EXTENDING THE INTERACTION OF BUILDING INFORMATION MODELING AND LEAN CONSTRUCTION

Pedram Oskouie[1], David J. Gerber[2], Thais Alves[3], Burcin Becerik-Gerber[4]

ABSTRACT

BIM intrinsically provides many features and methodologies to eliminate waste, promote a streamlined flow of work and the delivery of value to internal and external customers. This study builds on an existing interaction matrix of lean principles and BIM functionalities and explores new interactions between these two. The study also aims to expand the existing matrix by discerning new and uncovered BIM functionalities and lean construction principles. In an attempt to pinpoint new interactions, researchers have identified academic and industry based projects, which have integrated BIM methodologies and have employed lean concepts. The research then integrated these new projects to the interaction matrix to further understand how BIM contributes lean construction and how coupling BIM and Lean Construction may affect projects in terms of time, cost and value. The nurturing proposition of this research is that BIM functionalities are still largely unexplored, especially those related to the operation and maintenance stages of a facility. Their link to the Lean Construction theory may actually help promote an informed use of BIM for the Architecture, Engineering, Construction, and Owner industry and to promote more effective transformation, flow and value generation throughout the life cycle of construction projects.

KEYWORDS

Lean Construction, Building Information Modeling, BIM and Lean Interaction Matrix

INTRODUCTION

Two concepts, Lean Construction (Lean) and BIM (Building Information Modeling), have contributed to improving the delivered value and quality of the final construction projects to the clients. Project stakeholders such as designers, contractors and suppliers implement BIM as a platform for effective collaboration among various construction divisions and team members. Recent studies (Khanzode et al. 2006,

[1] Graduate Student, Sonny Astani Department of Civil and Environmental Engrg., University of Southern California, Los Angeles, CA 90089, USA, Phone +1 (213) 572-9373, oskouie@usc.edu

[2] Assistant Professor, School of Architecture, WAH 316, University of Southern California, Los Angeles, CA 90089, USA, Phone +1 (617) 794- 7367, dgerber@usc.edu

[3] Assistant Professor, Department of Civil, Construction and Environmental Engineering, San Diego State University, San Diego, CA 92182, USA, Phone +1 (619) 594- 8289, talves@mail.sdsu.edu

[4] Assistant Professor, Sonny Astani Department of Civil and Environmental Engineering, KAP 224C, University of Southern California, Los Angeles, CA 90089, USA, Phone +1 (213)- 740- 4383, becerik@usc.edu

Sacks et al. 2010) indicate that there are synergies between Lean and BIM, and these can efficiently enhance construction projects performance. Integrating Lean and BIM requires comprehensive understanding of the two concepts and comprehending how these two concepts can be utilized in different projects at various stages. Several functions of BIM and Lean are identified and applied by the industry; however, there are still several potential areas that require further exploration especially such as post construction phases which are getting less attention.

Many researchers have focused on the application of BIM and Lean in the design and construction stages but there have been fewer studies on how BIM can be leveraged in operation and maintenance (O&M) stages of a facility. A thorough investigation is required to validate how the employment of BIM in O&M stages can address lean principles and reduce waste and increase the value to the owner. The main purpose of this paper is to extend the critical observations from the design and construction phases to post construction and the facilities management practices. A study by Reidy et al. (2005) indicates that a great portion of building lifecycle costs is dedicated to the O&M phase.

In order to effectively cut down the project lifecycle costs and construction waste, there is a need to control, monitor and verify the design from early stages and set rigorous plans for maintaining the building during its future operation. Al- Hammad et al. (1997) discuss that defects caused by improper planning, unqualified design and ignoring the requirements of preventive maintenance during the design stage remarkably increase the cost and effort for building O&M. Building owners place great emphasis on the capital costs of a project at the expense of future running costs. The life-cycle cost of an asset is defined as the present value of the total cost of that asset over its operating life, including initial capital cost, occupation costs, operating costs, and the cost incurred or benefit derived from the disposal of the asset at the end of its life (Arditi and Nawakorawit 1999). Sacks et al. (2010) identified 56 interactions demonstrating both positive and negative synergies among BIM and Lean while mainly focusing on the stages of design, preconstruction and construction. The authors of this paper, however, have taken the project lifecycle into deliberate consideration in order to pinpoint new interactions between BIM functionalities and Lean principles. This study builds on an existing interaction matrix of lean principles and BIM functionalities (Sacks et al. 2010) and explores new interactions between these two.

