How To Measure the Benefits of BIM

A Case Study Approach

by

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ABSTRACT

As a term and method that is rapidly gaining popularity, Building Information Modeling (BIM) is under the scrutiny of many building professionals questioning its potential benefits on their projects. A relevant and accepted calculation methodology and baseline to properly evaluate BIM's benefits have not been established, thus there are mixed perspectives and opinions of the benefits of BIM, creating a general misunderstanding of the expected outcomes. The purpose of this thesis was to develop a more complete methodology to analyze the benefits of BIM, apply recent projects to this methodology to quantify outcomes, resulting in a more a holistic framework of BIM and its impacts on project efficiency. From the literature, a framework calculation model to determine the value of BIM is developed and presented. The developed model is applied via case studies within a large industrial setting where similar projects are evaluated, some implementing BIM and some with traditional non-BIM approaches. Cost or investment metrics were considered along with benefit or return metrics. The return metrics were: requests for information, change orders, and duration improvements. The investment metrics were: design and construction costs. The methodology was tested against three separate cases and results on the returns and investments are presented. The findings indicate that in the tool installation department of semiconductor manufacturing, there is a high potential for BIM benefits to be realized. The evidence also suggests that actual returns and investments will vary with each project.

DEDICATION

To my amazing family and friends and my wonderful mentors, you may not know who you are, but I do. "I've learned that people will forget what you said, people will forget what you did, but people will never forget how you made them feel."
– Maya Angelou

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I would also like to thank those who will remain nameless that were instrumental to my case studies and industry data. I am thankful to those who provided me raw data and assisted in assuring its soundness.

Lastly, I would like to thank those researchers out there that are striving to report project data and create valuable frameworks for BIM. I am grateful for your data and valuable insights into future research.

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INTRODUCTION

Overview

As many have done before, a clear definition of the term Building Information Modeling (BIM) must be established prior to discussions about the benefits of BIM. The sheer quantity of definitions of BIM in circulation in publications hints at the assortment and tendency for misinterpretation by readers. In fact, most publications attempt to define BIM in their own terms and, with over 1,000 publications on this topic, BIM takes on a variety of definitions.

Technology is not new to the building industries; however, the specific software, programs, and applications have evolved over the years, becoming manifested as different systems. Referred to in different publications as BIM, VC 3D CAD, IS, CIC, and IT (Building Information Modeling/Management, Virtual Construction, 3 Dimensional AutoCAD, Information Systems, Computer Information Construction, and Information Technology, respectively), all of these systems help to integrate the many functions of the building industries to create a more interactive information sharing space.

Definitions

According to Jung and Gibson, "CIC (Computer Information Systems) is the integration of corporate strategy, management, computer systems, and IT throughout the project's entire life cycle and across different business functions. Computerized information systems (IS) are widely recognized as an enabler, not only for effective project management, but also for automation of engineering and construction tasks" (1999).

Originally invented to streamline labor-intensive tasks, IS (information systems) have become deeply interrelated with business processes and expanded further to supporting or molding corporate strategy (Jung and Gibson, 1999). The involvement of IS in the higher-level management structure should be measured in order to make sure it is utilized effectively and for the correct purpose(s). Despite the specific naming convention, computer-aided integration in construction has recently manifested itself in the form of BIM applications and is causing much discussion about its costs and benefits.

As noted in their evaluation of the business sense of BIM, Aranda-Mena et al. found that, "For some, BIM is a software application; for others it is a process for designing and documenting building information; for others it is a whole new approach to practice and advancing the profession which requires the implementation of new policies, contracts and relationships amongst project stakeholders" (2008). There are various stakeholders that interact when BIM is utilized, thus their perspectives must be taken into consideration when defining BIM and establishing its benefits. In order to determine if BIM has the potential to provide positive quantifiable project benefits, a common definition of BIM must first be accepted.

Entire journal articles have been dedicated to surveying building professionals, from contractors to architects and engineers, for their perceptions of BIM and their definitions (McGraw Hill, 2009; Zuppa, 2009; Becerik-Gerber and

Rice, 2010; FMI and CMAA, 2007), focusing on their differences rather than similarities. The McGraw Hill "The Business Value of BIM" Report, a commonly referenced document by contractors, defines BIM as, "The process of creating and using digital models for design, construction and/or operations of projects" (2009). In "The Business Value of BIM" Report, the contractor's perspective is the dominant reference for BIM, putting BIM in terms of its technical aspects as a model or documentation tool (2009). Another definition of BIM as, "an intelligent 3D virtual building model that can be constructed digitally by containing all aspects of building information – into an intelligent format that can be used to develop optimized building solutions with reduced risk and increase value before committing to a design proposal," focuses on the design perspective (Woo et al., 2010). Zuppa, et al. found that, "BIM was most frequently perceived of as a tool for visualizing and coordinating AEC work and avoiding errors and omissions" (2009). The literature fails to define BIM more in terms of the owner, another important stakeholder. There is no agreement on the definition of BIM nor a consensus of the outcomes multiple stakeholders (contractors, architects, engineers, and owners) will receive from its utilization on a construction project.

For the purposes of this paper, the definition credited to the National BIM Standard (NBIMS) is used as, "A Building Information Model (BIM) is a digital representation of physical and functional characteristics of a facility. As such it serves as a shared knowledge resource for information about a facility forming a reliable basis for decisions during its life-cycle from inception onward. The BIM is a shared digital representation founded on open standards for interoperability" (2006). This definition focuses solely on BIM containing adequate life-cycle building information and does not refer only to one group of stakeholders, thus it is used as the underlying definition and purpose of BIM for this paper. Furthermore, the mention of "3D" is used interchangeably with "BIM" unless otherwise noted, and "2D" is used to denote non-BIM or standard construction procedures that do not utilize BIM or 3D as a tool.

The frequency and variety of the definitions of BIM illustrate the confusion in defining and quantifying BIM and putting it in terms of potential benefits. This deficiency not only prohibits the collaborate process between stakeholders, but it also makes the measurement of BIM's effectiveness too general and qualitative. For example, architects are more likely to see the benefits of BIM as enhancing coordination, productivity, and business operations; whereas contractors see improvements in scheduling, estimating, and drawing processing (Zuppa, 2009). Furthermore, as the perceived benefits differ across stakeholders, comparisons of benefits across projects becomes exponentially difficult to obtain and non-uniform. Despite the industry-perceived potential for BIM, most construction organizations do not utilize a formal methodology to evaluate its benefits (Becerik-Gerber and Rice, 2010). There is a need for a relevant methodology to evaluate the expected benefits of BIM on any type of project, from a business perspective, in conjunction with a valid baseline.

Problem Statement

The utilization of BIM has not been empirically and clearly established to be beneficial to the overall outcome of a construction project. Owners are faced with the dilemma of making a decision of whether or not to utilize BIM based on speculated benefits. The largest barriers to BIM implementation and acceptance across the building industries are recognition and enforcement by owners and a balanced framework for implementation that considers both monetary and managerial outcomes (Succar, 2010). In fact, the latter is a prerequisite for the former, as owners are looking to adopt BIM as a tool once it has been proven effective.

Some of the challenges with establishing BIM's effectiveness are the varying nature of partial frameworks and case studies presented by the literature regarding BIM. The literature presents results that are qualitative and not easily compared. Many frameworks focus on the general implementation, rather than an analysis of the choice to implement (Jung and Joo, 2011 and Taylor, 2007). Furthermore, the proof in existence does not appeal to an executive or someone at the business level that is prepared to make a decision such as whether or not to employ BIM as a tool. At the executive level, a proper "BIM business case" would need to be established that contains some of the vocabulary and relevance to upper level management in the particular company, as well as a plan or framework for implementation.

Objective

The objective of this thesis is to empirically measure BIM data from 2D and 3D projects to determine if the utilization of BIM can be beneficial in construction projects. Furthermore, it is the goal of this thesis to provide case studies of BIM benefits via an examination of 2D versus 3D projects at a particular organization.

As highlighted by Succar, it is as equally important to establish metrics and benchmarks to assess overall performance and benefits derived from BIM as it is that those metrics are to be consistently accurate and adaptable to different industry sectors and organizational sizes (2010).

Research Methodology Summary

Prior research methodologies found in the review of past literature were: case studies, surveys, interviews, and individual analyses and theories. According to Bakis et al., a case study is the most appropriate investigation method for the business benefits of new information technologies, when compared to the formal experiment and the survey (2006). Case studies present the information in the context of a particular project, inclusive of the project's characteristics and give actual project data. Experimentation and surveys are ineffectual because the impact of a new system has variables and factors that cannot be extracted out of the original context. Furthermore, the business benefits of a new system are commonly a victim of subjectivity, perception, and general estimation via surveys and interviews (Bakis et al., 2006). Another commonly used method is for an individual to assign a weight to each of the potential benefits of the system, especially those that are intangible, to determine its importance. Then a rating of impact could be assigned based on the magnitude of the impact the benefit could have on a particular business process. Once again, these are subjective determinations (Bakis et al., 2006). The subjectivity of methods to assign value to BIM, from interviews to surveys, makes quantification and comparisons of benefits across projects ineffectual. Furthermore, a "benefit" and measure of "success" can also have different meanings depending on the individual. This thesis sought to present data in the least-subjective and most quantifiable context. The research for this thesis involved two parts:

- Part 1: An analysis of the literature regarding BIM and its potential benefits
- Part 2: Case studies of a particular organization's 2D versus 3D projects and resultant benefits analysis

Research Scope

The scope of this thesis is to provide a business case for BIM utilization for project stakeholders faced with the decision of whether to employ BIM in their construction projects, most commonly referred to as "owners." As evidenced by the literature, the owners' perspective is rarely conveyed in estimation of BIM's benefits, thus this thesis focuses on that perspective.

This thesis has limitations due to the nature of the project data available with regards to BIM. The first limitation is on the metrics as quantifying cost and benefits of "IT investments" will produce results that are immeasurable, such as: efficiency, effectiveness, and performance (Andresen, 2000). The second limitation is on the variety of methods in which historical project measurements could have been recorded. This is a challenge that can be mitigated via project review meetings, where stakeholders are present to review the data. Lastly, the chosen method (i.e. case studies, surveys, experiment, etc.) will have limitations and associated challenges. These are discussed in Sections 2.2, 7.1, and 7.2.

Summary of Thesis

This thesis documents and seeks to measure the benefits resulting from the utilization of BIM in construction projects. The following is a summary of the thesis.

- Chapter 2 presents a review of the literature regarding BIM and potential benefits, with an analysis of the data presented from the top four sources.
- Chapter 3 describes the research methodology including discussions on the challenges, general methods, measurement strategy, and scope of this thesis.
- Chapter 4 demonstrates the data collection conducted and metrics established for the measurement of the benefits of BIM utilized in the subsequent Cases as described.
- Chapter 5 provides more detail on the data analysis methods employed.
- Chapter 6 presents the results of the said Cases, and quantifies the benefits of BIM according to the metrics set forth in Chapter 4.
- Chapter 7 initiates discussion of the results presented.

- Chapter 8 delves into organizational, intangible precedents and outcomes, specifically: executive, communication, risk management, and change management.
- Chapter 9 concludes with final thoughts on the case studies as well as identifies future implications and research concerning BIM and benefits analysis.

Chapter 2

LITERATURE REVIEW

Introduction

A review of the literature was performed to analyze the current information available with regards to benefits derived from BIM utilization, with the goals of: 1) determining the proper metrics for measurement of BIM benefits; 2) seeking the results or data of those metrics from a variety of projects; 3) assisting in the further development and insight into an applicable benefits framework model to be applied to the case studies in this thesis as well as to future projects.

