intelligent components, stored in catalogs that enable the reuse of design information including 3D and 2D information. In addition to enjoying greatly increased engineering capacity, the client OGER International has been able to increase its capacity for innovative types of precast concrete, including hollow-core GFRC panels. The CCJ project presents us with a case where implementing BIM technology allowed for production control in the development of precast system design. The production control was achieved by modelling the precast system elements directly from the built geometries enabling direct and seamless extraction of fabrication documentation again increasing reuse of project information and infusing methods knowledge up-front in the process. These BIM based modelling efforts are further seen as enabling of value stream mapping.

In the second project example, the results of the team's collaboration that exemplify BIM and Lean Construction interaction can be seen in the form of the development of fully coordinated work packaging and more efficient delivery of onsite instruction sets. The KAUST Solar Towers are a unique system for climate control on a new university campus in Saudi Arabia. The extreme temperatures of the climate require extensive cooling systems, and the design team has developed an innovative low-energy solution. Comprised of a double-glazed skin and supported by a post-tensioned, precast concrete diagrid, the towers are chimneys that convert the sun's energy into air movement, by creating a venturi effect in the atrium space between buildings. The architecture and structural design was performed by HOK in the USA, while OGER International managed construction methods and concrete production. GT worked with OGER International to develop an execution level-of-detail model, permitting the construction methods team to resolve and validate the details of the project in advance of shop drawing production. Comprised of precast components, steel embeds, post-tension tendons and fixing bolts, the execution model contains all concrete details to be built onsite. In addition, the cladding system was incorporated into the model to verify the integration of these two complex systems.

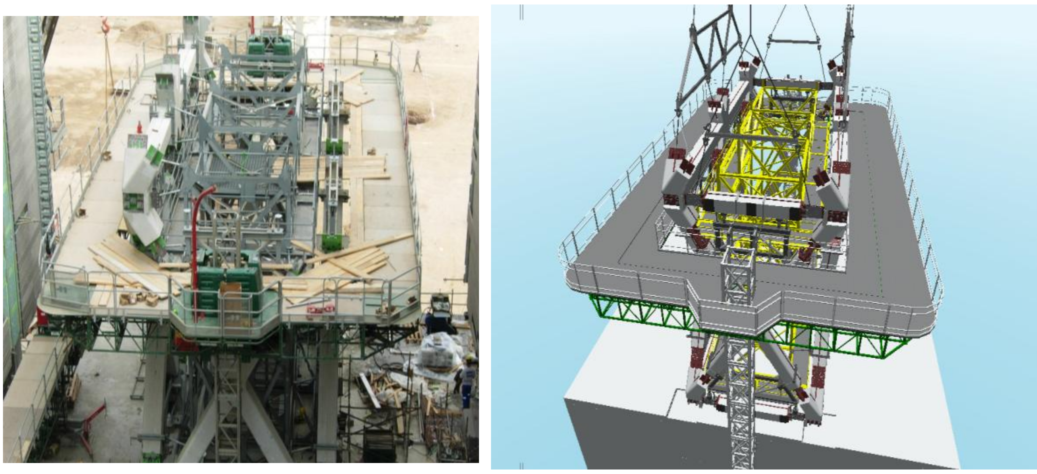

Figure 6: The KAUST Solar Chimney BIM based work package document illustrating construction sequence. Courtesy of OGER International and Gehry Technologies, Inc.

After validation of both steel and concrete details, the execution documents were produced per OGER International's specification. 2D profiles from the digital model were used to fabricate the steel components with CNC cutting tools. The moulds for the precast components were developed and detailed in the 3D model as well. After fabrication, quality control measures were performed on the components to compare as-fabricated to as-designed; measurements from the 3D model were used to validate, and where necessary modify, the steel components before delivery to site. In addition to developing and detailing the permanent works in the project model, all temporary works were developed and validated prior to construction with the 3D model. Standard lifting scaffolds, as well as custom built jigs, spreader devices and fixing tools, were developed by the construction methods team through the 3D model. By validating all temporary works in advance of procurement and site erection, the team was able to reduce the risk of project delay and cost normally associated with such activities.

To communicate the complex erection sequence to the dozens of workers onsite, the team developed two innovative approaches. The first was the fabrication of several 1:100 plastic rapid prototype models, approximately the size of a shoebox, of one diagrid. Made of dozens of components, the plastic assemblies were used to teach the teams about the planned construction process in advance. In addition, an A5 booklet outlining the 100+ steps to assembly a solar chimney was produced using 3D information with minor text description in two languages. Several copies were distributed to the construction teams onsite, with frequent reference to their resemblance to LEGO instructions. What began as an exercise to verify and detail precast components became a total project model, covering precast, façade and mechanical systems in the Solar Tower. OGER International was able to achieve project deadlines with a reduced staff, while also delivering a whole new degree of clarity to their fabrication and assembly teams.