EXTENDED LEAN CONSTRUCTION PRINCIPLES

Lean principles support required techniques for implementing Lean concepts in construction. They emphasize whole process optimization through collaboration, continuous improvement, elimination of waste and a focus on delivering the value desired by the end- user (Enache-Pommer 2010). According to Ballard and Howell (2003), some of the main characteristics of a Lean Project Delivery (LPS) are that the product and process are designed together, all product lifecycle stages are considered in design, learning is incorporated into the project, and the fact that stakeholder interests are aligned. Sacks et al. (2010) have derived other Lean principles by taking into consideration two lean concepts: flow and value. In this research, there are two more lean principles identified in three principal areas described below.

Increase Relatedness and Collaboration: This principle implies the necessity to eliminate any impediment, which causes insufficient relatedness of project participants. Relatedness has to be fostered for different specialties who collaborate to develop the "product" and its related processes together where project participants take into account each other's needs throughout different project stages. Participants need to develop relationships founded on trust if they are to share their mistakes as learning opportunities for their project, and all the other projects (Lichtig 2005).

Tightly Coupling of Learning with Action: Project value can be enriched by the process of performing work, learning from action and improving work. Rather than using single flow for action, firmly linking learning with action should be implemented based on the feedback of how satisfactory the performed work has been in terms of meeting quality requirements and expectations (Lichtig 2005).

EXTENDED BIM FUNCTIONALITIES

BIM functionalities are widely known for design and construction processes. The next step is identifying BIM functionalities that contribute to Lean construction. We first propose the new functionalities which are utilized during the preconstruction and construction phases and afterwards we discuss the functionalities that mainly focus on the operation and (O&M) phase and support BIM- enabled facilities management. As stated by Kurdi et al. (2011) a useful management tool for selecting the appropriate strategy to maximize the facilities output will reduce building lifecycle costs and maximizes profits. BIM functionalities facilitate applying the necessary management techniques by generating a framework for collaboration, organizing building data and providing access to them throughout facility's lifecycle. After analyzing projects for their potential interactions, Gerber et al. (2010) have found a large array of implemented BIM based methods and activities that are directly related to Lean. Of note is the flow and fidelity of information from these BIM methods that facilitate Lean principles in the design and construction of these projects. The next paragraphs introduce new BIM functionalities added to those identified by Sacks et al. (2010).

Support the Make Ready Process: The "make ready" process is part of the Last Planner System™ in which the constraints related to a specific task are reviewed at the medium-term planning level or look-ahead level. BIM can support the make ready process by allowing project participants to visualize 4-6 weeks ahead of execution and BIM helps them analyzing which tasks will have to be performed and what additional constraints may be identified by examining the model for each specific task (Ballard and Howell 1998). Despite the fact that not everything that takes place during installation is modelled in BIM, the model gives a birds-eye view of the situation crews might encounter and help each trade to get ready for construction (Sacks et al. 2009).

Facilitating Real- Time Construction Tracking and Reporting: BIM provides the ability to monitor real time construction progress, transfer retrieved data and compare it with available information database with the purpose to evaluate progress and make future decisions in advance, based on the project historical information.

Support Augmented Reality: By integrating BIM with augmented reality, a better understanding of construction progress, precision and accuracy of constructed elements can be achieved through superimposing as- built and as- planned model; As a result the construction project manager might be able to detect defaults and to make

control decisions and effectively report deficiencies to the responsible project participants.

FUNCTIONALITIES THAT SUPPORT OPERATION AND MAINTENANCE

The O&M phase of construction projects usually incorporates a large portion of total project cost. Facilities Management (FM), as the main and most sensitive segment of this phase requires excessive collaboration and interoperability among various divisions of computer-aided design, engineering and software systems. National Institute of Standards and Technology (NIST) released a report in 2004 indicating annual cost of $15.8B due to inadequate interoperability and ineffective operation and maintenance of ongoing facilities (Gallaher et al. 2004). BIM is accompanied with beneficial functionalities that enable efficient Computer Integrated Facilities Management (CIFM). Benefiting from IFC (Industry Foundation Classes) file formats developed by the International Alliance for Interoperability (AIA), BIM provides an enriched information database so that project information generated during design and construction phases can be easily transferred to the operation phase (Isikdag et al. 2008). From the Lean design and construction point of view, BIM supports facilities management processes by facilitating information flow, reducing variability, and standardization. Current deficiencies and challenges with the manual methods for FM and the fact that manual practices are time-consuming and laborious have increased industry interest in utilizing BIM in order to improve FM practices.