After analyzing over 600 sources of information including: journal articles, conference proceedings, published case studies, press releases, professional presentations, and online articles, there remained twenty-one sources that had some information regarding the benefits gained from BIM utilization, but in general terms. These twenty-one sources were publicized and/or published within the past ten years, thus representing recent data with respect to BIM. The twenty-one sources obtained were organized according to a system that assigned a "classification" of data presented. For comparisons of the twenty-one sources, please see Tables A1-A4 in Appendix A – Literature Review.

Classifications

The first classification of the literature was "case study and quantifiable findings," this represented studies that contained quantified measurements of the benefits of BIM presented from a case study. The second classification was "case study," in which a BIM project was analyzed, but no numerical benefits or measurements were presented. The third classification was "case study and model or process," this type presented a case study and a model about how the benefits of BIM were obtained excluding any quantifiable savings as a result of BIM utilization. The fourth classification was "model or process," in which a framework or suggested evaluation process was put forth, and, was either (1) not used on a BIM project or (2) if claimed to be utilized on a project, no quantifiable results were presented. The fifth classification, "survey," contained independent surveys that were carried out, asking various questions of different individuals, soliciting their opinions or perceptions of the concepts and benefits obtained from BIM utilization. The sixth classification, "survey and case studies," contained a survey from a specific project and, in some cases, interviews of team members of a project in which BIM was utilized. The seventh and final classification, "theory and general assumptions," contained publications that presented a framework or suggested benefits ungrounded in actual BIM project data. No one source had a framework model, applied it to a project to be made into a case study, and presented quantifiable case study data.

As stated previously, each type of data classification (case study, experiment, survey, and interview) has various constraints and barriers to establishing a universal benefits analysis of BIM (Bakis et al., 2006). See Appendix A for summary tables of the literature review that presents general findings, sources, and issues related to utilizing the data for comparisons on other BIM projects. Overall, there were the most classifications of: "01" case studies and quantifiable findings; and “07” theories and general assumptions. The highest frequency of source type was “01” journal article.

Main Sources

From these twenty-one sources, there remained four sources with some quantifiable results based on case study data. These four sources were carefully examined to extrapolate any usable data. Below, a summary is provided for these sources and the data they presented.

Source #1

In Garrett and Garside’s case study, a new semiconductor fab is constructed, termed as “basebuild,” and 3D modeling was utilized six months after design commenced (2003). Garret and Garside found that this pilot program represented slightly less than 1 percent of the total project cost, with conversion of the 2D model accounting for approximately 75 percent of the total pilot cost, and the model saved more than the cost of implementation. The analyses classified savings as: identified physical conflicts (clash reports) saved $0.75M; schedule conflicts (scheduling interface) saved $1.2M; and data conflicts (attribute management) saved $0.5M (2003). Furthermore, Garrett and Garside estimate that in the future, BIM could have the outcomes of, “Overall reduction in design time would be on the order of 20 percent to 50 percent, possibly greater.” In their article, they state that construction management and finance management teams were able to jointly define a method of measuring the relative value of savings and avoidances, a third party Quantity Surveyor was hired to assign values to other savings and avoidances, and subcontracts were developed with highly detailed scope (Garret and Garside, 2003). The calculation methodology of project returns and investments for BIM is unclear in this source.

Source #2

J.C. Cannistrato, a Plumbing, HVAC, and Fire Contractor in the Massachusetts area, utilized data from 408 projects over 6 years totaling $558,858,574 to quantify how much BIM saved them (2009). In their company press release, they reportedly found that change orders for "2D" projects represented 18.42 percent of base contract, change orders for "3D" projects represented 11.17 percent of base contract, and change orders for "Collaborative BIM" projects represented 2.68 percent of base contract (Cannistrato, 2009). These results are taken from the Mechanical Contractors' perspective and are limited in their application to other case studies. Additionally, the results are published in a general company press release and are not subject to peer review.

Source #3

Khanzode et al. presented a case study of fast track project for a new $96.6M Medical Office Building (MOB) facility and parking garage (2008). In their analysis of BIM on this project, Khanzode et al. reported, "MEP systems include labor savings ranging from 20 to 30 percent for all the MEP subcontractors, 100 percent pre-fabrication for the plumbing contractor, only one recorded injury throughout the installation of MEP systems over a 250,000 square foot project area, less than 0.2 percent rework for the whole project for the mechanical subcontractor, zero conflicts in the field installation of the systems and only a handful of requests for information for the coordination of the MEP systems between contractors and the designers, 6 months' savings on the schedule, and about $9M savings in cost for the overall project" (2008). Furthermore, via project team member interviews and stated opinions, they found zero change orders related to field conflicts on this project (compared with an estimated 1-2 percent of the cost of MEP systems) and 2 RFIs relating to field conflict and construction related issues. According to Khanzode et al., "the project team compared this fast track project delivery to a traditional Design-Bid-Build project delivery to compare how much savings accrued due to the use of VDC tools and a fast track project approach that hedged the effects of inflation. This study indicates a savings of $9M and 6 months to the owner due to the use of the BIM / VDC tools and a collaborative project delivery approach (based on escalation of: 2004 = 3.4 percent, 2005 = 10.5 percent, 2006 = 7.5 percent)" (2008). Some distinct variables include: the costs and savings are only related to MEP systems and those contractors' opinions, the designer did not participate, no formulas are presented, and estimates of costs and benefits are based on opinions of project team members.

Source #4

Kuprenas and Mock utilized a BIM case study of Central Los Angeles Area New Learning Center #1 (2009). In this 685,000SF facility with an elementary school and middle school, the "Intra-trade BIM model benefits and cost savings realized were: (coordination-inserts) reduced rework - $50,000 and shortened construction durations - $10,000; and (visualization - underground electrical) sequencing - $250,000; (sequencing-MEP and FP systems) preassembly - $25,000, bundling - $10,000, and shop fabrication - $25,000" (2009). Furthermore, the "Inter-trade BIM model benefits and cost savings realized were: (coordination) conflict checking (between trades) - $4,000,000 and (visualization-underground electrical) bulletins - $250,000" (2009). These results are taken from the contractors' perspective, not founded in background calculations or methodology, and are limited in their application to other case studies.

Summary

From these four sources, no data existed on the methodology with which to calculate returns on other projects and how to form a valid comparison of 2D vs. 3D methods to extract benefits. Additionally, from the four sources, only one remained that was specifically applicable to the background metrics set forth by this paper. Upon further analysis of the most applicable journal article, Source #1, it was discovered through communications that the past project team members disagreed with the findings presented. Source #2, while it provided some quantifiable findings, was taken from a company newsletter, thus the source credibility can be in question. In Source #3, the data was based on a narrow scope and a smaller project, making it difficult to generalize the findings. Source #4 was limited to the contractors' perspective and was from a specialized project. Furthermore, all sources' case studies suggested different measurements, focused on new construction, and had varying definitions of BIM.

The results of the literature review performed here are in agreement with other literature reviews carried out on the topic of BIM and BIM's expected outcomes, asserting that both case studies and academic research fail to analyze and quantify universal benefits and costs of BIM on a project (Becerik-Gerber and Rice, 2010; Succar, 2009). Unfortunately, in FMI and CMAA's eighth annual survey of owners they found that, "Nearly 25 percent of survey respondents do not know how much information technology (IT) – related spending takes place on individual projects to support achieving project objectives" (2007). Thus, the current methods for the evaluation of BIM and information systems' related benefits are not sufficient as they do not promote a dominant framework methodology and visibility to comparable data on other projects. Participants in FMI and CMAA's survey of owners agree that there has to be a strong business case focused on ROI and value added, for all parties involved, to commit to BIM use (2007). The need for a proper business case, consisting of a framework methodology and baseline, to evaluate the benefits of BIM has gone unmet.

The outcome of the literature review proved that there is neither a consistent approach within individual organizations nor a consistent approach across organizations to evaluate BIM or similar information systems' benefits (Andresen et al., 2000; Succar, 2009). Furthermore, current frameworks are ineffective as they show a fragmentation in the very core of BIM's goals, such as, "Scheduling, estimating, and design are the most demanding areas where the discrepancy between the practitioners' needs versus actual exploitation was found to be significant" (Jung and Joo, 2011). When the system is not meeting the very intent, such as project efficiency, it becomes clear that the initial process and framework were not clearly defined. In order for a framework to be effective, the strategies for implementation via the framework should be examined and evaluated (Jung and Joo, 2011). The system cannot stand on its own; it needs consistent measurement and evaluation.

The dilemma faced by owners regarding BIM utilization is due to a lack of dominant and transparent performance information that establishes BIM as being beneficial in construction projects. Information Management Theory (IMT), as established by Dr. Dean Kashiwagi, holds that, when the key information is available, no decision is required (2011). However, when choosing whether or not to employ BIM on a particular project, owners do not have information to substantiate their decision in a transparent fashion. That is, the literature has illustrated that projects have determined potential benefits of BIM, but few quantifiable measurements and sparse framework methodologies for benefits calculation are present. Therefore, no conclusive information can be stated and owners are left to make a decision without a business case.

With BIM being promoted as a coordination tool and a way to align resources, it is quite contradictory that the resources BIM is alleged to conserve are not measured themselves. As such, IMT theory would predict that a convoluted perspective of BIM will result in a further complex implementation of BIM, should an owner decide to implement without a business case. The lack of measurements prior, during, and after BIM utilization in a company on a particular project hint at the lack of a framework to alleviate this void for owners.

Determining Proper Metrics

The determination of what to measure and who to measure in construction projects are challenges in quantifying changes and benefits. The terms "Key Performance Indicator" (KPI) and "productivity" are common terms, but authors identify them as lacking consistency. Models such as: lost productivity method, measured mile analysis, baseline productivity analysis, system dynamic modeling, earned value analysis, sampling methods, and comparison methods are commonly referred to (Ibbs et al., 2007), but inconsistently used across case studies. More commonly, construction projects are measured via KPIs. However, KPIs are often not uniform across projects and result in confusion regarding: what should be measured, how it should be measured, what are the sources of change, and how to evaluate project success or failure. Furthermore, with these suggested models and KPIs, few studies utilize internal and external project data with measurable results to validate them. Productivity is a popular measure (Ibbs et al., 2007; McEniry, 2007; Thomas and Napolitan, 1995), but is based on a subjective, observable quantity.

According to Cox et al., KPIs are compilations of data measures used to assess the performance of a construction operation or a particular task (2003). Generally, these measures have comparisons of estimated or planned and actual or completed quantities. Furthermore, the measures are often of both the intangible and tangible types. These generalizations make comparisons of KPIs quite challenging across projects and organizations. Cox et al. identifies that current models fail to recognize which indicators will accurately portray the changes in performance (2003). This thesis holds that the quality, rather than the quantity, of measurements should be upheld. There is a void regarding the measurement of project changes and outcomes with respect to BIM utilization.

The KPI suggested by the majority of the literature are not incorrect, rather, they are not precise enough and result in an overload of subjective measurements. Examples of qualitative KPI suggested by the literature are: safety, turnover, absenteeism, and motivation (Bassioni et al., 2004; Cox et al., 2003; Ibbs et al., 2007). In contrast, examples of quantitative KPI suggested by the literature are: units/man-hours, dollars/unit, cost, on-time completion, resource management, quality control, percentage complete, earned man-hours, lost time accounting, and punch list (Bassioni et al., 2004; Cox et al., 2003; Ibbs et al., 2007). A survey and analysis revealed top rated KPIs in order of: on-time completion, no preference, units/MH, safety, and quality control/rework (Cox et al., 2003). A common and concise list of KPI would be beneficial for proper project comparisons of change.

Two common references for quantification of KPIs and comparisons are industry studies or databases and construction productivity claims made in court; however, both have limitations of application. Industry studies and databases can be misleading, as Thomas found a range of error in predicting the inefficiency for a single project to be 10-40% differential (Thomas, 2010). Loss claims can become a comparison and source of data for other projects, as contractors file and attempt to quantify cumulative impact of multiple change orders and productivity (Jones, 2001; Gulezian and Samelian, 2003). However, there are challenges in utilizing these measurements due to their litigious nature and highly project-specific variables. Furthermore, once KPI are established, a range or level of success and failure must be established.

