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How to measure the benefits of BIM — A case study approach

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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 paper 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. Actual returns and investments will vary with each project.

1. Introduction

1.1. 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 1000 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.

As noted in their evaluation of the business sense of BIM, Aranda-Mena et al. [1] 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." 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.

1.2. Definitions

Entire journal articles have been dedicated to surveying building professionals, from contractors to architects and engineers, for their perceptions of BIM and their definitions [2–5], focusing on their differences rather than similarities. The McGraw Hill "The Business Value of BIM" Report [2], 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." This report chiefly portrays the contractors' perspective in their definition of BIM, putting BIM in terms of its technical aspects as a model or documentation tool [2]. 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

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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 [6]. Zuppa, et al. [3] found that, "BIM was most frequently perceived of as a tool for visualizing and coordinating AEC work and avoiding errors and omissions." The literature fails to define BIM more in terms of the owner. There is no agreement on the definition of BIM or 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) Project Committee of the BuildingSMARTalliance [7] 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." This definition focuses on BIM containing adequate life-cycle building information and does not refer to one group of stakeholders, thus it is used as the underlying definition and purpose of BIM for this paper.

In addition to the impact of perspective, the "maturity level" of BIM in a particular organization will affect their understanding of BIM and definition. Succar [8] defines "BIM Maturity" as, "the quality, repeatability and degree of excellence within a BIM Capability." BIM Capabilities are listed in terms of three stages: 1) object-based modeling; 2) model-based collaboration; and 3) network-based integration. It is an organization's extent of their performance or ability within a particular stage which is measured to determine BIM Maturity according to the five maturity levels, as seen below in Fig. 1. BIM Maturity Levels at Stage 1 [8]. For example, an organization performing testing or pilot projects to determine the benefits of BIM may be at the first stage (object-based modeling) and within that phase they are at an "ad-hoc" or "defined" maturity level, working to be more optimized with increasing testing. Furthermore, the particular organization's level of BIM maturity can be assessed via general objectives within a level similar to Fig. 2. BIM Maturity Map [9], or across a matrix of competencies, similar to the BuildingSMARTalliance's BIM Capability Maturity Model, as seen in Fig. 3. BIM Maturity Matrix [10]. Organizations' varying levels of maturity should be taken into consideration in comparisons of one organization's BIM business case to another.

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 collaborative 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 [3]. Furthermore, as the perceived benefits differ across stakeholders, comparisons of benefits across projects become 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 [4]. 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.

1.3. Objective

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 [8]. 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 [11,12]. 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. For the purposes of this objective, the "business case" would contain quantifiable proof of the benefits that BIM has provided on projects. Potential future benefits and investments regarding entire organizational implementation, rather than project implementation, cannot be measured prior to acceptance. The business case is therefore value-based and for organizations seeking quantification of the results of BIM, likely at a preliminary BIM Maturity Level as discussed in Section 1.2.

The objective of this paper was to empirically measure data from Non-BIM and BIM projects to determine if the utilization of BIM can be beneficial in construction projects. Furthermore, it was the goal of this paper to provide case studies of BIM benefits via an examination of Non-BIM versus BIM projects at a particular organization. As highlighted by Succar [8], 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 consistently accurate and adaptable to different industry sectors and organizational sizes.

1.4. Research methodology summary

Prior research methodologies found in the review of past literature were: case studies, surveys, interviews, and individual analyses

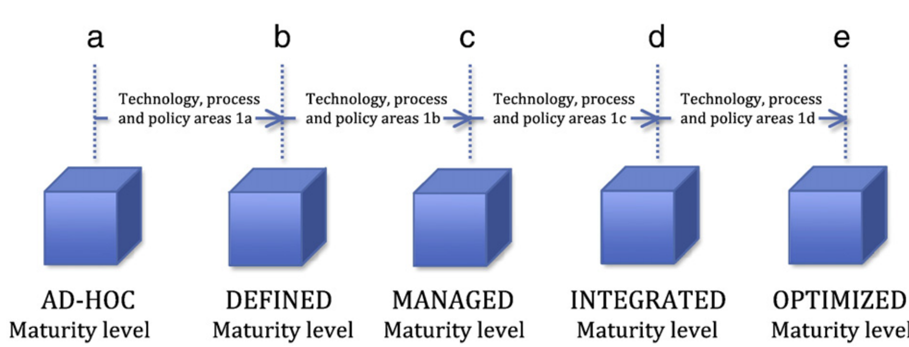

Fig. 1. BIM maturity levels at Stage 1 [8].

