

BIM for retrofits: A case study of tool installation at an advanced technology facility

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The benefits of using Building Information Modeling (BIM) for new construction projects are well documented in academic research and validated by its widespread adoption in the Architecture/Engineering and Construction (AEC) industries. BIM use for existing facilities requiring periodic upgrades and retrofits is comparatively less represented. This paper explores the impact of BIM at the labor work-face for a retrofit project; with a case study of process tool installation at an advanced technology facility. The paper provides a literature review of BIM for retrofits, describes the case study and then identifies issues and/or constraints that are unique to retrofits. The research shows that the BIM maturity of the construction supply chain combined with the constraints presented by the existing facility were causing an interrupted construction workflow. A root-cause analysis further led to the conclusion that BIM implementation requires process re-engineering at all phases of a project to accommodate the new value stream created by the use of BIM. In conclusion, the rudiments of a theoretical framework is proposed to map the stakeholder value associated with BIM and the potential impact of this value-system on labor productivity. This paper is a part of a larger research project which is studying the impact of BIM on labor performance.

Keywords: BIM, retrofit, workflow, tool-install

Introduction

Changing facility design to accommodate new technologies have led many industrial owners to prefer retrofit to green-field construction projects in order to remain profitable in an increasingly unpredictable economy. Sanvido & Riggs (1991) define a *"retrofit project"* as the modification or conversion of an existing process, facility, or structure which may alter the cost, kind, quality or quantity of the products or services being produced by the facility. Most advanced technology facilities such as oil & gas refineries, semiconductor manufacturing plants, pharmaceutical industries and other industrial and manufacturing facilities consider retrofits for incorporating new technology, expanding production, reducing environmental impact and improving operational efficiency. Past research studies have shown that retrofit projects comprise 64% of all commercial construction projects (McGraw-Hill, 2010) and 70% of all projects in the process industry (Ben-Guang, Fang-Yu, Kraslawski, & Nyström, 2000). While there can be several types of facility upgrades, the scope of this paper considers equipment or process tool installation in existing advanced technology facilities.

Existing buildings and legacy systems can pose new challenges which are technical (*e.g.* capturing & maintaining accurate as-built data, lack of interoperability, high data volumes), organizational (*e.g.* stakeholder collaboration, new workflows) and cultural (*e.g.* learning curve, increased effort) in nature (Volk, Stengel, & Schultmann, 2014). In some cases, sections of the facility may remain operational during upgrades, adding another layer of operational complexity. Despite these challenges, the construction trades face increasing pressure to; (a) maintain a high level of performance to ensure a faster time to market for the manufactured products and (b) optimize construction labor headcount to alleviate the congestion on site. Past research has advocated improving labor productivity through the increased use of BIM and off-site prefabrication (Eastman & Sacks, 2008; Hanna, Yeutter, & Aoun, 2014; Teicholz, 2013). Although BIM is not a pre-condition for prefabrication, it can be considered an enabler for reliable prefabrication by offering capabilities such as early detection of coordination issues on site, material tracking and computer aided manufacturing. However, research on BIM and prefabrication primarily focus on their usage for new construction completed with a 3D model and BIM, rather than implementation on existing buildings built without the use of BIM (Volk et al., 2014). Therefore, the typical workflow of BIM planning and implementation for new

construction projects if replicated for retrofit projects may not show similar benefits because of the fundamental differences in BIM use and the unique conditions presented by retrofit projects. This paper explores this phenomenon by conducting a case study analysis of BIM use for tool installation at an advanced technology facility.

The objective of this paper is to (a) present a brief literature review of BIM for retrofit projects and (b) explore the impact of BIM used in its current maturity level on labor productivity in a retrofit project. Analysis of the case study presents two significant research findings. First, that in the case of retrofits, geometrical information in BIM is an important aspect, which if not managed accurately can impact labor productivity adversely. Second, poor labor productivity caused by workflow interruptions attributed to BIM, find their origins in decisions made by project stakeholders in the initial phases of planning and management of the BIM process. Finally, the conclusion proposes a theoretical framework to map the stakeholder value associated with BIM in a retrofit project and its potential impact on labor productivity.