Zuppa et al. assert that, "The main success measures of construction projects are cost, schedule, quality, productivity, and safety" (2009). Others see quality control, on-time completion, cost, safety, dollars/unit performed, and units per man hour (Suermann and Issa, 2008). Aranda-Mena et al. see similar technical, operational, and business benefits (2008). Furthermore, surveys such as the McGraw Hill "The Business Value of BIM" Report, survey individuals' perceptions of value of BIM based on a predetermined list of success criteria such as cost, schedule, scope, changes, etc. (2009). The term KPI is commonly utilized; however, these metrics and their calculation methodology vary across projects and individuals as seen in the literature review. The varying definitions of success and value complicate the evaluation of BIM's benefits. Sebastian highlights the importance of defining KPIs in terms of quantifiable added values to build the business case for BIM (2010).

To this end, a key list was compiled of the top mentioned benefits of BIM based on the literature review. From those, units were derived and a master list was developed. The most quantifiable benefits were: schedule, change orders, and RFIs. Please see the Appendix, Table A5 – Literature Review – Top Mentioned Benefits from the Literature Review for complete information.

Chapter 3

RESEARCH METHODOLOGY

Overview

After a thorough review of the literature, it became evident that a value-based methodology and framework for the presentation of the benefits obtained from BIM utilization was necessary. In the development of this thesis, it became necessary to develop a framework methodology to quantify the benefits of employing BIM by:

- Establishing metrics or KPI to collect to quantify the costs and benefits of BIM
- Testing the metrics against case studies, specifically projects that are in 2D versus 3D in the same organization in order to minimize variables
- Evaluating the resultant information from the case studies to quantify benefits and costs associated with BIM utilization
- Providing conclusions from the data
- Validating the resultant framework model established to evaluate the net benefit or lack thereof from BIM

Both the framework and the case study data could provide industry information on the benefits from the utilization of BIM and promote like comparisons of benefits measured on other related BIM projects to build the business case for BIM utilization. Existing publications and case studies are inadequate for a large amount of owners to justify BIM utilization, thus until there is an agreement on the benefits and costs, adoption of BIM will be a great challenge to many organizations (Aranda-Mena et al., 2008; FMI and CMAA, 2007).

Challenges

FMI Management Consulting and the Construction Management Association of America's (CMAA) eighth annual survey of owners (2007) ranked "BIM hurdles," with "Unclear business value and ROI" coming in at seventh place out of eleven owner-identified barriers to BIM adoption. The "business value" of any computer aided collaboration or information systems comprises both monetary and intangible outcomes. The difficulties with the evaluation of the business benefits of information systems can be best categorized into six areas: (1) some of the business benefits may be intangible; (2) organizational changes may occur as a result of the introduction of a new system; (3) business benefits are evolutionary over the life-cycle of the system; (4) diverse stakeholders involved will subjectively evaluate the system and may have conflicting opinions; (5) users may feel intimidation or fear of the new system and how it will affect their jobs negatively; and (6) practical difficulties such as improper utilization, interconnected systems, and inability to divide related systems and benefits (Bakis et al., 2006). In the construction industry, some examples of quasi-tangible benefits are: productivity, information availability, and enhanced decision making; with intangible benefits being: better risk management, competitive advantage, and gained market access (Becerik, 2006). Intangible considerations are challenging to quantify in monetary terms and are outside the scope of this paper, as their analyses are prone to subjectivity and estimation. Some intangible benefits are listed in Appendix A. Additionally, the extraction of these benefits from the business objectives and processes the system aims to support cannot be expressed independently, or in a universal manner (Andresen et al., 2000; Bakis et al., 2006). The lack of a formal methodology or process for establishing a business case for BIM encourages speculation and improper estimation of its benefits. Methods have been proposed of how to evaluate the benefits of information systems in general, but they are reactive and prescriptive in nature, relying on individuals' perceptions of value.

Measurement Strategies for this Research

The framework methodology is in line with the problem statement of this thesis, to fill the void of a balanced framework for BIM implementation that considers both monetary and managerial outcomes. The general IT measurement process proposed by Andresen and Baldwin was also taken as inspiration in this thesis. Please see Figure 1. Process of Measuring IT Benefits below. For this thesis; however, a value-based framework is proposed in which monetary and managerial outcomes are analyzed. Monetary outcomes will be established via the metrics set forth in chapter 4 and managerial outcomes will be evaluated and discussed in section 6.4 and chapter 8.

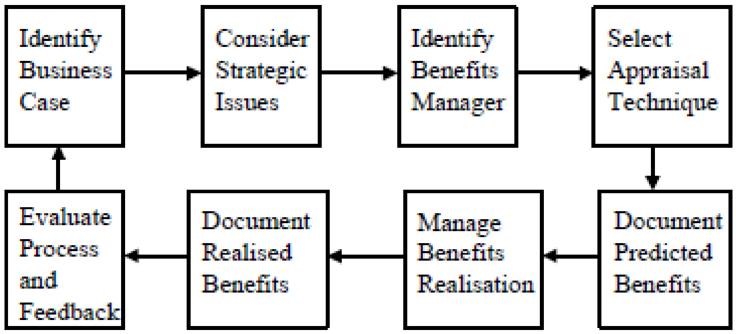

Figure 1. Process of Measuring IT Benefits (Andresen and Baldwin, 2000)

In the literature review, general models were taken for inspiration to form the more qualitative portions of the framework with respect to the managerial outcomes of BIM. Specifically, organizational factors needed to be taken under consideration and BIM's resultant impact analyzed. A complete "business case" would appropriately take into consideration executive, communications, risk management/strategic planning, and change management factors. Bakis et al. correctly formed this link in their *Evaluating the business benefits of information systems* (2006). Please see Figure 2 – Linking the Business Case of an Information System below for more detail.

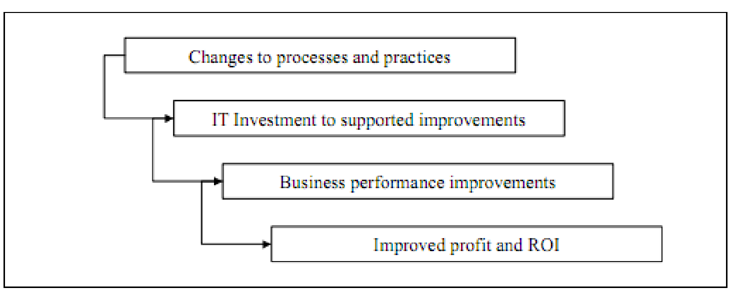

Figure 2. Business Case of an Information System (Bakis et al., 2006)

For the monetary side of the framework, both current and historical project data was utilized for the Non-BIM and BIM data sets. Data was analyzed and percentages computed by comparing 2D to 3D projects, with a differential computed. To properly quantify and represent these returns and investments, metrics were developed to share this information without compromising confidentiality. In accordance with the objective of this paper, the metrics were also devised to create a calculable comparison to other projects by establishing the percentage comparison of Non-BIM data to BIM data.

From this managerial and monetary analysis, a mapping of the business case for this thesis was developed. The business case for BIM takes into account key tangible and intangible outcomes. Please see Figure 3 - Business Case for this Thesis below for a map of the process.

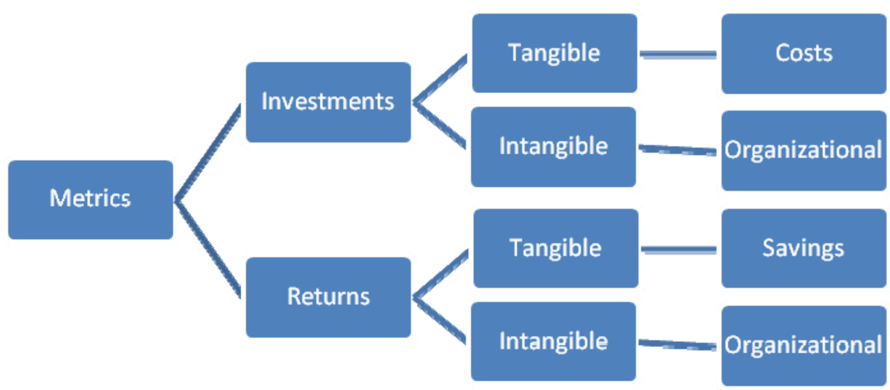

Figure 3. Business Case for this Thesis

Based on the findings of the literature review and the preceding analysis, the monetary and quantifiable outcomes of BIM need to more clearly established.

This was carried out in this thesis via establishing quantifiable metrics and applying them to case studies. Please see Figure 4 – Framework Development for this Thesis below. The basic methodology for the computation of the returns and investments of BIM in this paper consisted of:

- Gathering background information on the case studies
- Collecting historical Non-BIM data for the case studies
- Capturing and reviewing recent BIM data for the case studies
- Determining the metrics to utilize
- Reviewing the metrics with the project team members
- Analyzing the data in accordance with the chosen metrics
- Drawing conclusions from the data
- Reviewing findings with the project teams and various stakeholders

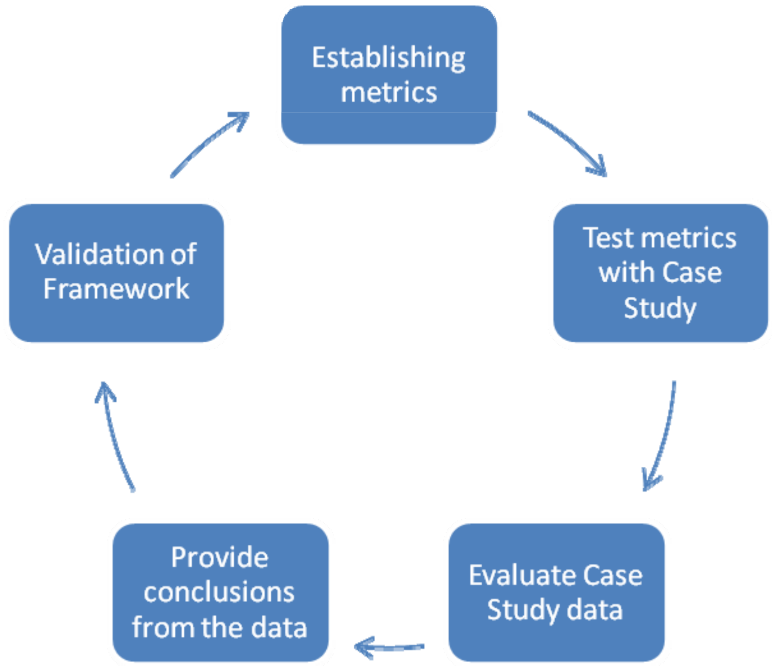

Figure 4. Framework Development for this Thesis

Scope of this Thesis

Based on the literature review, the data that attempts to quantify BIM's benefits is highly contextual, most prevalent for new construction, and from the contractors' perspective, making other facilities, such as existing manufacturing buildings, difficult to analyze and compare. In alignment with the objective of this paper, projects with a high potential for receiving the benefits of BIM must be carried out as case studies to test the soundness of the proposed methodology. The construction of semiconductor manufacturing facilities is very expensive and complex, with costs around roughly $1 billion in the 300mm fab environment (Chasey and Merchant, 2000). Additionally, costs see an exponential increase with every new process. The processes keep evolving on a regular basis with

Moore's Law, originally stated in 1965, testifying that every 18 to 24 months the capabilities of integrated circuits double and the price of such chips is cut in half (Intel 2008).