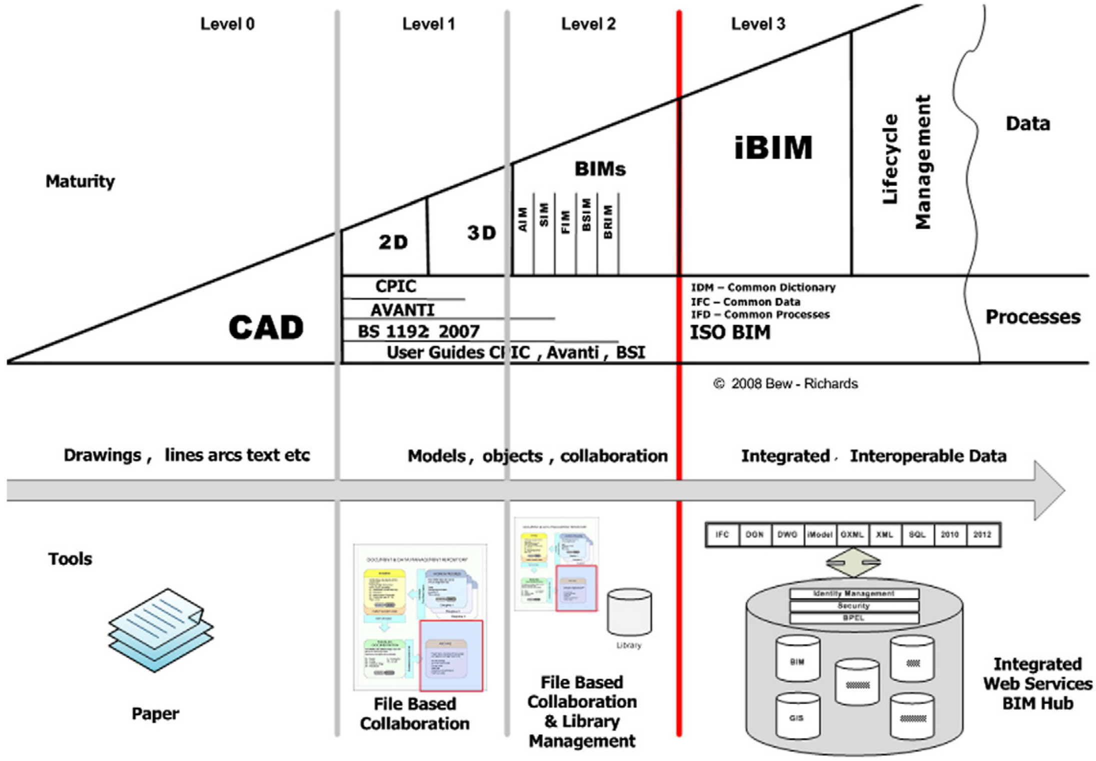

Fig. 2. BIM maturity map [9].

and theories. According to Bakis et al. [13], 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. 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 and should not use these as the only source of information [13]. Another commonly used method is for an individual to assign a weight