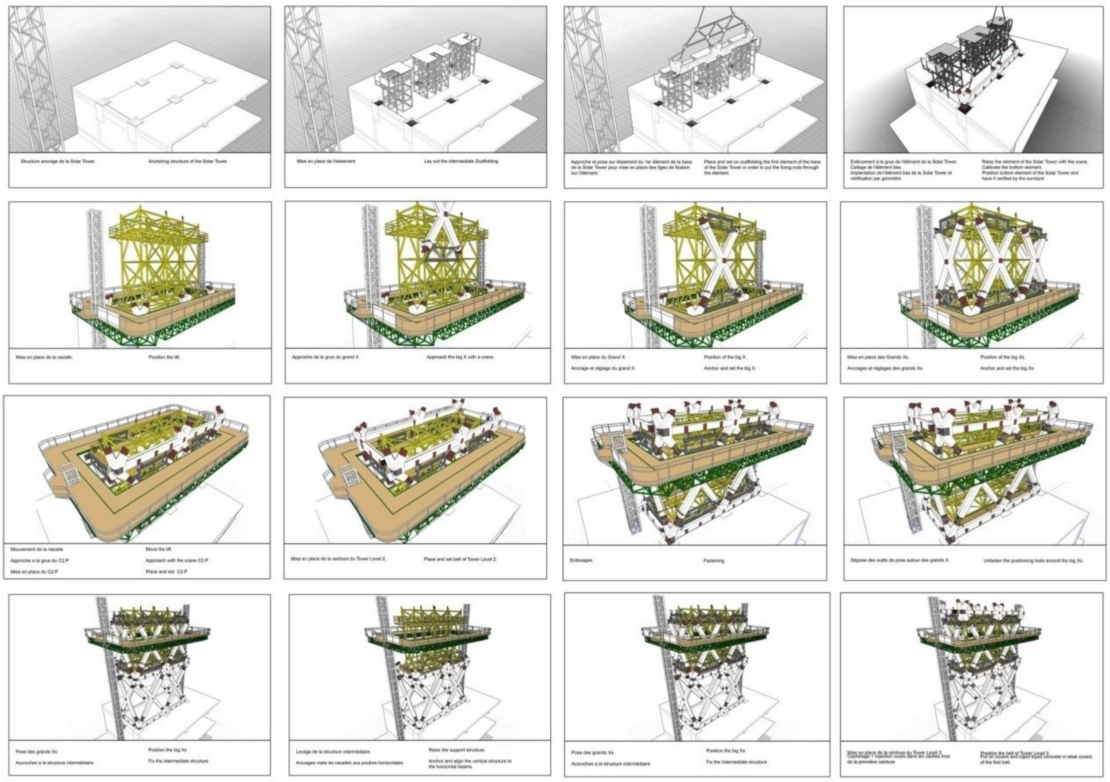

Figure 7: The KAUST Solar Chimney under construction and snapshot image of BIM based work package document. Courtesy of OGER International and Gehry Technologies, Inc.

The approach taken in case study three projects could be linked to two BIM and Lean interactions: (1) Direct transfer of fabrication instructions to numerically-controlled machinery, such as automated steel or rebar fabrication, eliminates opportunities for human error in transcribing information and (2) Automated generation of drawings, especially shop drawings for fabrication (of steel or precast, for example) partly enables review and production to be performed in smaller batches because the information can be provided on demand (Sacks et al, 2010a).

CONCLUSION AND OUTLOOK

The cases described have been chosen specifically for their exemplifying of interactions between Lean and BIM practices. The analysis is post priori and the research acknowledges the initial project goals were not necessarily explicitly modelled on Lean Construction principles. However, the authors, in fact, see this as increased validation of the hypothesis that Lean and BIM need to be further conjoined. What the cases illustrate are a series of projects in which BIM technologies and methodologies have been deployed and where the results have proven to be examples of Lean to learn from. All three case studies have proven to be advances in the core tenant of delivering increased value to clients while significantly reducing waste in the form of time, material, and financing. The paper clearly points to further development in the form of integration of the two currently independent paradigms of research BIM and Lean. It is in the view of the authors that they are inextricably linked but that the literature and research needs to be furthered to prove out the case. To that end the authors will continue to monitor and pursue practice based case research further enumerating areas of existing overlap and seeking out means for further conjoining. The expected outcome is to add to the definition of BIM as a Lean process and to provide further impetus for its re-definition through learning from Lean processes. A final conjecture is, as initial forays into BIM technology implementation and their problems diffuse, the industry will witness the leveraging of these platforms into ever more Lean practice methodologies.

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REFERENCES

Eastman C., Teicholz P., Sacks R., and Liston K. (2008). BIM Handbook: A guide to building information modeling for owners, managers, designers, engineers, and contractors, John Wiley & Sons, Inc., Hoboken, NJ, USA.

Harvey, R., Bahgat, T., Gerber, D., Kotronis, J., Pysh, D. (2009) "BIM as a Risk Management Platform Enabling Integrated Practice and Delivery." *Journal of Building Information Modelling,* Fall 2009

Khanzode, A., Fischer, M., Reed, D. (2005) "Case Study Of The Implementation Of The Lean Project Delivery System (LPDS) Using Virtual Building Technologies On A Large Healthcare Project." *Proceedings IGLC-13,* July 2005, Sydney, Australia.

Sacks, R., Koskela, L., Dave, B.A., Owen, R. (2010a) "The Interaction of Lean and Building Information Modelling in Construction." ASCE *Journal of Construction Engineering and Management,* Accepted Manuscript

Sacks, R., Radosavljevic, M., Barak, R. (2010b) "Requirements For Building Information Modelling Based Lean Production Management Systems For Construction." *Automation in Construction*, Accepted Manuscript

Sacks, R., Treckmann, M., Rozenfeld, O. (2009a) "Visualization of Work Flow to Support Lean Construction." ASCE *Journal of Construction Engineering and Management,* Vol. 135, No. 12.

Sacks, R., Rozenfeld, O., Rosenfeld, Y. (2009b) "Spatial and Temporal Exposure to Safety Hazards in Construction." *ASCE Journal of Construction Engineering and Management,* Vol. 135, No. 8.