This rise in costs has made any strategy for cost reduction quite attractive and worthy of a pilot or test. Nevertheless, as Gil et al. assert, "Four main factors contribute to the challenges in managing fab projects: complex designs, speed, reducing costs, and frequent but hard to anticipate changes" (2005). Indeed, the semiconductor manufacturing environment presents many unique challenges and opportunities for BIM to reduce costs. Few BIM enthusiasts have tried to implement BIM-related processes in a semiconductor environment, notably Garrett and Garside, touting such benefits as, "not only showing the factory and how it will look, but also providing detailed cost estimates based on the material data extracted from the Multi-Dimensional CAD design including labor rates, bills of materials and construction and install/qual schedules" (2003). While these benefits seem to be an expected outcome of BIM in most construction environments, in the semiconductor manufacturing areas, these benefits and others have yet to be stated as metrics and a baseline established.

As a building sector with high potential for benefits derived from BIM, a leading semiconductor manufacturer, Company 1, was utilized for case studies to best test the methodology of BIM benefits evaluation. Company 1 was seeking to improve efficiencies and become leaner through the utilization of BIM in its design, construction, operations, and updating of facilities. Company 1 completed a series of pilot projects in its efforts at deploying the 3D modeling phase of BIM for design and construction in its tool installation process. A series of pilots were carried out in Company 1's fabrication facilities (fabs) which are defined as high-tech facilities that contain the manufacturing tools required for the production of semiconductors (Gil et al., 2005). For Company 1, tool installation consists of construction of equipment inside the existing fab manufacturing space, with mechanical, electrical, plumbing, and some structural activities taking place. Due to Company 1's employment of BIM in only the 3D modeling stage at the time these case studies were performed, to simplify terms, "2D" and "3D" will be the terms used to represent "Non-BIM" and "BIM."

The BIM business process for Company 1 was to develop the 3D design and construction models in parallel with the 2D models, acting as a supplement rather than a replacement. The 3D models were utilized in the tool installation department in three specific functional areas, which are areas of a fab that carry out a specific process on the silicon wafers, such as lithography (Gil et al., 2005). These three functional areas were selected for various reasons and represent the most complex tool installations. Gil et al., note that certain design characteristics make a particular functional area more stringent, thus they are indicative of the most "difficult" case (2005). The case studies at Company 1 provided this thesis with an opportunity to properly examine the benefits of BIM utilization garnered by a large owner, under multiple projects.

Chapter 4

DATA COLLECTION

Overview

Company 1 decided to first employ the 3D process in 2001 and utilized it on subsequent projects. Therefore, there is an array of data, both current and historical, with regards to the case study data set forth in this thesis. Additionally, the objective of this thesis requires that both 2D and 3D project metrics are compared in order to build the benefits business case regarding BIM utilization. Each project comparison carried out at Company 1 is assigned as a "case." There are three BIM case studies at Company 1:

- Case 1 – returns
- Case 2 – investments
- Case 3 – returns and investments of a particular functional area

Description of Case Studies

Each case study was carried out with the intent to present a valid comparison of 2D versus 3D project metrics. It is essential that the cases are described and background information relating to the data presented. As previously described, the cases at Company 1endowned this thesis with an opportunity to appropriately examine the benefits of BIM utilization as seen by a large owner, under multiple projects.

Case 1 is based on two 2D historical projects and two 3D pilot projects in similar functional areas. This Case was carried out at no additional costs to the owner and was not a competitively bided scope of work, thus could not be used to accurately portray 3D investments.

Case 2 is based on a current project that is utilizing both 2D and 3D in the same three functional areas. This Case provides a baseline for the 3D design and construction investments portion.

Case 3 is a study on one particular functional area, based on two historical 2D projects, two historical 3D projects, and the current 2D and 3D project. The data were compared as total 2D vs. total 3D metrics for the specific case's functional areas.

Metrics

A proper benefits analysis, in line with the objective of this thesis measures not only returns, but also calculates the investments required for BIM. As discussed in the review of the literature, a matrix of the potential benefits derived from BIM was composed. From this matrix, it was determined that the most quantifiable returns were: schedule, change orders, and RFIs. Investment metrics were: project cost and pilot cost. Please see the Appendix, Table A5 – Literature Review – Top Mentioned Benefits from the Literature Review for complete information. The return metrics are in accordance with the objective of this paper to create a quantification of BIM benefits. These were quantified from a comparison of 2D projects to 3D projects. Values were reported with respect to 2D projects, 3D projects, and percent change or differential in units of: quantity per assembly, cost of change per cost of total project, and actual versus standard duration in order to promote a valid comparison with other projects in the future that will utilize this framework. Percentage values are given in lieu of dollar values comply with agreements on confidentiality. Please see Table 1 – Return Metrics below.

Table 1

Return Metrics

Criteria	Calculation	Unit
RFIs	Quantity of RFIs / assembly or tool quantity	#
Change Orders	Cost of change / total cost of project	%
Schedule	Actual duration / standard duration	%

The costs for the 3D design investment category are best separated out into two distinct sub-categories: A&E costs and 3D background model creator costs. The A&E costs were based on the costs incurred as a result of the 3D design of the three specific functional areas. They were a summation of the items: design, assembly non-variable costs, and an allowance for the 3D design. The 3D background model creator costs were a summation of the items: laser scanning, background model creation, 3D block creation, an allowance, hardware/server for storage, collaboration software, surveying, and training. The 3D background model creation was carried out for the entire factory and not solely the functional areas that would be receiving 3D design. Thus, the 3D background model creator costs are higher as they are applicable to all functional areas, not just those three receiving 3D design. 3D modeling is an additional step for Company 1's designers and is thus a cost. However, in some cases this background model may already be created and just need updating or it could be further extended and used on future projects, thus representing a future savings.

The investment metrics were carefully devised in accordance with the objective of this paper to create a universal comparison. The metric “A&E costs as a percentage of total awarded A&E scope” represents how much of the A&E costs are due to the costs incurred as a result of completing both 2D and 3D design packages. The metric “3D background model creator costs” represents how much of the total factory design costs are represented by the 3D tools. The metric “contractor costs” represents the cost if these areas were in 2D versus cost if these areas were in 3D, and reveals that contractors would provide savings if these areas were in 3D. The metric “overall savings with 3D scope awarded” represents the addition of the costs of design and savings of construction in these areas utilizing 3D.

Table 2

Investment Metrics

Metric	Calculation	Unit
Design Cost		
A&E Costs	3D cost of A&E services/ cost of total design 2D and 3D scope awarded	$ / $ = %
3D Background Model Creator Costs	3D cost of 3D Background Model Creation / cost of total design 2D and 3D scope awarded	$ / $ = %
Construction Cost		
Contractor Costs	3D Contractor Costs / cost of total construction 2D and 3D scope awarded	$ / $ = %
Design + Construction Costs		
Overall Savings with 3D in Design and Construction	3D Design Cost + 3D Construction Cost / cost of total construction 2D and 3D scope awarded + cost of total design 2D and 3D scope awarded	$ / $ = %

Characteristics

The data from the Cases was collected utilizing Company 1's database of project information as well as via numerous project meetings with stakeholders. Data could only be reported in formats agreeable to Company 1, as the organization was generous enough to allow access and comparisons of their data.

The data was originally recorded during the construction of the project Cases. Access to Company 1's databases of information as well as project stakeholders (especially Project Managers) was critical to the proper collection of all, representative data. All data was first collected in U.S. dollar (USD) values and quantities. All calculations were carried out in USD, validated in USD, and percentages were derived. Due to the confidentiality requests of Company 1 and assertions to maintain a competitive advantage, dollar values could not be reported in this thesis. Instead, Company 1 allowed the reporting of ratios or comparisons of costs to derive percentage values.

Chapter 5

DATA ANALYSIS

Overview

The case study data was collected via metrics that Company 1 had already recorded or was in the process of capturing on each project. The involvement of key stakeholders, such as Project Managers, was paramount to ensuring data was accurately captured. Change order data was recorded as work orders were received and final reconciliations were performed by the project finance group. RFI data originated from an owner-driven system for the tracking and classification of these requests. Schedule information was obtained via a scheduling software and owner Project Managers reconciliations.

Validation

Reliability of the data was ensured and validated by project team members from the construction and finance departments, as well as various stakeholders throughout the case studies via monthly update meetings. At these meetings stakeholders would be present and demonstrate their concerns, if any, with the data and the steps to take to ensure its quality. All steps were taken to ensure the quality of the data and involvement of the project team members that originally recorded the data. Both 2D and 3D data were validated.

Testing

Excel spreadsheets were utilized as the main tool for computations. Returns and investments were captured via either historical or current data, then entered into a basic excel spreadsheet. Much care was taken to ensure values were correctly transferred and were validated against the original data for accuracy. Original dollar-values were utilized to compute percentage values relative to totals. In line with the methodology of this thesis, projects were carried out under the same owner, Company 1, allowing a more closed-system approach to the case studies. Thus, external factors were held more constant than comparable case studies.

Chapter 6

RESULTS

Case 1: Returns

As previously mentioned, Case 1 served as a historical account of the returns experienced from BIM utilization at Company 1 on the projects described. The data shows a positive differential or a net gain from 3D projects. For complete data, please see Table 3 – Case 1 Returns from 2D to 3D below.

Table 3

Case 1 Returns from 2D to 3D

Metric	Unit	2D	3D	Δ (2D vs. 3D)
RFIs	Quantity/tool	6	3	3
Change Orders	% of standard project costs	12%	7%	42%
Schedule	% behind standard schedule	15%	5%	67%

Case 2: Design and Construction Investments

Case 2 was established to illustrate the investments or cost of 3D on a current project. The data shows that costs are incurred due to 3D Design and a savings is experienced due to 3D Construction. The RFP for Case 2 required that the electrical, mechanical, and process piping contractors submit their bids in two different formats. The first format required was the cost of the entire scope of work for their discipline in 2D (standard). The second format was the cost of three identified functional areas to be performed in 3D (BIM). Upon comparing the 2D bids for the three functional areas with the 3D bids for the same three functional areas, they revealed that the contractor would pass down a savings of five percent to the owner with the utilization of 3D in those areas.

To reiterate, percentage values are a comparison of 3D costs for that particular metric versus the cost of total 2D and 3D scope awarded for that metric. For example, Construction Costs are calculated as 3D Contractor Costs / cost of total construction 2D and 3D scope awarded. Construction savings suggest that contractors are experiencing a savings due to the utilization of BIM in key areas. This is significant as Company 1 has the opportunity to maintain those contractors that experience this savings with ongoing work. For complete Case 2 data please see Table 4 – Case 2: Investments from 2D to 3D below.

Table 4

Case 2: Investments from 2D to 3D

Metric	Unit	Differential (2D vs. 3D)
Design Costs		
A&E Costs	% of total awarded design scope	31%
3D Background Model Creator Costs	% of total awarded design scope	34%
Construction Costs		
Contractor Costs	% total awarded construction scope	(-5%) (savings)
Design + Construction Costs		
Overall Savings with 3D in Design and Construction	% total awarded design and construction scope	(-2%) (savings)

Case 3: An Area's Returns and Investments

As a check to provide another data set, a specific functional area was focused on and the returns and investments were analyzed. This area had the most precise tool-to-tool comparisons across projects. Consequently, it is also deemed the most complex functional area. Company 1 sees cost savings and benefits adequate to merit this area's total utilization of the 3D process.

Therefore, a case study of this area is highly indicative of typical benefits. Using the same metrics as Case 1, the returns of Case 3 were calculated and can be seen in Table 5 – Case 3 – Returns from 2D to 3D below. The results show a change order savings as a significantly higher percentage than Case 1, which contains this functional area as well as two others. The percentage suggests that this functional area is receiving the highest returns from change orders.