Controlling Lifecycle Cost Data: Dividing the lifecycle of a construction project into three major stages of design, construction, O&M, each stage consists of an individual set of components associated with a thick- set database of information such as cost, location and so on. In order to effectively manage all the information, analyze them and to transfer them forward to the next stages of lifecycle, BIM plays the role of a robust database with the capability of storing information and providing convenient access to the information for all project stakeholders. Consequently, historical costs of the project can be stored for future applications such as renovation and remodeling. Effective and immediate access to information minimizes the time and labor needed for retrieving information and reduces the occurrence of ineffective decisions that are made in the absence of information (Ergen et al. 2007).

Controlling Lifecycle Environmental Data: Throughout the project lifecycle, components' information may be updated or modified. For instance, environmental data has to be updated regularly for environmental impact studies that start from the early stages of design and continue through the project lifecycle by monitoring environmental compliance. The ability to control lifecycle costs and environmental data leads to predictable building performance and tighter budget planning (Sabol 2008).

Effectively Locating Building Components: Locating building components, equipment and facilities for maintenance, preservation and repairing purposes is a regular task performed by FM personnel and technicians. Gallaher et al. (2004), argue that currently, an inordinate amount of time is spent locating and verifying specific facility and project information from previous activities. They mention that, as- built drawings (from both construction and maintenance operations) are not routinely provided and the corresponding record drawings are not updated and therefore, information on facility condition, repair parts status, or a project's contract or

financial situation is difficult to locate and maintain. By using BIM tools, onsite FM personnel can navigate into BIM models and use BIM functions such as view, search, filter, and highlight to guide themselves to the target component (Becerik-Gerber et al. 2011).

Facilitating Retrieval of Real-Time Integrated Building, Maintenance and Management Data: In order to execute inspections and facilities commissioning, FM personnel need to pull out real- time information of parameters such as location, condition and timing from different building databases; therefore an instant access to the required information is needed. BIM enables real- time FM by integrating data and building model and presenting a three dimensional interface with highly functional dashboard of capabilities (Freeman 2009).

Improving Maintainability Studies: Maintainability studies begin in early stages of building lifecycle due to the fact that majority of deficiencies taking place during building's operational phase could have been foreseen and avoided throughout the design and construction stages. To avoid expenses and risk factors associated with the building maintainability, BIM provides an effective platform to monitor building materials and elements to ensure that they are operating in compliance with environmental and functional requirements throughout the building lifecycle. Moreover, As- built models could serve to automate the maintainability- checking processes through the use of geometric and semantic BIM data, which provide information about the actual dimensions and location, spatial relationships, and maintainability- related documents (Becerik-Gerber et al. 2011).

Streamlining Space Management: Space management is the process of projecting space requirements, identifying deficiencies, allocating available space to users in an equitable way, monitoring use, assisting users with space usage problems, and resolving space problems with the intention to minimize energy, maintenance, and other operating costs. BIM promises to improve space management by integrating building data with historic data; automating process of space validation; and by improving space planning and forecasting, space suitability assessment and post- occupancy evaluation. Moreover, data extracted from BIM applications, can be easily transferred to available space management software through IFC formats.

Fostering Efficient Planning and Feasibility Studies for Non-Capital Construction: Renovation, retrofits and demolishing of existing buildings are considered to be one of the responsibilities of FM group. Owners often do renovations and retrofits to save energy costs and meet new codes. Traditional renovation methods use references such as blueprints, scanned 2D drawings and so on. Taking advantage of building information database, facility managers can perform energy efficiency analysis for different design alternatives in order to document new construction conditions.