Tabular BIM Capability Maturity Model 5/30/2006

Maturity Level	A Data Richness	B Life-cycle Views	C Roles Or Disciplines	ITIL Maturity Assessment	D Business process	F Timeliness/ Response	E Delivery Method	H Graphical Information	I Spatial Capability	J Information Accuracy	K Interoperability / IFC Support
1	Basic Core Data	No Complete Project Phase	No Single Role Fully Supported	No ITIL Implementation	Separate Processes Not	Most Response Info manually re-	Single Point Access No IA	Primarily Text - No Technical Graphics	Not Spatially Located	No Ground Truth	No Interoperability
2	Expanded Data Set	Planning & Design	Only One Role Supported	Initiation	Few Bus Processes Collect Info	Most Response Info manually re-	Single Point Access w/ Limited IA	2D Non-Intelligent As Designed	Basic Spatial Location	Initial Ground Truth	Forced Interoperability
3	Enhanced Data Set	Add Construction/ Supply	Two Roles Partially Supported	Limited Awareness	Some Bus Process Collect Info	Data Calls Not In BIM But Most Other Data Is	Network Access w/ Basic IA	NCS 2D Non-Intelligent As Designed	Spatially Located	Limited Ground Truth - Int Spaces	Limited Interoperability
4	Data Plus Some Information	Includes Construction/ Supply	Two Roles Fully Supported	Full Awareness	Most Bus Processes Collect Info	Limited Response Info Available In	Network Access w/ Full IA	NCS 2D Intelligent As Designed	Located w/ Limited Info Sharing	Full Ground Truth - Int Spaces	Limited Info Transfers Between COTS
5	Data Plus Expanded Information	Includes Constr/Supply & Fabrication	Partial Plan, Design&Constr Supported	Limited Control	All Business Process(BP) Collect Info	Most Response Info Available In	Limited Web Enabled Services	NCS 2D Intelligent As-Builts	Spatially located w/Metadata	Limited Ground Truth - Int & Ext	Most Info Transfers Between COTS
6	Data w/Limited Authoritative Information	Add Limited Operations & Warranty	Plan, Design & Construction Supported	Full Control	Few BP Collect & Maintain Info	All Response Info Available In BIM	Full Web Enabled Services	NCS 2D Intelligent And Current	Spatially located w/Full Info Share	Full Ground Truth - Int And Ext	Full Info Transfers Between COTS
7	Data w/ Mostly Authoritative Information	Includes Operations & Warranty	Partial Ops & Sustainment Supported	Limited Integration	Some BP Collect & Maintain Info	All Response Info From BIM & Timely	Full Web Enabled Services	3D - Intelligent Graphics	Part of a limited GIS	Limited Comp Areas & Ground	Limited Info Uses IFC's For Interoperability
8	Completely Authoritative Information	Add Financial	Operations & Sustainment Supported	Full Integration	All BP Collect & Maintain Info	Limited Real Time Access From BIM	Web Enabled Services - Secure	3D - Current And Intelligent	Part of a more complete GIS	Full Computed Areas &	Expanded Info Uses IFC's For Interoperability
9	Limited Knowledge Management	Full Facility Life-cycle Collection	All Facility Life-Cycle Roles Supported	Limited Optimization	Some BP Collect&Maint In Real Time	Full Real Time Access From BIM	Netcentric SOA Based CAC	4D - Add Time	Integrated into a complete GIS	Comp GT w/Limited Metrics	Most Info Uses IFC's For Interoperability
10	Full Knowledge Management	Supports External Efforts	Internal and External Roles Supported	Full Optimization	All BP Collect&Maint In Real Time	Real Time Access w/ Live Feeds	Netcentric SOA Role Based CAC	nD - Time & Cost	Integrated into GIS w/ Full Info Flow	Computed Ground Truth w/Full	All Info Uses IFC's For Interoperability

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Fig. 3. BIM maturity matrix [10].

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 [13]. The subjectivity of methods to assign value to BIM, from interviews to surveys, makes quantification and comparisons of benefits across projects ineffectual. This paper sought to present data in the least-subjective and most quantifiable context. The research for this paper 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 Non-BIM versus BIM projects and results.

2. Materials and methods

2.1. Literature review

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; and 3) assisting in the further development and insight into an applicable benefits framework model to be applied to the case studies in this paper 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. Overall, the highest frequency of source type was journal article, with the most classifications of "case studies and quantifiable findings" and "theories and general assumptions." Please see Table 1 — Literature review — sources below for more details.