Table 5

Case 3: Returns from 2D to 3D

Metric	Unit	2D	3D	Δ (2D vs. 3D)
RFIs	Quantity/tool	2	3	-1
Change Orders	% of standard project costs	23%	7%	70%
Schedule	% behind standard schedule	15%	7%	53%

Using the same metrics as Case 2, the returns of Case 3 were calculated and can be seen in Table 6 – Case 3 – Investments from 2D to 3D below. As previously stated, it is difficult to separate out the 3D background model creator cost, as it is the model of the entire factory and not just a functional area. Consequently, design the costs are slightly higher than would be applicable to the specific functional area. In contrast, the contractor savings are higher than for Case 2.

Table 6

Case 3: Investments from 2D to 3D

Metric	Unit	Differential (2D vs. 3D)
Design Costs		
A&E Costs	% of total awarded design scope	29%
3D Background Model Creator Costs	% of total awarded design scope	47%
Construction Costs		
Contractor Costs	% of total awarded construction scope	(-6%) savings
Design + Construction Costs		
Overall Savings with 3D in Design and Construction	% of total awarded design and construction scope	(-1%) savings

Project Manager Surveys and Interviews

Individual interviews of tool area Project Managers and Coordinators were conducted in order to provide insight into individual perspectives and gauge their experiences and overall atmosphere of the BIM environment at Company 1. Raw data from interviews did not contribute to the calculation of benefits; rather it served as contextual information. Utilizing the same series of questions for the interviews, the individuals were asked if BIM caused an increase, decrease, or stayed the same in the following categories: accountability, verification, software/hardware costs, learning curve, and coordination meeting attendance. Overall, they reported: an increase in attendance by the contractors at the coordination meetings, a diminishing BIM software learning curve, and decreased contractor accountability as a result of BIM utilization. Please see Table 7 – PM Interviews below for more information.

Table 7

PM Interviews

Category	Increased	Decreased	Stayed the Same
Accountability	38%	62%	-
Verification	50%	50%	-
Software/Hardware	50%	50%	-
Learning Curve	38%	24%	38%
Coordination Meeting Attendance	100%	-	-

Project Managers were encouraged to share their experiences and comments throughout the interview. From this, it was determined that there were barriers to BIM utilization at Company 1 in past projects. Project Managers suggested that the employment of BIM on projects leads to a decreased headcount on site during construction, which is one of their main goals. It was conveyed that both safety and cost are affected by the number of workers on site. BIM has the perceived potential at Company 1 to reduce on site headcount by enabling prefabrication and visualization.

Chapter 7

DISCUSSION

Limitations: Literature

As evidenced by Table A3 – Literature Review – Summary of Source Types in Appendix A, there are a variety of suggested benefits of BIM in the literature review. However, these benefits do not have a proposed calculation methodology and have not been quantified nor a baseline established. Garrett and Garside presented a case study and findings similar to the case studies in this paper; however, with very different project scope, methodologies, visibility, and quantification (2003). Koo and Fischer presented a study that examined the utilization of 4D (scheduling) modeling; however, the case study is retrospective and did not utilize 4D modeling during the actual construction process, was based loosely on interviews and post-mortem analyses, and did not present a classification of the monetary benefits or metrics to evaluate (2000). Tillotson et al. found generic benefits of intelligent 3D design in an environment similar to Cases 1, 2, and 3 in their paper. However, the calculation and background methodology of these generic benefits is not presented, and some distinct variables for these case studies became evident that may not occur in other case studies such as: additional field design hours were allowed and different designers were selected for the pilot projects (Tillotson et al., 2002). These variables and missing calculation methodologies are barriers to comparing data presented by these sources with other case studies. In their publication, "BIM's Return on Investment," Autodesk suggested a basic calculation for the return on investment of BIM, but no data quantified via their methodology was validated (2007). The literature review did; however, suggest potential areas of benefits of BIM. These potential top benefits are classified in Appendix A. As this thesis sought to quantify and provide a value-based framework, units were derived with respect to these potential benefits. These units are a result of careful consideration and were not directly suggested by the literature.

The literature presented a variety of hierarchies and theoretical models for the first implementation of BIM at an organization, which was beyond the scope of this thesis. Such theories and relationship-based models serve more as suggestions and lessons learned than a value-based framework. For more information regarding how to implement BIM with these qualitative hierarchies, such as phases and execution strategies, see Appendix A – Table A1 – Literature Review, codes 17-21.

Limitations: Case Studies

The case studies presented in this paper were based on an owner's perspective and had less visibility to details regarding third party savings, such as from the contractor or designer. Additionally, some of the data available was historical, thus an ideal state would be proper tracking of metrics by the team while the project is in progress. Please see Appendix B – Future Tracking Metrics for suggested ongoing tracking metrics for Company 1.

The ideal setting for this methodology would be a case study in which both BIM and Non-BIM were carried out under not only the same owner, but also the same contractors; similar scopes of work, the findings were shared among project stakeholders, and with numerous representative projects. The ideal setting described would provide both consistency and uniformity for future comparisons. There are limitations in every project associated with the individual stakeholders' varying degree of visibility, how much information can be obtained, and under what conditions. For example, an owner is less likely to have a contractor's field labor productivity rates and will have a lower degree of visibility to their contractors' actual savings. The contractor alone knows how much they spend or save as a result of BIM and how much of that savings they choose to pass on to the owner. Furthermore, contractor costs for generating 3D shop drawings, reduced headcount (in the field and in the office), reduction in insurance rates, offsite fabrication savings, and safety rates may not be highly visible to all parties. Actual savings become proprietary due to the business nature of these transactions. Nevertheless, the business case presented here is predicated on benefits that are quantifiable and realized by the owner.

The scope of this thesis does not cover a "learning curve" associated with being seen as proficient or able to provide adequate BIM support (Zuppa et al., 2009 and Becerik, 2006). No methodologies for the learning curve are proposed, thus they are not in the purview of this thesis.

Chapter 8

ORGANIZATIONAL CONSIDERATIONS

Overview

The frameworks suggested by the literature for implementation regarding BIM and analysis of its benefits provided little attention to monetary gains or losses as an outcome. The quantitative framework developed thus far in this thesis is expanded upon based on more organizational and project management results, which tend to have intangible precedents and outcomes. The precedents and outcomes can be evaluated to ensure they meet the prerequisites of the framework and overall BIM implementation.

In their analysis, *Building information modeling (BIM) a framework for practical implementation,* Jung and Joo propose that organizational strategies and policies can affect the success or failure of BIM implementation in an organization (2011). In this light, the organization itself can be a barrier to BIM implementation, regardless of the potentially quantified benefits BIM is posed to offer. Jung and Gibson suggest "corporate strategy, management, computer systems, and information technology as the four main concerns of IS [information systems]" (1999). Furthermore, Talyor suggests "social and organizational contexts need to be taken into consideration to understand the adoption of this BIM technology" (2007).

There is a large need for managerial effectiveness as an antecedent of BIM success (Jung and Joo, 2011). Organizational and project management functions will be affected by the implementation of BIM and they should be analyzed with respect to the four (4) different levels suggested here:

- Executive Level
    - Corporate strategy
    - Stakeholders
    - Legal aspects
- Communications Level
    - Positive and negative effects
    - Changing roles and responsibilities
    - Unanswered questions
- Risk Management/Strategic Planning Level
    - Preconstruction
    - Technical risks
    - Alignment
- Change Management Level
    - Pace
    - Paradigms
    - Contracts

The importance of appropriately and directly formalizing a BIM framework for the proper executive, organizational and managerial functions is paramount to the future implementation of BIM in the building industries and its overall sustainability.

Level 1: Executive

At the executive level, BIM strategies should be concerned with: understanding the corporate strategy, clearly identifying and communicating with key stakeholders, and the legal aspects. Commonly referred to as a business case, the concept is that the strategy utilizes proper business language and is effective to the business in that it can affect the value chain and promote a more complete representation of the supply chain, allowing a more integrated approach (Jung and Joo, 2011). BIM must operate across disciplines and is not exclusive to one entity; rather, the sharing of information is critical to its success.

Corporate Strategy

The corporate strategy sets both the stage for the organization's performance and any external event or change in process that could impact the company. In their, *Planning for computer integrated construction,* Jung and Gibson propose various areas to evaluate BIM, in their effort to create a framework (1999). For example, corporate strategy assesses the opportunity that can be improved or created by using IS. This is accomplished by prioritizing corporate strategies of an organization, and then assessing each business function to determine how it supports such strategies. It is also emphasized that executives within a company should be involved in this analysis because they have exemplary insight to represent the company's strategy (Jung and Gibson, 1999). As recognized by Sebastian, "Most clients struggled to translate their ambition and objective of BIM into effective project implementation strategies," (2010). It is not enough to have a goal of moving towards BIM, rather the strategy is paramount. Furthermore, not only should key executives be involved, but key future users should also be engaged.

Stakeholders

BIM is more than software; it's an active process that engages stakeholders that could be impacted by its utilization. As suggested by Jung and Joo, "practical BIM implementation effectively incorporates BIM technologies in terms of property, relation, standards, and utilization across different construction business functions throughout project, organization, and industry perspectives" (2011). BIM crosses business functions of: planning, sales, design, estimating, scheduling, material management, contracting, cost control, quality management, safety management, human resources management, financing, general administration, and research and development (Jung and Joo, 2011). The sheer quantity of business functions hints at the importance of involving those key stakeholders and decision-makers in each business function that can contribute to both the implementation and sustainability of BIM; thus reinforcing their role in the framework before, during, and after BIM utilization.

Some of the essential questions to consider for key stakeholders are presented by Sebastian in his *Breaking through business and legal barriers of open collaborative processes based on Building Information Modeling (BIM).* For example, in order to be effective, a framework must consider the economic gain of open collaboration for the stakeholders in the building industry (Sebastian, 2010). The issue of openness is not exclusive to the construction industry. Often seen as a barrier to BIM adoption by owners are the current regulations that, “Many building permit-issuing agencies are not yet ready to review digital information and require paper-based submissions” (Sebastian, 2010). Authors have noted that, despite the recognition of the importance of key stakeholder involvement, current BIM proof does not warrant buy-in from executives.

Legal Aspects

BIM also has some very important legal and regulatory considerations for its implementation framework and as a direct result of openness. Sebastian further discusses the legal consequences of having such openness of information and intellectual property rights, raising some important questions, such as: “Are there any regulatory impediments to BIM Standards proceeding? What new regulation needs to be put in place? Who is liable for the information in the digital model? How are the users protected? (Sebastian, 2010). Currently, there is no universal BIM legal framework or guide, with the National BIM standards (NBIMS) appearing to be the most commonly cited source for project development in the literature (Succar, 2009). There is a need for a more universal model, one in which the benefits and costs are clearly delineated. Sebastian analyzed the benefits associated with BIM from the business and legal perspectives as being: consistent information resulting from the integration of all data in a centralized model; efficient and fast design and engineering, as drawing, analyzing, verifying and decision-making are done through simultaneous processes involving all disciplines; efficient planning and production based on accurate quantity estimation and coordination; high quality buildings due to the elimination of design errors; sustainable solutions through continuous validation of the design alternatives against the client requirements; and effective facility management using the data contained in the model for managing, remodeling, and maintaining the building over time (2010). Similar to the benefits suggested in other sections in which surveys and interviews were conducted , the quantification of these benefits is not direct and is based more on subjectivity than a monetary value.

As quantifying the benefits of BIM is a challenge for everyone with changing KPIs and metrics, so too is the measurement of the barriers. According to Sebastian, these barriers can be organized into five main issues: lack of immediate benefits of BIM for the stakeholders; changing roles, responsibilities, and payment arrangements; uncertainty of the legal status and intellectual property of the model; inadequacy of the existing contractual frameworks, including the agreements on liability and risk allocation; and lack of consensus on the protection of information in conversion and interoperability, and against loss and misuse of data (2010). Benefits and barriers should be held to the same standards of quantification. A monetary as well as an intangible organizational and project management value should be established. Some of these risks are discussed in the following sections.