Enabling Personnel Training in Virtual Reality: Another challenge in FM practices is to systematically train FM personnel for accurately operating different facilities. Traditionally, FM personnel get acquainted with facilities by attending technical presentations and site visits. The labor hours and cost devoted to the conventional training process for FM personnel to gain competence on systems are relatively high. BIM systems can provide more ability for rendering the designs with some degree of realism, making building designs more accessible to nontechnical project participants and stakeholders than is possible with technical drawings (Sacks

et al. 2010). Using an interactive 3D model, FM personnel can experience a virtual reality in which they can virtually control and perceive existing facilities. This approach enhances learning experience and also enables post evaluation

Expediting Search and Rescue: Emergency situations need to be carefully considered throughout the design phase of a facility. BIM can be deployed to improve safety of building occupants in case of unexpected events. Positioning of critical equipment and elements can be determined early by making use of BIM's graphical features and interfaces. Moreover, the process of reaching critical facilities and locating occupants during an actual emergency can be expedited by accessing BIM based accurate information rather than assumptions and estimates.

DISCUSSSION

The interaction matrix, illustrated in Table 3, is derived from Sacks et al.'s (2010) and it holds the same interface except that the new matrix is extended and developed with new Lean principles and BIM functionalities. The previously identified interactions are shown by "X" and the new Lean principles and BIM Functionalities are represented by the bolded font in the table. In addition, some of the previous Lean principles and BIM functionalities are not shown in the table since there has been no new interactions found for them in this research. In contrast to Sacks et al. (2010) methodology, which breaks down lean principles to sub- categories, this paper primarily employed main categories for presentation of interactions between BIM– enabled FM and lean construction. The driving idea for this approach is that some of the sub- categories of Lean principles provided by Sacks et al. refer to the production process while the BIM-enabled FM mainly addresses the general Lean concepts.

Critical interpretation of the interaction matrix could inspire novel management methods and provide insights on how BIM and Lean can be integrated to enhance the value and quality of the delivered project. Sifting through the interactions, one can observe that "Reduce Variability" and "Reduce Cycle Times" are the highest concentrated Lean principles. This highlights the fact that the main effort during construction and maintenance stages has to be planning ahead and prevention of any unnecessary tasks, which lead to undesired results. On the other hand, the highest concentrated BIM functionalities are "Reuse of Model Data for Predictive Analyses", "Visualization of Form", "Facilitating Real- Time Construction Tracking and Reporting" and "Facilitating Retrieval of Real- Time Integrated Building, Maintenance and Management Data" respectively. This implies an interest in taking advantage of emerging "Real- Time Data Acquisition and Analysis" technologies especially in the phases of the construction and post construction. Integrating these technologies with visualization capabilities of BIM facilitates the decision- making and consequently leads to a lean construction.

CONCLUSION

This paper presents an extended interaction matrix for BIM and lean construction supported by both empirical and academic evidence. The authors took the project lifecycle as the base point for investigation and focused on the phases in which the FM practices are considered to comprise a great portion. The authors believe that there is a growing interest in exploiting BIM for improving FM practices and minimizing the costs related to maintaining and expanding facilities.

Table 1: Extended Interaction Matrix of Lean Principles and BIM Functionalities

BIM Functionality	#	A — Reduce Variability	B — Reduce Cycle Times	C — Reduce Cycle Times	D — Select an appropriate production control approach	E — Select an appropriate production control approach	F — Standardize	G — Standardize	H — Use Visual Management	I — Use Visual Management	J — Ensure Comprehensive Requirements Capture	K — Ensure Requirements Flow Down	L — Verify and Validate	M — Go and see for yourself	N — Decide by consensus consider all options	O — Cultivate an extended network of partners	P — Increase Relatedness or Collaboration	Q — Tightly Coupling of Learning with Action
Visualization of Form	1	X									X, 7, 8	X	X, 7	X	X, 7			
Reuse of Model data for predictive analysis	2	X, 7, 8	X,6	X					6		X	7	X, 7		7			
	3		X,1	X									X, 1					
Automated generation of drawings and documents	4	X		X,4	X													
Collaboration in design and construction	5	X		X							X	X	X		X		3	
Online/ electronic object-based communication	6		X	X	X	X				X, 6			X	X				
	7	X		4	X	X		X	X	X		X				X		
	8	X, 2		X													2	
Support the Make Ready Process	9					4	4											
Generating As- Built Models	10	**5**											**5**					
Monitoring Construction Process	11	**5**	**5**			**5**	**5**											
Real- Time Evaluation of Productivity	12	**2**	**2**	**2**	**2**													**2**
Support Augmented Reality	13	**5**											**5**	**5**				
Controlling Lifecycle Cost Data	14		**17**	**17**				**17**										
Controlling Lifecycle Environmental Data	15		**14**	**14**				**14**										
Effectively Locating Building Components	16			**9**						**9**								
Facilitating Retrieval of Real- Time Integrated Building, Maintenance and Management Data	17		**10**	**10, 13**						**10**								
Improving Maintainability Studies	18		**10**															
Streamlining Space Management	19		**16**							**16**			**16**					
Fostering Efficient Planning and Feasibility Studies for Non-Capital Construction	20		**12**	**12**														
Enabling Personnel Training in Virtual Reality	21									**15**								**15**
Expediting Search and Rescue	22		**11**	**11**														