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. Please see Table 2 — Literature review — summary of top four sources below for these sources and the data they presented.

Upon further examination of 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 Non-BIM vs. BIM methods to extract benefits. The data was mostly taken from the contractors' perspective, lacking owner input. 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 #01, it was discovered through communications that the past project team members disagreed with the findings presented. Source #02, while it provided some quantifiable findings, was taken from a company newsletter, thus the source credibility can be in question. In Source #03, the data was based on a narrow scope and a smaller project, making it difficult to generalize the findings. Source #04 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'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 [4,28]. Unfortunately, in FMI and CMAA's [5] 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." Furthermore, there is neither a consistent approach within individual organizations nor a consistent approach across organizations to evaluate BIM or similar information systems' benefits [20,28]. 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 [5]. The need for a proper business case, consisting of a framework methodology and baseline, to evaluate the benefits of BIM has gone unmet.

2.2. Common 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"

Table 1
Literature review — sources.

Source #	Reference	Type	Classification
01	Garrett and Garside (2003) [14]	Journal article	Case study and quantifiable findings
02	Cannistrato (2009) [15]	Press release	Case study and quantifiable findings
03	Khanzode et al. (2008) [16]	Journal article	Case study and quantifiable findings
04	Kuprenas and Mock (2009) [17]	Conference proceedings	Case study and quantifiable findings
05	Koo and Fischer (2000) [18]	Journal article	Case study
06	Tillotson et al. (2002) [19]	Journal article	Case study
07	Woo et al. (2010) [6]	Conference proceedings	Case study
08	Aranda-Mena et al. (2008) [1]	Conference proceedings	Case study and model or process
09	Andresen et al. (2000) [20]	Journal article	Model or process
10	Bakis et al. (2006) [13]	Journal article	Model or process
11	Autodesk (2007) [21]	Internet article, report	Model or process
12	El-Mashaleh et al. (2006) [22]	Journal article	Survey
13	Zuppa et al. (2009) [3]	Conference proceedings	Survey
14	Becerik-Gerber and Rice (2010) [4]	Survey and internet article	Survey
15	FMI/CMAA (2007) [5]	Survey/report/press release	Survey
16	McGraw Hill (2009) [2]	Report	Survey and case studies
17	Becerik (2006) [23]	Report	Theory and general assumptions
18	Krigsvoll (2008) [24]	Conference proceedings	Theory and general assumptions
19	Suermann and Issa (2008) [25]	Journal article	Theory and general assumptions
20	Gil et al. (2005) [26]	Conference proceedings	Theory and general assumptions
21	Homayouni et al. (2010) [27]	Conference proceedings	Theory and general assumptions

Table 2
Literature review — summary of top four sources.

Source #	Data
01	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 $2 M Physical conflicts (clash reports) saved $0.75 M Schedule conflicts (scheduling interface) $1.2 M Data conflicts (attribute management) $0.5 M
02	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)
03	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 $9 M savings in cost for the overall project.
04	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

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, but inconsistently used across case studies [29]. 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 [29–31], but is based on a subjective, observable quantity.

According to Cox et al. [33], KPIs are compilations of data measures used to assess the performance of a construction operation or a particular task. Examples of qualitative KPI suggested by the literature are: safety, turnover, absenteeism, and motivation [29,33,34]. 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 [29,33,34]. Zuppa et al. [3] assert that, “The main success measures of construction projects are cost, schedule, quality, productivity, and safety.” Others see quality control, on-time completion, cost, safety, dollars/unit performed, and units per man hour [25]. Cox et al. [33] identifies that current models fail to recognize which indicators will accurately portray the changes in performance. This paper 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. To this end, a key list was compiled of

Table 3
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 %

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, RFIs, and project or pilot cost. Please see Table 3 — Literature review — top mentioned benefits below for complete information.

3. Research methodology

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. Please see Fig. 4 — Framework development for this paper below. In the development of this paper, 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 Non-BIM versus BIM 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.