Level 2: Communication

At the communication level, BIM strategies should be concerned with: its effects (positive and negative), its impact on changing roles and responsibilities, and remaining unanswered questions. These communication factors must be carefully analyzed prior, during, and after BIM implementation in an organization, as they are key intangible aspects that could affect the overall success of the BIM framework posed here.

Positive and Negative Effects

Through the proper framework, BIM is poised to result in positive effects in the area of communications. By encouraging the sharing of information, BIM is a tool that fosters exchange of information, schedule communication, and organizational transformation. BIM enthusiasts believe, “BIM is a tool that can foster integration because it not only improves project communication and information exchange, but also creates a platform that serves as a framework for collaboration” (Ospina-Alvarado and Castro-Lacouture, 2010). By themselves, frameworks function as a tool to communicate the means and goal to achieve an objective, such as the utilization of BIM.

The schedule, a critical tool in project management, can be positively affected by BIM. Accordingly, “Using BIM for scheduling purposes can help to generate and control the schedule for the project team from the design model that can be automatically updated as the project evolves. Therefore the schedule will reflect more accurate the duration of the project and will serve as a decision making tool” (Ospina-Alvarado and Castro-Lacouture, 2010). In this light, merely the capabilities of BIM to promote communication of schedule for example, it can be seen that the emphasis is that a Project Manager uses the information beyond the original intent and for their unique purposes. Sebastian has a very positive outlook overall on the effects that BIM could have on improving communications for an organization, he comments, “Although a certain participant holds the coordinating role, a complex hierarchy is not required. An attention should be given to build the trust that guarantees the open book philosophy and the ethics of collaboration regarding the sharing and integration of information" (2010). BIM can promote open exchange of information both across multiple disciplines and individuals.

Timeliness, if capitalized, can have a positive impact as well with BIM utilization. The early-design stage is vital for adoption of BIM because in this stage, when merely 1% of the project cost is used, the key decisions that commit 70% of the life-cycle cost of the building are taken (InPro, 2009). Furthermore, critical documents are created at this time, and BIM would be well poised to positively impact tools such as project execution plans, procedures, and manuals (Jung and Joo, 2011). While these efforts have the potential to have good results, with each positive also comes a negative.

As with any new system, negative impacts may be equal to or greater than the positive impacts. Compared to other industries, information systems utilized in construction are not very advanced and often applications exist independently and have little or no capacity for communications with each other (Jung and Gibson, 1999). Interoperability is a hotly debated issue for BIM; however, there are various guides from the NBIMS and AIA if this kind of tool is desired.

In fact, "A report by the National Institute of Standards and Technology in the United States described "inadequate interoperability of technology in the design and construction industry in the United States alone as a $15.8 billion problem annually" (Gallaher et al. 2004). Outside of the technical and interoperability issues, rests the main change agent or inhibitor, the individual stakeholder. Unfortunately for BIM, “Not all stakeholders can easily share information and not all stakeholders want to disclose all information” (Sebastian, 2010). There is undoubtedly a very large organizational force running through these stakeholders in their various job roles.

Changing Roles and Responsibilities

The main beacons of change for BIM implementation will be those leaders and managers with an understanding of the framework presented here, potentially fostering new roles and responsibilities. Sebastian identified an emerging role of Model Manager on BIM projects, along with the usual roles of Project Manager and Process Manager (2010). More specifically, “The model manager needs both ICT and construction process competencies. The model manager deals with the system as well as with the actors. He provides and maintains the technological solutions required for BIM functionalities, manages the information flow, and improves the ICT skills of the stakeholders. The model manager does not take decisions on design and engineering solutions, nor the organizational processes, but he holds a supporting role in the chain of decision-making” (Sebastian 2010). While these responsibilities may seem similar to those of a project manager, they are quite distinct.

Further defining the model manager’s responsibilities, Sebastian enumerates that they must have a commanding role in the development of BIM and relevant tools by: defining the configuration and level of details of the model, checking and merging, clash detections, contributing to collaboration methods by facilitating decision-making and communication protocols, integration of task planning and risk management; management of the flow and storage of information, identification of communication errors, and decision or process (re-)tracking (Sebastian, 2010). It is important to delineate the differences among project management, process management, and model management.

A project manager's main focus is maintenance of cost, time, and quality; whereas process management's center of attention is creating tactics for communication, collaboration, and decision-making among team members. According to Sebastian, "The new role of a model manager is not necessarily conflicting with the existing roles of a project manager and a process manager" (2010). Instead, there are numerous opportunities for collaboration. As the client's representative, the project manager executes the management of project scope, objectives, resources, and schedule in the client's best interest. Seen as a decision-maker, the PM is also in charge of assuring all stakeholders fulfill their contractual obligations. When it comes to the more technical aspects of the project, such as design and engineering, the model manager can provide the PM with the needed information from BIM (Sebastian, 2010).

Promoting collaboration among project stakeholders on a more strategic level, the process manager's role is complementary to that of the project manager, and also depends on the model manager. The process manager forms the inter-organizational processes to accomplish an effective collaboration that will benefit the project's lifecycle (Sebastian, 2010). In collaboration with the client and model manager, the process manager can foster the strategies for communication and decision-making into the BIM based collaboration methods, protocols, and risk management plans. It is important to emphasize the early and frequent involvement of the project manager, process manager, and model manager in the framework understanding and implementation to further promote the lifecycle of BIM in the particular company.

Unanswered Questions

Despite the best efforts to clearly delineate the communication strategies, roles, and responsibilities, confusion may still persist in this area. Among the most debated questions are: "Is the architect still the leading designer in the integrated design and engineering? Who is in charge of the total quality of the design? Who assures that all interface problems (clashes) are solved and that the model is full-proof? Which new agreements on responsibilities and input-output workflows should be made if every discipline is involved almost simultaneously in the process? Since a new role of model manager has come to place, what are the general and specific tasks of the model manager with respect to the project manager and the process manager?" (Sebastian, 2010). These questions are common and should not be seen as a deterrent to BIM, rather, they should be viewed as essential areas to address in the very early stages of BIM implementation to ensure a smooth framework. Communication should be open and transparent.

Level 3: Risk Management and Strategic Planning

For the risk management and strategic planning level, BIM strategies should be concerned with: preconstruction, mitigation of technical risks, and alignment. These key preliminary areas lay the foundation not only for successful BIM implementation, but also for proliferation across the project's life-cycle.

Preconstruction

A major appeal for the utilization of BIM in construction is the management and prediction of risks prior to construction. The concept that risks are discovered early can save both time and money, as the costs to resolve risks rises after design is complete escalate. In their study of eight projects, Kiziltas and Akinei found that during preconstruction, general contractors used BIM mainly for constructability analysis and design consistency check to eliminate unexpected problems and rework during the construction phase (2010). In the early days of BIM proliferation, clash detection was touted as a main benefit to BIM, as stakeholders would meet to review clashes between building assemblies and across disciplines, posing solutions based on their expertise. As it has gained momentum and utilization across projects, BIM has the increasing potential to reduce both risks across project life-cycles and amongst team members.

Technical Risks

Risks can occur in both design and construction phases, but BIM encourages pre-planning by looking at the design, constructability issues, and operations prior to construction. Effective pre-planning and risk mitigation efforts prior to the initiation of construction are paramount to effective risk management (Kashiwagi, 2011). However, the key is to get early involvement by all stakeholders, not just designers. Contractors must also be involved and participate in the clash detection sessions where solutions are formed. As

Sebastian noted, “BIM-wise collaboration is believed to be able to reduce the traditional project risks. BIM simplifies the risk management in a project through a more accurate estimation of cost, time, and quality” (2010). A tool, such as BIM, is only successful as the individuals that take advantage of its benefits, with proper training and encouraged collaboration between all individuals on the project team.

Alignment

While BIM guides and frameworks do not specifically list alignment as a requirement, the outcomes of alignment such as collaboration and pre-planning are necessary prerequisites. Just as the model crosses the phases of a project, so teamwork should cross disciplines. On a strategic level, the model should be created in an environment that encourages participation from designers and contractors alike. Both the need and barriers of alignment of designers and contractors for successful BIM implementation have been referenced in multiple sources: Aranda-Mena, 2008; Homayouni et al., 2010; Ospina-Alvarado and Castro-Lacouture, 2010; Taylor, 2007. This alignment should be upheld across organizations and individuals within these organizations alike. Risks that need to be further investigated in this realm are, “the scarce availability of BIM experienced personnel for the formation of a highly qualified team, and the challenges to integrate the new expertise in the sustainable business strategy of the organization” (Sebastian, 2010).

Level 4: Change Management

On the level of change management, BIM strategies should be concerned with: pace, paradigms, and contractual implications. These transformations parallel changes experienced in the past with the first implementations of 2D CAD. Taylor specifically addresses the similarities between the initial proliferation of 2D CAD and the current introduction of BIM or 3D CAD in his *Antecedents of successful three-dimensional computer-aided design implementation in design and construction networks* (2007). Any paradigm shift will have change management implications.

Pace

BIM invokes a very fast-paced and early change environment**.** Furthermore, any change can experience resistance, as quick changes are increasingly difficult to implement. As identified by Sebastian, “Model-based decision-making will result in the changes to the internal processes of the project stakeholders. The analyses performed through the multidisciplinary collaboration at an early stage must be emphasized in order to achieve the benefits of using the models to support decision-making and to make the comparison between available design alternatives” (2010). The model itself cannot realize its full potential and move forward without the stakeholders operating at the same pace.

Paradigms

In many ways, the challenges associated with BIM represent a quintessential paradigm shift. The “normal way” of doing things will be challenged by new processes (Lu and Li, 2011). For example, BIM is more technology-based, with less utilization of physical drawings. Often, individuals will compare the movement from "blueprints" to "CAD" as a shift similar in difficulty and importance as the current shift to "3D CAD" or BIM. However, BIM has been reported to have a slower rate of acceptance than 2D CAD, as this requires a fundamental change in perspective of the previously accepted silos of design and construction (Taylor, 2007). Instead of keeping these silos separate, BIM promotes integration of common concerns and needs across design and construction. Taylor identifies the top concerns of designers as: liability and contractual issues; and concerns of contractors as: the cross-pollination of ideas and technology competence (2007). From these concerns, it can be seen that BIM requires more of a paradigm shift than its predecessor technology shift from blueprints to CAD.

Contracts

The culmination of these implications at the various levels that will affect BIM implementation must be properly accounted for in the contractual and liability arenas. Sebastian (2010) and Taylor (2007) both discuss contractual changes and new liabilities that are a result of collaboration and open sharing of the relevant information. In the area of contracts, it has been observed that projects have added at least one paragraph, to multiple pages of requirements and rules due to BIM utilization on a particular project (Taylor, 2007). However, some projects may require more detail or contractual obligations for their BIM standard. Entire models for project delivery, such as Integrated Project Delivery (IPD) have been proposed in response to these concerns. IPD is stated to specify the roles, activities and required contributions of the stakeholders in each project stage, thereby encouraging early contribution, experience, and proactive involvement of key participants (Sebastian, 2010). On a more technical level, BIM carries an additional liability concern by designers since printed plans are not traditionally drawn to scale, but a BIM is required to be more accurate, with contractors making adjustments to the model prior to field work (Taylor, 2007). Contractual and liability concerns with BIM should be properly understood and accounted for prior to BIM implementation, as BIM represents a modification or change to existing processes and methods.