Table 2: Interaction Matrix: Explanations of Cell Contents

Index	Explanation	Evidence from Practice/or Research
1	Once cost estimate and 4D Schedule were generated automatically, cash flow analysis charts and information can be developed. As a result, owner and contractor will be able to forecast required budget and cost of the project far ahead of time. In addition, if any construction circumstances result in even slight changes in design, cash flow data will get updated accordingly.	Not Yet Available
2	With BIM interfaces, real- time productivity can be measured, so that any defects in terms of production in workstations can be rapidly detected and resolved in early stages of work. This will result in learning from experience and consequently improves future methods of implementation.	Taneja et al. 2011
3	Collaboration occurs better when project participants are gathered in a room while viewing themselves as equal participants in the process and when the initial collaboration centers on exploring and defining the problem, rather than commenting on someone's proposed solution. With BIM, design and construction participants come to collaborative meetings from a position of inquiry, rather than advocacy.	William A. Lichtig, 2005
4	Facilitating coordination and forecasting required Labor, Equipment and Material (LEM), BIM prevents conflicts in site and consequently prevents any rework and reduces cycle times. Additionally, BIM Efficient coordination will enhance project safety as well and avoids any delay in work resulting from safety issues.	Not Yet Available
5	Comparing generated As- Built model with As- Planned, discrepancies between these two can be easier detected. In addition, quality assurance and control can be accelerated through this procedure resulting in a better product to the owner.	Golparvar- Fard et al., 2009
6	With BIM and its interfaces, site logistics, material staging and equipment layout can be easily determined and various alternatives can be discussed and evaluated in order to establish best and most effective solution. This will result in trouble- free circulation of construction related equipment and workforce.	Rudolph & Sletten Co., Dry Creek Rancheria Conference Center, 2007
7	BIM can contribute to creating a platform for end-users to observe design model as they already live in the building and it helps them exploring the whole building and evaluating how design addresses their requirements. Designer and client will then appraise end-user's feedbacks to review design and manage requirements and deliver the best product and prevent any undesirable design. In addition, reviewing data from simulated user occupancy can simply lead to a more efficient design especially in terms of designing facilities.	Weilin and Qiping Shen, 2011
8	Project managers acquire tasks that are shown in the Master Plan, break them down about 4-6 weeks before the tasks are scheduled to start and screen each one for what is needed in order to make these tasks ready for construction (e.g., outstanding RFIs/change orders, pre- fabrication of items with a lead time of less than 4-6 weeks, fine-tune the sequencing of trades according to current conditions, redefinition of layout). Finally, BIM models provide Bills of Materials (BOM) required to perform the task and can be used during the Make Ready process to order materials.	Not yet Available
9	BIM interfaces allow maintenance people to inspect different parts of the building in advance of actually going on- site to service them. By utilizing BIM, facility technicians will be able to find their target piece of equipment, acquire its location and look up the manufacturer's information, supplier contact, warranty data and service record to pinpoint the best approach for maintenance.	ENG Studios/ YouBIM
10	Facility managers take advantage of BIM applications with centralized, real- time and online access to project information. The applications provide an integrated database of historical record of all equipment, providing invaluable information regarding the actual performance of equipment within the building and provide instant access to facility information through an easy-to-navigate web-based 3D / BIM interface. Having all the required data ready, countless hours of finding information is saved comparing to the traditional methods.	ENG Studios/ YouBIM
11	Enriched structure of the BIM would provide specific advantages in facilitating the fire response management process and decreasing the costs associated with incoordination. Some of the tasks identified to be supported by BIM are: Locating fire sensors and fire alarms inside the building, providing information about installed electronic control systems, locating emergency exists in the building, tracing positions of electrical installations and pipelines surrounding the building, providing information about materials of building elements.	Umit Isikda, 2008
12	BIM software allow facility managers to collect all the information on existing conditions and perform critical analysis on available design alternatives in order to effectively operate renovations and predict future energy usage and efficiency of the new- designed facility.	WLC Architects- Rancho Cucamonga Middle School 2010