Background

Literature Review

Retrofit projects differ from green field projects in the intensity of the constraints posed by the project types. Table 1 outlines some of the constraints common to retrofits. The literature review discusses findings from three subject areas; (1) BIM implementation frameworks for new and existing facilities, (2) prefabrication as a method for improving labor productivity in retrofits and, (3) existing conditions documentation.

Table 1
Constraints in retrofit projects

Source	Constraints
(Sanvido & Riggs, 1991)	• Information (lack and uncertainty of existing data) • Time (acute pressure for time to market of product) • Space (space congestion, access and work sequencing) • Environment (working with hazardous or toxic materials, noise & vibration)
(Loughran, 2003)	• Maintaining optimum production levels • Demolition & disposal of hazardous materials • Maintenance of Environmental/Health/Safety (EHS) requirements • Access for production workers
(Ben-Guang et al., 2000)	• Removal or protection of existing equipment • Reuse of existing equipment • Experimental studies of uncertainties in design • Late changes in retrofit design

Within the first category of papers, Succar (2009) presents an ontology to identify the roles within a BIM process, the deliverables needed throughout the BIM process, and the interactions taking place between stakeholders. He provides a systematic analysis of a user-based description of BIM implementation, depicted in three stages; (1) object based modeling (referring to the migration from 2D to 3D), (2) model based collaboration (integrated data sharing & communication) and, (3) network based integration (dissolution of project phases and the transition to real-time nD collaboration with intelligent models). Analysis of academic frameworks and industry guidelines help identify a few factors which are essential for any BIM implementation plan. These include the development of a BIM Execution plan, a contract addendum for BIM, standards for the 3D CAD model and BIM development, management and deliverables, the Level of Development of the model, the interoperability and information exchange standards and the establishment of performance benchmarks to measure the effectiveness of BIM. In contrast, Volk et al. (2014) summarize the lack of overall implementation of BIM in a retrofit scenario as; identifying challenges such as capturing structural, concealed or semantic building information under changing environmental conditions and of transforming the captured data into unambiguous semantic BIM objects and relationships. This category of research sets the stage for future studies.

The focus on prefabrication efforts in the construction industry is to improve productivity and promote lean construction (Cowles & Warner, 2013). This is particularly true for mechanical and electrical contractors. However, the amount of preplanning required for the proper execution of prefabricated/off-site construction can pose a barrier (Haas, O'Connor, Tucker, Eickmann, & Fagerlund, 2000). A second barrier to the proper execution of prefabrication are the equipment and automation technologies utilized by subcontractors in fabrication facilities. Simonian & Korman (2013) conducted a survey of electrical contractors, to identify the relationship between BIM as an enabler for prefabrication. The results of their particular survey show that, *"there is a strong correlation between contractors who do not fabricate facilities and who do not use BIM".* The survey also indicated that the greatest value from BIM was the ability to visualize the system in three dimensions. The use of prefabrication is expected to nearly triple over the next five years (Cowles & Warner, 2013). As we approach this increase in production, a more coordinated cross-trade collaboration is expected to arise, particularly under alternative project delivery methods.

In order to effectively prefabricate and install building components in an existing facility, accurate capture and representation of as-built conditions is necessary. Rojas et al. (2009) present a method of producing COBie data from the extrapolation of information from traditional drawings. A COBie format can preserve the information even if 3D models become redundant. Jung, Hong, Jeong, Kim, Cho, Hong, & Heo (2014) discuss the popular method of laser scanning the interior of structures for proper capture of as-built conditions. Point clouds, the output from laser scans, can be converted to surface models in one of two ways; manually drafting in the CAD software or the use of automatic surface generation algorithms. According to Tang, Huber, Akinci, Lipman, & Lytle (2010), this process is fundamentally manual and time consuming and there are several technology gaps in the automatic model generation process such as; modeling of more complex structures and non-ideal realistic geometries, handling realistic environments with clutter and occlusion, representing models using volumetric primitives rather than surface representations and developing quantitative performance measures for tracking the progress of the field.