Summary

With research and applications of computer-aided integration in construction being touted starting around 1999 in the literature, it's a wonder that despite all the concerns raised over the years and intangibles, there is still a positive attitude towards BIM in the literature (El-Mashaleh et al., 2006). According to Homayouni et al., "Researchers have found successful collaboration that spans organizational boundaries enhances the productivity of the design and construction process. Researchers and practitioners alike argue that using BIM should lead to tighter collaboration and closer communication among project participants working in cross-organizational environments" (2010). A framework for proper assessment is increasingly critical. Thus, benefits do not come without a price, as lessons learned, "We find that inter-organizational BIM-enabled projects and successful inter-organizational collaboration have shared theoretical categories: fostering integrated teams; implementing tools and strategies to encourage clear communication across the team; and developing transparent technology use" (Homayouni et al., 2010). With BIM proliferation comes some areas of challenges. As Bakis et al., 2006 and Homayouni et al., 2010 assert, without an organizational environment that promotes collaboration and the open and freely exchange of information, such as partnering, the full potential and implementation of integrated systems cannot be realized.

Organizational and project management functions will be affected by the implementation of BIM and they should be analyzed with respect to the four (4) different levels suggested here: 1) Executive, 2) Communications, 3) Risk Management/Strategic Planning, and 4) Change Management. The framework presented here ensures that organizations read and respond to these four levels, carefully considering the benefits and costs associated at each level. While the factors presented do not have a direct numerical quantification, the organizational-specific responses to these levels, when coupled with the previous quantified benefits provide an organization seeking an analysis of whether they should utilize BIM with a realized framework for decision-making.

Chapter 9

CONCLUSIONS

Outcomes

The calculation methodology and findings of the Cases 1-3 present a valid evaluation for the utilization of BIM. The success of BIM depends on many factors such as the size of the project, team members' BIM proficiencies, the communication of the project team, as well as other organizational external factors. The Cases in this analysis do not quantify these aspects or other intangible benefits since their quantification is subjective in nature. Therefore, BIM's success is relative to the project and the organization.

While the literature did portray a positive outlook and future for BIM, quantified results and metrics used to measure its proposed benefits were not consistently applied. Therefore, this thesis concludes that BIM has not definitely been proven to have positive benefits, measured under a value-based framework.

This thesis did, however, provide quantifiable project data via three Cases of BIM utilization through established return and investment metrics and laid down a framework for benefits measurements. The benefits framework involved:

- Return Metrics: Change Orders, RFIs, and Schedule
- Investment Metrics: Design Costs and Contractor Costs
- Organizational Considerations: Executive, Communication, Risk Management and Strategic Planning, and Change Management

At Company 1, calculated returns were: change orders saw a savings of five percent of standard costs in Case 1, RFIs decreased 50 percent per tool or assembly, and duration reduction was a savings of 9 percent based off the standard duration. Calculated investments were: 31 percent increase in design costs due to A&E costs, 34 percent increase in design costs due to 3D background model creation, and a contractor savings of 5 percent of contractor costs. When totaled in dollar value and percentages computed, investments in both design and construction resulted in a savings of 2 percent of combined awarded design and construction scope. Thus, the contractor savings outweighed the design costs as a percentage of the scope awarded. A more complete portrayal of the savings experienced at Company 1 could be conveyed if a dollar value is derived for the returns. Nevertheless, the findings of the Case Study at Company 1 indicate that in the tool installation department of semiconductor manufacturing, there is a high potential for BIM benefits to be realized. Moreover, contractors experienced a realized savings that they passed on to the owner.

The data provided by Case 3 held that in specific areas of semiconductor manufacturing, such as those that are more complex, may have increasing returns as compared to less-complex areas. More testing on specific areas can be carried out in a particular project environment; however, this provides some insights as there are numerous areas of this type in semiconductor manufacturing.

For a project trying to determine if BIM has or will benefit them, this paper presents a valid framework methodology and baseline. The metrics for collection presented in this paper provide a starting point for the stakeholders to begin their analysis. The methodology of this thesis is consistent in a closed system, such as Company 1. However, variables in other organizations or projects that are exterior to this system must be analyzed if this framework is to be utilized.

Additionally, it is critical that all perspectives are represented in the metrics, from contractor, designer, to owner. This can be best established via project stakeholder meeting in which metrics are validated. Obtaining proper baseline data on the Non-BIM (2D) metrics is essential for a proper analysis of BIM (3D) benefits and an "apples to apples" comparison. Lastly, ongoing project performance measurement is critical to benefits realization. The metrics in this paper should first be quantified, and then other potential metrics can be addressed as listed in Appendix A.

Since these metrics are based off of a standard, they are very easily employed across projects and sectors by companies that have Non-BIM performance metrics to insert as their standard and BIM pilot projects as their comparison data set. With this framework analysis of benefits, companies utilize their own standard as a basis of comparison. Innovations progress with time or become obsolete, thus the utilization of BIM beyond 3D will be a good indicator of the benefits that companies may be receiving as a result of a more complete BIM utilization.

Recommendations

With change orders seeing a savings of five percent of standard costs in Case 1, this resultant savings could be substantial with a large scope of work. An RFI decrease of 50 percent per tool or assembly may have an impact in savings if processing time and resources are scarce, as is generally the case in the manufacturing environment. Duration reduction is critical, thus a savings of 9 percent based off the standard duration can have a tremendous impact, especially if the critical path is affected.

As stated by Chasey and Merchant," Because of restrictive construction schedules, sequencing and coordination of different construction activities will also become a big issue. Constructors will need to develop new ideas and methods to be able to design and construct a fab that ramps up quickly and works efficiently in an uncertain and changing environment" (2000). Those in a semiconductor manufacturing environment will have to decide if the upfront investment costs of BIM are worth the potential returns later in the project. For Gil et al., "Designers and customers argue that benefits and cost savings of a flexible product design in the long term outweigh its up-front cost and risk of rework" (2005). The challenges of the semiconductor manufacturing environment make strategies for reducing costs, such as BIM, quite attractive.

The calculation methodology in Cases 1-3 could be further refined on future projects, depending on the availability of information. For Case 1, in future measurements, a cost associated with the creation and responding to the RFI or cost avoidance may be a useful measure depending on the objectivity of the analysis. Also, a classification of a type of RFI specifically related to BIM would be useful to a future analysis. Schedules should be more diligently tracked, milestones should be uniform, and actual versus planned dates should be more carefully compared. As a semiconductor manufacturer, certain schedule constraints exist outside the control of the project at hand. For example, Gil et al.

found that, “more than eighty percent of the requested tool arrival dates were changed at least once, if not more frequently for times around sixty days. This is a common occurrence, with the tool suppliers’ premature commitment to a date” (2005). These factors should be taken under consideration when comparisons are created. For Case 2, an ideal state would be to have the cost incurred only as a result of the 3D scope of work, only in the areas that will utilize this process and not the entire factory. Additionally, as actual costs could not be revealed in this thesis due to the proprietary nature of the bidding information of Company 1, comparisons where actual costs are able to be reported would provide increased visibility.

As Company 1 seeks the returns associated with the full utilization of BIM, consideration should be given to its future opportunities for savings and reduced cost over the full life-cycle of the BIM process. In the manufacturing setting, BIM has the potential to further impact factory layouts, with a more flexible model that can keep the pace with its dynamic environment. Garrett and Garside note exponential benefits if the BIM layout analysis could includes space usage changes, utility loadings and routings, tool pedestal changes, labor and material costs, and also highlight potential physical interferences of equipment and facility systems (2003). An analysis and metric for these industry-specific types of potential future applications should be developed.

In particular, Company 1 should evaluate the potential benefits for BIM in “dimensions” beyond 3D (modeling), and to assist in and provide information regarding: planning scenarios and site information, architectural program, floor plans, layouts, engineering calculations, specifications, contract documents, legal description, change orders, supporting documentation for litigation, shop drawings, procurement documents, progress photographs, alarm diagrams, warranty data, purchase requests, cost estimates, organizational occupants, personnel lists, handicap designation, hazardous materials (reduction in airborne molecular contaminants), Operating manuals, maintenance records, inspection records, simulations, continuation of operations plans, disaster recovery plans, contingency plans, asset inventory, energy analysis, project closeout documentation, proper lean implementation, electronic document transfer, supply chain management (internal and external), forecasting, risk management, and safety applications (NBIMS, 2006). Future research on the measurement of the benefits of BIM could utilize more sector-specific metrics, such as those listed above, to provide a sector-specific representation and level of detail in accordance with the calculation methodology presented.

Future Research

The literature suggests that the full potential of BIM has not been realized, as it was noted full implementation is hindered by a lacking business case for owners. Nevertheless, there are many articles and publications related to the future potential of BIM in dimensions beyond 3D; notably scheduling, sustainability, and facilities management. Furthermore, some suggest that a more formal review and certification system of BIM could lead to increased adoption. As Succar postulates, “Also, a valid set of BIM metrics will lay the foundations for a formal certification system which can be employed by industry leaders, governmental authorities and large facility owners/procurers to pre-select BIM service providers and attest to the quality of their deliverables" (2010).

Applications of BIM regarding scheduling (4D) hold potential beyond visualization to a greater assessment of innovations and to evaluate construction alternatives. Jongeling et al. present 4D content quantitatively via workspace areas, work locations, and distances between concurrent activities (2008). Furthermore, Homayouni et al. 2010; Krigsvoll, 2008; Kang et al., 2007; Koo and Fischer, 2000, provide many insights into the other dimensions of BIM and their possible implications on the investments and returns of BIM projects. Organizations seeking to employ BIM beyond 3D are encouraged to conduct further analysis prior to employment of BIM; ensuring metrics are established for data collection to evaluate if the other dimensions are truly beneficial.

The literature is beginning to identify how the BIM model can be used in broader applications, such as extracting data needed for a sustainability assessment of design (Nguyen et al., 2010).
McGraw Hill's *Green BIM: how building information modeling is contributing to green design and construction* report identified, "Because of the way BIM facilitates green design, construction, and sustainable outcomes, the growth of green building as an accepted, widespread practice is helping to accelerate BIM adoption" (2010). The report further provides case studies and data to support this topic. In their efforts at establishing relationships between Greening Strategies, Lean Principles, and BIM, Enache-Pommer et al. found the utilization of all three approaches resulted in efficient healthcare buildings (2010).

BIM is very frequently portrayed in the Design and Construction phases; however, the entire lifecycle should be in the purview of BIM implementation. As Lewis et al. asserts, "The lifecycle cost of the operational life of a building is about 60 to 85 percent of the total lifecycle cost, whereas the design and construction is about five to ten percent" (2010). Among various tasks to be performed after construction is complete, companies would like to use BIM for punch-list administration, keeping up to date manufacturing and installation information about maintenance items, which are needed during repair and replacements (Kiziltas, Akinci, 2010). However BIM is not viewed by some to be limited to those applications, "The use of building information modeling (BIM) promises to part of the solution to reducing interoperability and integration challenges for facility management" (Lewis et al., 2010). Facilities Management has much to gain if similar benefits are realized due to BIM implementation, as, "Viewed over a 30-year period, initial building costs account for approximately just two percent of the total, while operations and maintenance costs equal six percent, and personnel costs equal 92 percent" (Public Technology Inc., U.S. Green Building Council, 1996). Operations and Maintenance as a cost is quite substantial and any advancements or promise of reducing that cost, albeit BIM, should be properly investigated and follow a framework metric to evaluate its impacts.

As BIM is more than just 3D modeling, other applications of BIM may have benefits not under the purview this thesis. Additionally, sector-specific benefits may arise and should be evaluated for each project and organization as deemed necessary. The benefits framework established by this thesis can be further developed as BIM reaches new dimensions. However, the literature, to date, does not provide quantifiable metric suggestions nor a baseline for a comparison of investments and returns. Until BIM is accepted as beneficial and adopted by owners, measurements and estimates beyond 3D are premature.