Table 2: Interaction Matrix: Explanations of Cell Contents (continued)

Index	Explanation	Evidence from Practice/or Research
13	Attaching RFID tags to components provides the ability to remotely identify and track each component individually. This feature provides more accurate supply chain visibility and improves information sharing and reduces manual paper-based record tracking. Moreover, having product history and process related information stored on tags attached to components provides easy access to data for various Product Lifecycle Manager (PLM) software applications and eliminates the need for network connectivity to retrieve data from a central database. Furthermore, it reduces human errors since the data storage/retrieval is automated in an electronic format which minimizes the risk of data loss.	Motamedi et al. 2009
14	BIM can create a comprehensive database for storing and also retrieving a set of specific environmental data such as the location or the functionality and specifications of the space. The database can frequently get updated and revised either manually or automatically as the facility ages through its lifecycle. This can also facilitate the future planning process for possible renovations and building upgrading.	Motamedi et al. 2009
15	Facility managers and technicians are provided with a virtual environment in which the actual building or the facility's 3D model is available. The FM personnel will be able to work with different devices and equipment in an interactive environment. This enhances the learning process with supporting visualization and enables FM personnel to get acquainted with facility operation more effectively.	EON Reality and Saudi Aramco 2009
16	BIM can visualize space and host space attributes for immediate access to facilitate identifying underutilized spaces, forecast space requirements, simplify space analysis, manage the move process, and compare actual with planned space utilization (Becerik et al. 2011). The building 3D model can be used as the basis for model development and performing space management analysis while the master model supports different spatial hierarchies such as location zones, functional spaces, rooms and places to organize interior space for multiple purposes.	Becerik et al. 2011 Sabol 2008-Sydney Opera House
17	In addition to facilitating cost estimation during design and construction, BIM can also assist recording cost data related to all building components and objects and facilities within the building throughout its lifecycle. FM personnel can easily access all detailed information regarding building elements cost and can perform cost analysis for any future construction plans in order to achieve predictable building performance and tighter budget planning.	Sabol 2008-Sydney Opera House

Enhancing construction quality by integrating BIM with lean concepts is still a potential area for further investigations. The future work of the authors will include an extension of the current matrix and exploring new interactions through studying more practical sources and case studies. Future studies will help lead to a rigorous and reliable framework for the industry to effectively execute lean construction.

REFERENCES

Al-Hammad A., Assaf S., Al-Shihah M., (1997). "The effect of faulty design on building maintenance" *J. of Quality in Maintenance Engr*g, 3(1) 29-39.

Arditi, D. and Nawakorawit, M. (1999). "Issues in building maintenance: property managers' perspective." J. of Arch. Engrg., 5(4), 117-132.

Ballard, G. and Howell, G. (1998). "Shielding Production: An Essential Step in Production Control", *J. of Constr. Engng. and Mgmt.*, ASCE, 124 (1) 11-17.

Ballard, G. and Howell, G. (2003). "Lean Project Management" *Build. Res. & Info.*, 31, 1-15.

Becerik-Gerber B., Jazizadeh F., Li N., Calis G. (2011). "Application Areas and Data Requirements for BIM-Enabled Facilities Management." *J. Const. Eng. Mgmt.*, 138 p. 431.