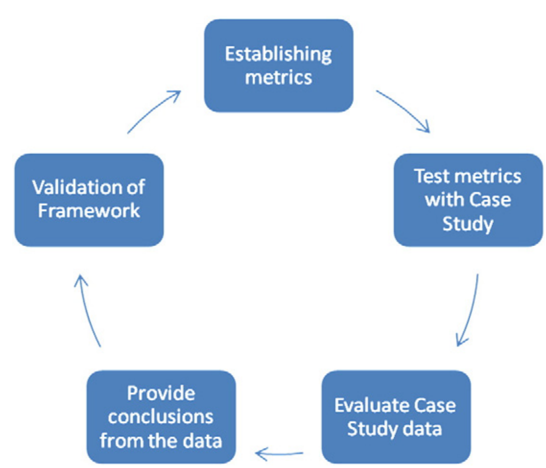

Fig. 4. Framework development for this paper.

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 [1,5].

3.1. Challenges

FMI Management Consulting and the Construction Management Association of America's (CMAA) [5] eighth annual survey of owners 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 [11]. 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 [23]. 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. 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 [11,20]. 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.

3.2. Measurement strategies for this research

The framework methodology is in line with the problem statement of this paper, to fill the void of a balanced framework for BIM implementation that considers both monetary and managerial outcomes. General IT measurement processes were also taken as inspiration in this paper [11,20]. Please see Fig. 5 — Process of measuring IT benefits [20] below. For this paper; however, a value-based framework is proposed in which monetary outcomes are analyzed.

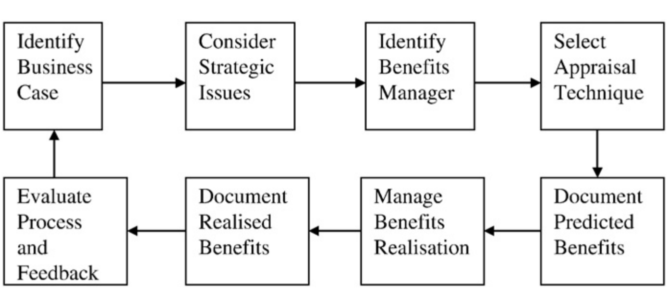

Fig. 5. Process of measuring IT benefits [20].

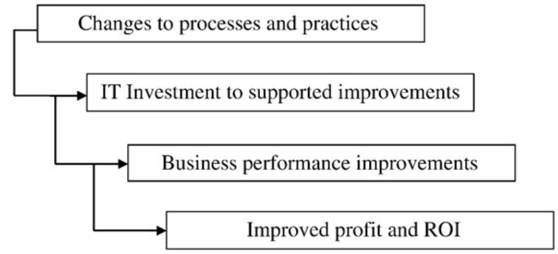

Fig. 6. Business case of an information system [13].

Furthermore, organizational factors needed to be taken under consideration and BIM's resultant impact analyzed. A complete “business case” would appropriately take into consideration executive, communication, risk management/strategic planning, and change management factors. For brevity, managerial requirements and outcomes were not analyzed in this paper, but have been discussed by other sources [13,20,35]. Please see Fig. 6 — Business case of an information system [13] below for more detail.

For the monetary side of the framework, both current and historical project data was utilized for the Non-BIM and BIM data sets from the case studies. Data was analyzed and percentages computed by comparing Non-BIM to BIM 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. 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.

3.3. Scope of this paper

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 300 mm fab environment [36]. 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 [37].

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. [26] assert, “Four main factors contribute to the challenges in managing fab projects: complex designs, speed, reducing costs, and frequent but hard to anticipate changes.” 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 [14], 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.” 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 [26]. 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. According to the BIM Maturity levels, discussed in Section 1.2, Company 1 can be described as at stage one (object-based modeling) [8] or level 1 [9,10], and (or a combination of these) during the time of this paper, due to their evolving understanding of BIM and formation of a business case.