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APPENDIX A

LITERATURE REVIEW TABLES

Table A1

Literature Review – Codes

Source Code	Reference	Type	Classification
01	Garrett and Garside, 2003	01	01
02	J.C. Cannistrato, LLC 2009	04	01
03	Khanzode et al., 2008	01	01
04	Kuprenas and Mock, 2009	02	01
05	Koo and Fischer, 2000	01	02
06	Tillotson et al., 2002	01	02
07	Woo et al., 2010	02	02
08	Aranda-Mena et al., 2008	02	03
09	Andresen, et al., 2000	01	04
10	Bakis and Aouad, 2006	01	04
11	Autodesk, 2007	05	04
12	El-Mashaleh et al., 2006	01	05
13	Zuppa et al.,	02	05
14	Becerik-Gerber and Rice, 2010	06	05
15	FMI/CMAA. 2007	07	05
16	McGraw Hill, 2009	03	06
17	Becerik and Pollalis, 2006	03	07
18	Krigsvoll, 2008	02	07
19	Suermann and Issa, 2008	01	07
20	Gil, et al., 2005	02	07
21	Homayouni et al., 2010	02	07

Table A2

Literature Review – Top 21 Sources

Code	KPIs analyzed or suggested	Issues	Data
01	Total project cost Total pilot cost Sequencing issues cost Physical conflicts (clashes) Schedule conflicts	New construction, base-build only scope, new facility, implementation of the pilot began approximately six months after detailed design began in 2D, no calculations or methodology, past project team members disagreed with the findings presented	Cost less than 1% of the total project cost ; Conversion of the 2D model approximately 75% of the total pilot cost ; Identified and resolved sequencing issues that avoided nearly $2M ; Physical conflicts (clash reports) saved $0.75M ; Schedule conflicts (scheduling interface) $1.2M ; Data conflicts (attribute management) $0.5M
02	Change orders	Not much detail on the calculations, specific to MEP industry, not peer-reviewed journal (press release)	Change orders representing % of base contract: 2D projects = 18.42%; 3D only = 11.17%; Collaborative BIM = 2.68% (Data is based on 408 projects over past 6 years, totaling $558,858,574)

Code	KPIs analyzed or suggested	Issues	Data
03	Labor savings Pre-fabrication savings Safety Field conflicts RFIs Schedule Overall project costs	New construction, hospital project, MEP systems only, contractor opinions, no formulas or backup data presented	MEP systems include labor savings ranging from 20 to 30 % for all the MEP subcontractors ; 100% pre-fabrication for the plumbing contractor One recorded injury throughout the installation of MEP systems over 250,000SF ; Less than 0.2% rework for the whole project for the mechanical subcontractor ; Zero conflicts in the field installation of the systems ; A handful of requests for information for the coordination of the MEP systems between contractors and the designers ; 6 months' savings on the schedule About $9M savings in cost for the overall project.
04	Coordination Rework Durations Conflict checking Visualization Sequencing Preassembly and prefabrication	New construction, 685,000SF facility, did not have involvement of designer, instead contractor, subs, and construction manager developed model elements and then combined into one model	Reduced rework - $50,000; Shortened construction durations - $10,000; Visualization (underground electrical); Sequencing - $250,000 (MEP and FP systems); Preassembly - $25,000; Bundling - $10,000; Shop fabrication - $25,000; Conflict checking (between trades) - $4,000,000; Bulletins - $250,000; Other changes - $250,000

Code	KPIs analyzed or suggested	Issues	Data
05	Schedule	Retrospective case study, does not list actual quantified savings, just general statements	Retrospective case study that determined if 4D could have helped overall project execution. Stated that the results show that 4D models are effective in determining the feasibility of the construction schedule. Some discussions in opposition were carried out after.
06	Engineering Design Field installation Change orders Design labor	Illustrates 3D design with 2 examples: (1) hookups and labor saved (2) FM on pumps, LCCA, and estimate of $ saved on alternative vacuum pump. Only describes approach, highly contextual, only 1 project, management strategies are differential, not a good model for beginners, older model 1999-2000, allowed additional field design hours and cost).	Generic benefits of intelligent 3D design and quantified them as: Engineering (reduce redundant efforts) 15% decrease; Design (increased effort for accuracy, planning, detail) 5% increase; Installation (reduced field engineering, man hours) 5-20% decrease; Change orders (reduced through improved accuracy) 35% ; Case study saw Design labor to issue a 3D design package, although sometimes greater, is comparable to that for detailed 2D packages. Secondly, the installation labor hours are typically significantly lower for the tools installed with 3D design packages

Code	KPIs analyzed or suggested	Issues	Data
07	Business outcomes Communicate alternatives Client satisfaction Risk	Data is solely based on interviews and public information, no real metric exists, based on expected outcomes, and no financial data is presented	Presents general findings and implications obtained from interviews and research from five case studies to suggest the generally accepted benefits of BIM and expected outcomes. It also suggests that there can't be one business case for BIM, applicable to all projects and organizations.
08	Fully coordinated model Visualization Simulation (mock ups) Schedule Accurate as-builts Asset management visualization Maintenance scheduling Lifecycle project information	Case studies are very brief and no quantifiable data is presented, benefits are stated in general terms	Utilized 3 case studies to illustrate the general options of implementation of BIM, non-quantified benefits of implementation, and lessons learned

Code	KPIs analyzed or suggested	Issues	Data
09	Typical IT benefits (such as reduced communication costs and reduced staff) Efficiency Effectiveness Performance	Subjectivity in assigning the type of benefit and populating the table, especially with assigning an impact, not directly applied to BIM	Proposed a framework to evaluate the benefits of an IT investment by first assigning the type of benefit (efficiency, effectiveness, or performance), and then filling the appropriate table with data relating to: business process, specific benefits, implications, metrics, ownership, likelihood, resultant benefit, and assigning an impact. Assert that this method is more viable than ROI and term it as "information economic analysis."
10	Typical IT benefits (such as intangibles and achieving business initiatives)	Suggests only a method and is not directly applied to BIM	Good background and framework for determining the value of information systems, limitations, intangibles, and methods. Suggests gathering information via the methods of individual ranking of intangible benefits and case studies.
11	Labor Productivity	Focuses on the first year's ROI and is a simple model, not taking into account specific project variables, formula is presented without case studies or applications	Suggests a simple formula for BIM ROI

Code	KPIs analyzed or suggested	Issues	Data
12	Firm performance, schedule performance, cost performance, customer satisfaction, safety performance, and profit		Survey, received from 74 firms, no owners represented. Suggests increases of: firm performance (2%), schedule performance (5%), and cost performance (3%)
13	Cost Schedule Quality Productivity Safety	Survey was more concerned with background/demographic and asked only 1 technical question relating to how BIM is defined (subjective), results were analyzed on a level of the individual and not the company's practices, and no performance metrics were given.	A survey was distributed to gain an understanding of the prevalent definition of BIM, and to identify BIM' perceived impact on the success measures of construction projects (202 AEC professional respondents) - responses: "1) BIM is an open standards based information repository for facilities' lifecycles 2) BIM is a tool for visualizing and coordinating AEC work and avoiding errors and omissions (most selected response); and 3) Other

Code	KPIs analyzed or suggested	Issues	Data
14	A list, resultant from the survey, with top results of: Visualization Field Errors Building Design As-builts	General assumptions, subjectivity, distributed in multiple channels and response rate is unknown, 99% U.S. based, mostly commercial and retail	Survey, frequently referenced findings resultant of a BIM survey (~400 respondents) of opinions and ideas, spring 2009
15	Communication Quality Documentation Schedule Quality results Productivity Consistency Labor Safety Business benefits	Data related to IT in general (not specifically BIM),	Found that the largest segment of owners (44%) have a budget for job related IT spending between 0%-0.4% of their construction budget, who has utilized BIM, ranking of a list of benefits, and ranking of hurdles

Code	KPIs analyzed or suggested	Issues	Data
16	RFIs Constructability Rework Budget Mock-ups Visualization Simulation Schedule	Survey questions are based on "perceived" value, no common method of calculation/estimation of benefit is suggested, case studies are all new buildings and less-complex facilities, not peer-reviewed	General questions on the "perceived" value of BIM and its ROI, sample is limited to survey respondents and highly cited in BIM articles, Study to assess adoption of BIM across the construction industry and to gauge the perception of value that firms are receiving by implementing BIM.
17	Typical OCPM benefits, tangible, quasi tangible, and intangible	Not directly applied to BIM	Classifications of benefits of ICT (tangible, quasi-tangible, intangible), focused mainly on online collaboration and project management (OCPM) technology to the design and construction industry

Code	KPIs analyzed or suggested	Issues	Data
18	Life-cycle cost analysis Supply chain effects Benchmarking	Benefits are not quantified and focus on stages of BIM implementation beyond 3D	Suggests alternate uses of BIM models in LCCA, benchmarking, energy data and modeling, O&M data, performance metrics, and forecasting; highlighting potential benefits
19	Rework Schedule Safety Performance	Not current (some surveys from 2007), survey data was taken over an extended period of time, multiple surveys, inconsistent respondents and response rate, respondents were from a limited audience, based on "perceptions" of value	Qualitative data collected via a survey to assess perceptions about BIM impacts on 6 key performance indicators (quality control, on-time completion, cost, safety, dollars/unit performed, and units per man hour. There is a positive correlation between a BIM-based approach and construction management productivity, established by the USACE's utilization of internal tracking metrics and performance comparisons.

Code	KPIs analyzed or suggested	Issues	Data
20	Design Layout modeling Automated estimation	Basebuild only scope, implementation of the pilot began approximately six months after detailed design began in 2D	"Overall reduction in design time would be on the order of 20% to 50%, possibly greater."
21	Productivity Communication	Model is and observations are based on a single scientific research lab project in the U.S. and through interviews from 70 professionals across the U.S., findings are general categories and suggestions for implementation	Gives a general methodology and steps and theory to implementing BIM. Came up with a typology of how the collaboration process is implemented in inter-organizational BIM integration.

Table A3

Literature Review – Summary of Classifications

Code	Source Classification	Frequency
01	Case study and quantifiable findings	4
02	Case study	3
03	Case study and model or process	1
04	Model or process	3
05	Survey	4
06	Survey and case studies	1
07	Theory and general assumptions	5
	Total	21

Table A4

Literature Review – Summary of Source Types

Code	Source Type	Frequency
01	Journal article	8
02	Conference proceedings	7
03	Report	2
04	Press Release	1
05	Internet article, report	1
06	Survey and internet article	1
07	Survey/report/press release	1
	Total	21

Table A5

Literature Review – Top Mentioned Benefits

Benefit	Frequency	Unit
Schedule	11	Days
Sequencing coordination	7	N/A
Rework	5	N/A
Visualization	5	N/A
Productivity	5	N/A
Project cost	5	$ or %
Communication	4	N/A
Design/engineering	4	N/A
Physical conflicts	4	N/A
Labor	3	N/A
RFIs	3	#
Safety	3	N/A
Change orders	2	$ or %
Maintenance applications	2	N/A
Prefabrication	2	N/A
Quality	2	N/A
Simulation	2	N/A
As-Builts	1	N/A
Pilot cost	1	$ or %

APPENDIX B

FUTURE TRACKING METRICS

Table B1

Future BIM Tracking Metrics

Metric	Reporting Frequency	Suggested Source
Change orders as a % of standard costs	Quarterly	Owner/Contractor
Avoidance log and associated costs	Quarterly	Contractor
RFI quantities in 2D versus 3D	Quarterly	Owner
Offsite prefabrication man-hours from Contractors	Monthly	Contractor
OCIP insurance headcount dollar savings % off site hours	Quarterly	Owner
Reconciliations of savings from Contractors using BIM	End of Project	Contractor
Reconciliations of savings from Designer using BIM	End of Project	Designer
Actual durations as a % of standard duration	End of Project	Contractor/Owner