Enache-Pommer E., Horman M., I. Messner J., Riley D. (2010). "A Unified Process Approach to Healthcare Project Delivery: Synergies between Greening Strategies, Lean Principles and BIM." Construction Research Congress, ASCE, 1376- 1385

ENG Studios Engineering & BIM Solutions, YouBIM Facility Management Software, EON Reality Experience, URL: http://www.eonreality.com/.

Ergen E., Akinci B., Sacks, R. (2007). "Life-Cycle Data Management of Engineered-to-Order Components using Radio Frequency Identification" *Adv. Eng. Inform.,* 21(4) 356-366.

Freeman S. (2009). "FM Issue: Demystifying BIM" Issue of Today's Facility Manager"

Gallaher M. P., O' Connor A. C., Dettbarn J. L. Jr., Gilday L. T. (2004). "Cost Analysis of Inadequate Interoperability in the U.S. Capital Facilities Industry." NIST, Gaithersburg, MD.

Gerber D. J., Becerik-Gerber B., and Kunz A. (2010). "Building Information Modeling and Lean Construction: Technology, Methodology and Advances from Practice." Proc. 18th Int'l. Group for Lean Const., Haifa, Israel, July 14-16.S

Golparvar-Fard M., Pena-Mora F. and Savarese S. (2009). "D4AR- A 4-Dimensional Augmented Reality Model for Automating Construction Progress Monitoring Data Collection, Processing and Communication" *J. Info. Tech. in Const.,* 14, 129- 153.

Howell, G. (1999). "What is Lean Construction." *Proc. Ann. Conf. Int'l Gr. Lean Const.*

Isikdag U., Underwood U. and Aouad G. (2008). "An investigation into the applicability of building information models in geospatial environment in support of site selection and fire response management processes." *Adv. Eng. Infor.* 22, 504-519.

Khanzode A., Fischer M., Reed D., Ballard G. (2006). "A Guide to Applying the Principles of Virtual Design & Construction (VDC) to the Lean Project Delivery Process." CIFE, Stanford University.

Koskela L. (1992). "Application of the new production philosophy to construction." *Technical Rep. No. 72*, CIFE, Dept. of Civ. Eng., Stanford Univ., Stanford, CA

Kurdi, M.K., Abdul-Tharim A.H, Jaffar N., Azli M.S., Shuib M.N., Ab-Wahid A.M. (2011). "Outsourcing in Facilities Management- A Lit. Review." 20, 445- 457.

Lichtig, W. (2005). "Sutter Health: Developing a Contracting Model to Support Lean Project Delivery" *Lean Construction Journal*, Vol. 2.

Motamedi A. and Hammad A. (2009). "Lifecycle management of dacilities components using radio frequency identification and building information model." *J. Info. Tech. in Const.,* 14, P. 238.

Reidy, R., Davis, M., Coony, R., Gould, S., Mann, C., Sewak, B. (2005). "Guidelines for Life Cycle Cost Analysis" Stanford University Lifecycle Cost Analysis Team.

Sabol L., (2008). "Building Information Modeling & FM." IFMA World Workplace.

Sacks R., Radosavljevic M. and Barak R. (2010). "Requirements for Building Information Modeling based Lean Production Management Systems for Construction" *J. Auto. in Const.,* 19, 641- 655.

Sacks, R., Koskela, L., Dave, B. A., Owen, R. (2010). "Interaction of Lean and Building Information Modeling in Construction." *J. Constr. Eng. Mgmt.,* 136(9), 968-980.

Schell D. (2001). "Oil refinery uses RFID to eliminate rework and reduce data entry by 70%", Business Solutions, Retrieved Oct. 2008, http://www. businesssolutionsmag.com

Shen W., Shen Q. (2011). "BIM- Based User Pre- occupancy Evaluation Method for Supporting the Designer- client Communication in Design Stage" Management and Innovation for a Sustainable Built Environment, Amsterdam, The Netherlands.

Taneja S., Akinci B., H. Garrett J., Soibelman L., Ergen E., Pradhan A., Tang P., Berges M., Atasoy G., Liu X., Shahandashti M. and Burak Anil E. (2011). "Sensing and Field Data Capture for Construction and Facility Operations" Journal of Construction Engineering and Management, ASCE,

WLC Architects Inc., Rancho Cucamonga Middle School, URL: http://www.wlcarchitects.com/