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 [26]. These three functional areas cannot be specifically named due to confidentiality, but were selected for their BIM utilization and represent the most complex tool installations. Gil et al. [26], note that certain design characteristics make a particular functional area more stringent, thus they are indicative of the most “difficult” case. The case studies at Company 1 provided this paper with an opportunity to properly examine the benefits of BIM utilization garnered by a large owner, under multiple projects. By comparing multiple projects in the same environment, the case studies have the advantage of a more stable environment in which external factors, such as fluctuations in the setting and complexity, can be held relatively constant.

4. Data collection

Company 1 decided to first employ BIM strategies 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 paper. Additionally, the objective of this paper requires that both Non-BIM and BIM 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 – based on two Non-BIM historical projects and two BIM 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 BIM investments.
- Case 2 – investments – based on a current project that is utilizing both Non-BIM and BIM in the same three functional areas. This Case provides a baseline for the BIM design and construction investments portion.
- Case 3 – returns and investments – a study on one particular functional area, based on two historical Non-BIM projects, two historical BIM projects, and the current Non-BIM and BIM project. The data were compared as total Non-BIM vs. total BIM metrics. This Case provides a baseline for both investments and returns.

4.1. Metrics

A proper benefits analysis, in line with the objective of this paper 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. The return metrics are in accordance with the objective of this paper to create a value-based quantification of BIM benefits. These were quantified from a comparison of Non-BIM projects to BIM projects. Values were reported with respect to Non-BIM projects, BIM 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 to comply with agreements on confidentiality. Please see Table 4 — Return metrics below.

The costs for the BIM design investment category are best separated out into two distinct sub-categories: Architectural and Engineering (A&E) costs and 3D background model creator costs. The A&E costs were based on the costs incurred as a result of the BIM design of the three specific functional areas. They were a summation of the items: design, assembly non-variable costs, and an allowance for the BIM 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 BIM design. Thus, the 3D background model creator costs are higher as they are applicable to the entire factory, not just those three receiving BIM 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 saving. The 3D background model investment also serves as an indication of the potential investment that an organization would have to take if it were to implement BIM beyond a project-by-project basis.

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 Non-BIM and BIM design packages. The metric “3D background model creator costs” represents how much of the total factory design costs are represented by the BIM tools. The metric “contractor costs” represents the cost if these areas were Non-BIM versus cost if these areas used BIM, and reveals that contractors would provide savings if these areas utilized BIM. The metric “overall savings with BIM scope awarded” represents the addition of the costs of design and savings of construction in these areas utilizing BIM. Please see Table 5 — Investment metrics below.

Table 4
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	%

Table 5
Investment metrics.

Metric	Calculation	Unit
Design cost		
A&E costs	BIM cost of A&E services / cost of total design Non-BIM and BIM scope awarded	$/$ = %
3D background model creator costs	BIM cost of 3D background model creation / cost of total design Non-BIM and BIM scope awarded	$/$ = %
Construction cost		
Contractor costs	BIM contractor costs / cost of total construction Non-BIM and BIM scope awarded	$/$ = %
Design + construction costs		
Overall savings with BIM in design and construction	BIM design cost + BIM construction cost / cost of total construction Non-BIM and BIM scope awarded + cost of total design Non-BIM and BIM scope awarded	$/$ = %

4.2. 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 due to confidentiality.

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, dollar values could not be reported in this paper. Instead, Company 1 allowed the reporting of ratios or comparisons of costs to derive percentage values.

5. Results

5.1. 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 BIM projects. For complete data, please see Table 6 — Case 1 — returns from Non-BIM to BIM below.

5.2. Case 2: design and construction investments

Case 2 was established to illustrate the investments or cost of BIM on a current project. The data shows that costs are incurred due to BIM Design and a savings is experienced due to BIM 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 Non-BIM (standard). The second format was the cost of three identified functional areas to be performed in BIM. Upon comparing the Non-BIM bids for the three functional areas with the BIM bids for the same three functional areas, they revealed that the contractor would pass down a savings of 5% to the owner with the utilization of BIM in key areas. For complete Case 2 data please see Table 7 — Case 2 — investments from Non-BIM to BIM below.