The literature review revealed that all successful BIM implementation plans address a few common factors such as BIM execution plans, contract addendums, standards, maturity levels, LOD specification etc. In the case of retrofits, in addition to these fundamental implementation factors, proper capture of existing conditions becomes critical. Although several general contractors and subcontractors in the industry claim to have achieved success in using BIM for retrofits, there is limited published research in academic journals which have dealt with the complexity of retrofitting tools in an advanced technology manufacturing facility. Some of the methods that are subjects of research are laser scanning for accurate capture of existing conditions and prefabrication as a means for reducing congestion and improving productivity on-site. However, there is an evident gap in literature documenting case studies quantifying the impact of BIM use at its current maturity levels on *labor productivity (metric)* and in *retrofit projects (context)*. The case study of tool installation at a semiconductor manufacturing facility provides an environment to explore both these phenomena (labor productivity and retrofits).

Method

Research Method

This study utilizes a mixed-methods research methodology involving strategies of an exploratory case study involving interviews (qualitative), and productivity studies through direct field observations (quantitative). A comparative analysis of the findings establishes relationships and helps develop a theory from observations. This paper focusses on the case study only. Yin (1994) describes case study research as an *"empirical inquiry that investigates a contemporary phenomenon within its real life context".* In a case study, the researcher explores in depth a program, an event, an activity, a process; bounded by time and activity, using a variety of data collection procedures over a sustained period of time (Creswell, 2003). The challenge lies in reproducing results as formal theories. Eisenhardt (1989) encourages multiple perspectives from multiple investigators and constant discussions on the validity of the constructs as they are discovered, to reduce researcher bias. Although the primary author conducted this study herself, she deliberated on the findings with a steering committee from the case study facility on a monthly basis and with the dissertation advisor on a bi-weekly basis. The scope of this paper is limited to (1) problem framing (*i.e.* framing the problem in its context), (2) solution incubation (*i.e.* developing the basics of a potential solution design from the analysis) and (3) future research (*i.e.* defining the approach for the refinement of the solution as part of future research) (see Figure 1).

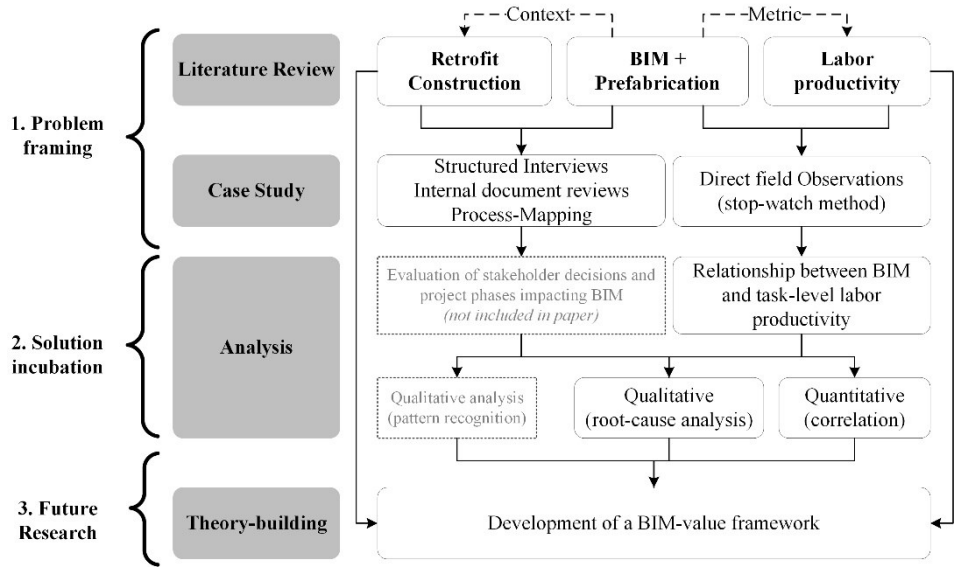

Figure 24: *Research methodology*

Case Study

The case study was conducted at an advanced technology manufacturing facility in the southwestern United States. The manufacturing functions are located in three buildings with a total approximate built-up area of 4 million square feet. The project scope included the installation of approx.790 new tools and approx.300 convert-in-place tools. Tool install includes multi-level complexities of designs, identified as minimum complex, medium complex and super complex. The super complex tools can include up to 1000 small projects (architectural, electrical, mechanical, plumbing and piping) and take up to 7,000 man-hours to install. Each tool occupies anywhere between 50 to 400 square feet of space. The total construction cost was estimated as approx. $400 million (excluding cost of process tools). The manufacturing operations were current during retrofitting. This increased congestion due to workspace constraints, hence higher levels of safety, security and protocols. Thus, off-site prefabrication of certain assemblies such as hangers, electric wire ways, pipe racks and process piping would reduce the impact on site.

All subcontractors (A/E, mechanical, electrical and process-piping trades) were organized through a multiple-prime unit price contract directly with the owner. In a multi-prime model, the owner establishes competitively bid prime contracts with a general contractor and specialty trade contractors on the project. This is a preferred contracting strategy used by an owner when the project is large and highly complex and a single party cannot assume the entire risk of the project (Rojas, 2008). Trade contractors prefabricate high and low purity process pipes, hangers, electrical wire-ways and electrical boxes at off-site fabrication facilities. The facility did not have an existing BIM. Hence, a third-party A/E firm was engaged to develop an updated 3D model for the facility using laser scans and field measurements. The BIM use for the project includes; laser scanning of existing infrastructure, development of a 3D model of the as-built, routing design of electrical, mechanical and piping systems, clash coordination, generation of bill of materials, prefabrication of assemblies and material tracking. While BIM was enabling an overall faster delivery of projects, reducing avoidance costs such as change orders and RFI's, the objective of management in this case, was to optimize the on-site construction labor resource.

Table 2
Identification of interruptions attributed to BIM

Interruptions		Definition	Immediate cause	Effect	Frequency
i1	Inconsistencies in BIM and existing site conditions	Deviation in representation of information in the 3D model versus actual conditions on site	• Inaccurately captured information (technology, learning curve, human error) • Changes after the model is issued (process lag, change management)	Workflow interruption (*e.g.* waiting, discussion, review) for the installer	23%
i2	Rework on prefabricated assembly	Adjustments or modifications on prefabricated component	• Component do not fit as designed • Incorrectly installed	Waste (material, time and money)	23%
i3	Clash on site (after installed per model)	Risk of encountering coordination issues on site after initial coordination in BIM	• Inconsistencies in 3D model	Temporary work stoppage, rework and waste	28%
i4	Waiting on communication	Absence of real-time two-way communication between installer and modeler for BIM related clarifications	• No internet access in the production areas	Time lag between the request and receipt of information	13%
i5	Lack of technology use	Lack of use of technologies such as robotic total stations, RFID, laser scanning and augmented reality with BIM	• Return on investment in technology not proven • BIM capability and maturity of team	NVAT spent on labor-intensive manual work such as measuring, layouts, material tracking, and consulting drawings	8%
i6	Out of sequence work	Out of sequence work not reflected in federated model	• Schedule and BIM are separate entities • Non-collaborative teams	Workflow interruption (*e.g.* waiting, discussion, review) for the installer and waste (material, time)	5%

Case study observations

The research team quantified the labor time utilization through a method of work-study. A 'work-study' method analyzes labor-time utilization at the task-level. The objective is to observe the work-method and work-time in order to determine the amount of time spent by labor on productive versus non-productive work and hence identify site or management constraints that hinder efficiency (Yi & Chan, 2014). Common data-collection techniques used for work-study are video photography, stopwatch timing, and work sampling. Since the facility was operational at the time of retrofits, video photography was not permitted in order to protect the proprietary manufacturing practices. Hence, the research team had to rely on a manual stopwatch method for time measurement.

Work done was classified as Value added time (VAT) and Non-value added time (NVAT). According to Hanna (2010) value-added activities make up only 41% of a construction workday, while the remaining 59% of the time can be attributed to non-value adding activities (ineffective and essential contributory). The non-value added activities were classified as *rework, movement, breaks, consulting drawings, discussion, measurement and waiting*. The data reflected an average 30% VAT on-site, and up to 60% VAT at off-site locations. According to Thomas et al. (1990), the work-study technique relies on collecting large amounts of data to establish average values, however, few attempts determine the causes of variations. Thus, the second set of observations measured the frequency of

interruptions occurring during the on-site installation activity during a workday which contributed to a high NVAT. This study was conducted as 24 - 5 hours/day direct site observations. A positive correlation (coefficient of correlation = 0.67, coefficient of determination = 0.45, $\alpha = 0.05$) was found between the frequency of the perceived workflow interruptions and the NVAT for that day. The interruptions traceable to BIM were further grouped in six major categories; (1) inconsistencies in BIM and existing site conditions, (2) rework on prefabricated assembly, (3) clash on site, (4) waiting on communication, (5) lack of technology use and (6) out of sequence work. Table 2 elaborates on the immediate cause and effect of the six categories.