5.3. 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. The name of the functional area cannot be disclosed; however, 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 BIM 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 8 — Case 3 — returns from Non-BIM to BIM 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.

Using the same metrics as Case 2, the returns of Case 3 were calculated and can be seen in Table 9 — Case 3 — investments from Non-BIM to BIM 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.

5.4. 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

Table 6
Case 1 — returns from Non-BIM to BIM.

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

Table 7
Case 2 — investments from Non-BIM to BIM.

Metric	Unit	Differential (Non-BIM vs. BIM)
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 BIM in design and construction	% total awarded design and construction scope	(−2%) (savings)

Table 8
Case 3 — returns from Non-BIM to BIM.

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

Table 10
PM interviews.

Category	Increased	Decreased	Stayed the same
Contractor accountability	38%	62%	–
Contractor verification	50%	50%	–
Software/hardware costs	50%	50%	–
Learning curve	38%	24%	38%
Coordination meeting attendance	100%	–	–

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. Project Managers conveyed their perception, for example, of the degree to which they witnessed an increase (or decrease) in contractors' level of accountability. 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 10 — PM interviews below for more information.

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.

6. Discussion

6.1. Limitations: literature

As evidenced by Table 3 — Literature review — top mentioned benefits, 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 [14] presented a case study and findings similar to the case studies in this paper; however, with very different project scope, methodologies, visibility, and quantification. Koo and Fischer [18] 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. Tillotson et al. [19] found generic benefits of intelligent BIM 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 [19]. These variables and missing calculation methodologies are barriers to comparing data presented by these sources with other case studies. 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 paper. 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 Table 1 — Literature review — sources, numbers 17–21.

6.2. 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 Table 11 — Future BIM tracking metrics below 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,

Table 9
Case 3 — investments from Non-BIM to BIM.

Metric	Unit	Differential (Non-BIM vs. BIM)
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 BIM in design and construction	% of total awarded design and construction scope	(−1%) (savings)

Table 11
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 Non-BIM vs. BIM	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

the business case presented here is predicated on benefits that are quantifiable and realized by the owner.

7. Conclusions

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.

This paper provided 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.

At Company 1, calculated returns were: change orders saw a savings of 42% of standard costs in Case 1, RFIs decreased 50% per tool or assembly, and duration reduction was a savings of 67% based off the standard duration. In Case 2, calculated investments were: 31% increase in design costs due to A&E costs, 34% increase in design costs due to 3D background model creation, and a contractor savings of 5% of contractor costs. When totaled in dollar value and percentages computed investments in both design and construction resulted in a savings of 2% 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 Studies 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 paper is consistent in a stable environment, 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 metrics is essential for a proper analysis of BIM 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 Table 11 — Future BIM tracking metrics.

7.1. Recommendations

As stated by Chasey and Merchant [36], "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." 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. [26], "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." 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. [26] 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." 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 BIM 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 paper 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.

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 [9,14]. 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. Additionally, once BIM reaches new levels of maturity, the investments and returns should be calculated and compared to those at previously lower levels.

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. Sources [24,27,32] provide many insights into the other dimensions of BIM and their possible implications on the investments and returns of BIM projects. Furthermore, some suggest that a more formal review and certification system of BIM could lead to increased adoption. As Succar [8] 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." Organizational and project management functions will be affected by the implementation of BIM and they should be analyzed [35]. Jung and Gibson [38] suggest "corporate strategy, management, computer systems, and information technology as the four main concerns of IS [information systems]." Furthermore, Taylor [12] suggests "social and organizational contexts need to be taken into consideration to understand the adoption of this BIM technology." There is a large need for managerial effectiveness as an antecedent of BIM success [11]. The benefits framework established by this paper can be further developed as BIM reaches new dimensions and is implemented in entire organizations. However, the literature, to date, does not provide quantifiable metric suggestions or 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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