Analysis

To further investigate the original cause of the BIM interruptions, a root cause analysis of the interruptions was conducted by asking 5-why's. This effort referred a series of interviews with project stakeholders and other internal document reviews. Table 3 identifies the root causes. In addition, it was also analyzed if the root causes could be classified as BIM. For the purpose of this research, the authors identify BIM as a process or an activity (modeling) that encompasses three subject areas:

- *Geometric Information:* Defined as the three-dimensional parametric modeling of geometry representing physical and spatial building components, including factors such as local attributes, spatial attributes and dimensions (G),
- *Descriptive Information:* This includes all functional characteristics and semantic data about the objects, including information such as the type, function, material, cost etc. It constitutes the object, specifications, performance requirements and all the information required to build and maintain the building (I),
- *Workflows:* This aspect refers to the process of planning, implementing and using 3D CAD models with geometric and descriptive information; including, but not limited to acquiring, managing, modifying and updating information (W).

From the case study it is inferred that a retrofit project will have certain inherent complexities including technical, organizational, cultural and functional; creating additional process steps in BIM implementation. It is also found that the existing conditions would in any case pose a challenge for task-level labor productivity. In order to analyze how BIM use (clash detection, prefabrication) affects labor productivity, two types of observations were conducted on site; (1) observation of VAT and NVAT using a stopwatch method and (2) identification of workflow interruptions attributed to BIM. Analysis of data presents the following findings:

- There is a positive correlation between the frequency of workflow interruptions due to an inconsistent use of BIM and non-value added time on site. Hence, it can be concluded that not having the correct data at the work-face can hinder labor productivity and thus reduce the benefits of BIM.
- Only 50% of the work-flow interruptions "perceived" by the field workers as BIM-related can be traced to one of the three aspects of BIM.
- 100% of the BIM-related issues are due to improper BIM workflows and 50% are due to the lack of an accurate and updated model.

The case study shows that when using BIM for retrofits, the lack of accurate and updated 3D models and established BIM workflows, creates interruptions at the labor work-face, hence, reducing productivity. A root-cause analysis of the interruptions attributed to BIM reveals that their causes can be traced back to a combination of factors such as; *BIM implementation (model authoring, quality management, change management, level of development), procurement, contracting, schedule, Information technology (IT) and Project Management*. A deeper analysis shows that the aspect of "BIM workflow", defined as the planning, implementation and use of BIM, is most critical for ensuring an accurate and reliable deliverable at the labor work-face and hence facilitate better labor productivity. It is also found that the geometrical data in BIM is an important aspect of information which should not be ignored, especially in the case of retrofits.

Table 3
Root causes of BIM interruptions

	Interruptions *(from Table 2)*	**Root-cause**	**Classified as BIM?**		
			G*	**I****	**W*****
i1	Inconsistencies in BIM and existing site conditions	1. BIM (model authoring)	✓	✓	✓
		2. Procurement (BIM capability/maturity of contractor)	N/A	N/A	✓
		3. Technology (automation not used)	N/A	N/A	✓
i2	Rework on prefabricated assembly	4. BIM (quality management)	✓	✓	✓
		5. Schedule (change in schedule)	*Not directly related*		
		6. Procurement (capability/maturity of contractor)	*Not directly related*		
i3	Clash on site (after installed per model)	7. BIM (Level of Development/Detail)	✓	✓	✓
		8. BIM implementation (Tolerance management)	✓	✓	✓
		9. Project Management (No supervision)	*Not directly related*		
i4	Waiting on communication	10. Information Communication Technology	*Not directly related*		
i5	Lack of technology use	11. Cost-benefit	*Not directly related*		
		12. Contract (capability/maturity of contractor)	*Not directly related*		
i6	Out of sequence work	13. Schedule (non-conformance to pull-plan)	*Not directly related*		
		14. BIM (change management)	N/A	N/A	✓

** Geometric Information, ** Descriptive Information, *** Workflows* ✓ Yes, classified as BIM

Conclusion

The complexity of the advanced technology manufacturing facility was a major limitation for this study. Frequent changes give the construction trades limited time to react, thus lowering their productivity. The retrofit conditions also affect productivity. The lack of an existing formal method for measuring productivity for the project made it difficult to compare our observations against a baseline. The second limitation is in the research method. Nevertheless, despite the limitations of a case study method, the complexity of the construction environment and the integration of the researcher in the field provides a solid foundation for the framework. As Glaser & Strauss (1967) argue; it is the intimate connection with empirical reality which permits the development of a testable, relevant and valid theory.

The significance of using BIM on a project is that if used correctly from the beginning of the projects lifecycle, offers opportunity for the development of high performing facilities through sustainable building construction processes with fewer resources and lower risk than a traditional process (Eastman et al., 2011). It can be argued that, BIM is a tool when used within the framework of alternative project delivery methods, project management strategies and collaborative work environments, will affect improvements in the construction supply chain. The first objective of this paper was to present a literature review of BIM implementation for retrofit projects. It was found that there is limited published research on BIM use for retrofits, with most publications offering research related to laser scanning for accurate capture of existing conditions, and prefabrication as a means for improving productivity on-site. However, there are limited studies which have qualitatively and quantitatively examined the impact of these interventions on task-level labor productivity. Such analysis is of concern especially to owners.

The second objective was to explore the impact of BIM used in its current maturity level on labor productivity for a retrofit project. The authors conclude that poor labor productivity caused by workflow interruptions (attributed to BIM) find their origins in decisions made by project stakeholders in the initial phases of planning and management of the BIM process. To this effect, as part of future research, a BIM-value framework is proposed which will evaluate the stakeholder expectations from BIM (or BIM-value) driving the decision-making during the planning, implementation and use of BIM and its impact on task-level labor performance. Figure 2 presents the rudiments of a framework which begins to identify the benefits of using BIM categorized by stakeholders of a retrofit project and the corresponding potential impact on labor productivity. The industry in general can benefit by extending the *BIM-value* framework as a risk-analysis tool for measuring the impact of BIM decisions' on the expected labor performance.

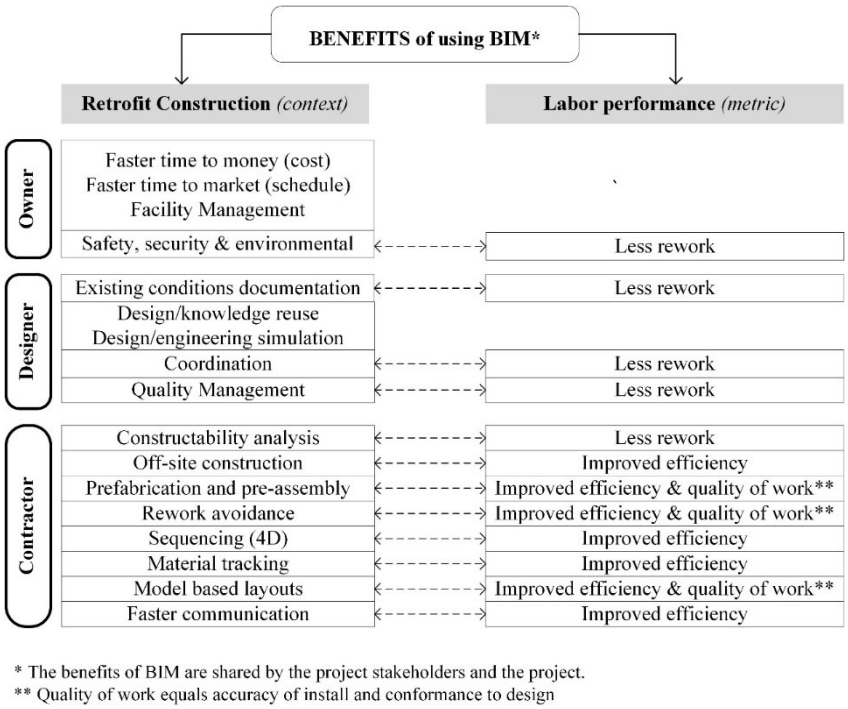

Figure 2: *BIM value framework*

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