Trends of Assessing BIM Implementation in Construction Research

Hamid Abdirad, M.Sc.[1] and Pardis Pishdad-Bozorgi, Ph.D.[2]

[1] Graduate Teaching Assistant, School of Building Construction, Georgia Institute of Technology, Atlanta, Georgia; Email: habdirad@gatech.edu
[2] Assistant Professor, School of Building Construction, Georgia Institute of Technology, Atlanta, Georgia; Email: pardis.pishdad@coa.gatech.edu

ABSTRACT

Building Information Modeling (BIM) is one of the most significant current discussions in AEC industry. Number of research on different aspects of BIM has been increased to show how this groundbreaking approach has impacted the industry. One widely used method to research on BIM is developing and measuring metrics to assess BIM implementation. This research investigates metrics developed in peer-reviewed papers to find trends and gaps in BIM implementation assessment. This paper presents a method for developing a comprehensive framework of metrics to be used throughout the industry and academia to measure BIM implementation aspects and goals. By reviewing ASCE database, this paper shows that most research has focused on BIM outcomes, and therefore, there is an extensive gap in research on BIM Input and BIM Process Assessment (e.g. evaluating human-technology interactions, collaboration, modeling performance, etc.).

INTRODUCTION

Building Information Modeling (BIM) is one of the most significant discussions in AEC industry. BIM provides a machine readable digital representation of building data in order to improve design, construction, and operation processes, and enhances building lifecycle functions (Aouad, Wu, and Lee 2011; Eastman, Teicholz and Sacks 2011). Assessing these improvements has been the subject of attention in both industry and academia for decision making and developments. According to McGraw-Hill Construction (2012), level of BIM adoption has been growing significantly within the industry. Similarly, the number of research on different aspects of BIM has been increased to investigate how this groundbreaking approach has impacted projects within the industry. One widely used method to research on BIM is developing and measuring metrics to assess BIM implementation and its impacts. This is not surprising because as the management literature states, if you cannot measure something, then you cannot control, manage, and improve it (Garvin 1993; Martin Petty, and Wallace 2009). According to the literature, different approaches for measuring BIM implementation have been used in the research for different reasons. For example, some scholars assessed BIM impacts on project outcomes to compare BIM vs. non-BIM projects (e.g. Barlish and Sullivan 2012; Chelson 2010; Coates et al. 2010). Some researchers focused on measuring BIM financial benefits and ROI (e.g. McGraw-Hill Construction 2009). Some scholars measured BIM to determine the maturity and capacity of BIM adoption (e.g. Sebastian and van Berlo 2010). Few researchers tried to develop proactive metrics for assessing BIM processing (e.g. Manzione, Wyse, Sacks, Van Berlo, and Melhado 2011; Senescu, Haymaker, Meza, and Fischer 2013). However, so far, no single study has comprehensively investigated trends of research on assessing BIM implementation. Such a study would be beneficial in finding gaps within the research, and providing directions for further in-depth studies on BIM performance assessment. Therefore, the objectives of this review paper are to investigate trends of developing metrics and assessing BIM within research and to demonstrate gaps in the research on BIM assessment. Furthermore, for the first time, it intends to show a method for developing a comprehensive framework of metrics to measure BIM aspects and goals. Parts of such a framework will be presented in this paper.

LITERATURE REVIEW

Grounds for Assessing BIM - BIM Aspects. Deutsch (2011) described that BIM is often perceived “as a business process supported by technology or as a technological phenomenon resulting in business outcomes.” Eastman et al. (2011) confirm that one aspect of BIM is its “Technological” aspect as a tool which supports building design processes and aims to construct virtual models of a building. Another aspect of BIM is the “Model” aspect (BIM product), which supports building realization and operation (Eastman et al. 2011). In this aspect, quality of information is critical to prevent unpredictable issues in projects (Crotty 2012). On one hand, poor-quality model negatively impacts design integration, procurement process, and construction realization and management (Crotty 2012); on the other hand, it impacts building functions and performance during its operation. Lastly, Deutsch (2011) points out the “Human” aspect of BIM and indicates that even though human issues are most important challenges to widespread adoption and well implementation of BIM, they are underrated in research on BIM. Eastman et al. (2011) indicate that collaboration among different parties and disciplines are keys to effective use of BIM. Expertise in operating software must coincide with collaboration for well exploiting BIM. Furthermore, BIM is implemented by people, who are error-prone and imperfect by their nature and may be inadequate in their communication, collaboration, training, and skills. On the other hand, human-computer interaction also exists in form of inserting, extracting, updating, modifying, and observing models and information (Deutsch 2011). Therefore, many factors within human aspects of BIM should be considered in BIM implementation.

BIM Goals and Objectives. Another basis for assessing BIM implementation is evaluating improvements in aforementioned BIM aspects. According to Smith and Tardif (2009), construction industry suffers from several challenges, including very low productivity, high energy and operation cost impact, and huge waste in construction. Eastman et al. (2011) describe how BIM can mitigate such challenges and how different parties can benefit from BIM. Reddy (2011) in a same way categorizes BIM’s objectives based on project parties and different disciplines of practices. From an owner's perspective, BIM helps to increase building performance, reduce financial risks, shorten a project schedule, obtain reliable and accurate cost estimates, and optimize facility management and maintenance. From an architect's perspective, BIM improves building design, analysis, simulation, and checking and therefore, it provides a basis to develop a better conceptual design, consistent construction documentations, and integration and communication among disciplines. From a contractor's perspective, constructability analysis and clash detection, quantity takeoff and cost estimation, construction planning and controlling, offsite fabrication, and facilitated handover are the BIM applications (Eastman et al. 2011).

Approaches to measure performance. Project performance is usually measured by metrics/key performance indicators (KPIs). By using metrics and KPIs "an organization can determine whether the outcome associated with a capability exists or the degree to which it exists" (Project Management Institute 2003, p. 15). By measuring metrics regularly throughout a project, metrics can reflect required actions and responsibilities of team members (Constructing Excellence 2006; Parmenter 2010). Metrics can be used for measuring both tangible and intangible criteria (Kerzner 2011). For some metrics, evaluation would be in form of quantitative metrics, while for some metrics, qualitative expert judgment would be considered (Project Management Institute 2003). Parmenter (2010) described that metrics and KPIs can reflect "past, current and future performance measures." According to Doppelt (2010 p. 5), "Lag indicators measure the effects of past activities, while lead indicators measure current activities that may eventually affect future results." Lag Indicators measure results and "do not have predictive power for future." Lead indicators measure progress of processes and can be used to predict future progress and performance (Barrett 2013). Kenett and Baker (2010) introduced "real-time indicators" for measuring current performance status within projects. A performance measurement system must cover all types of indicators for being helpful at different levels of an organization (Doppelt 2010; Kaplan 2010). Focusing on lag indicators cannot demonstrate processes and underlying reasons of performance outcomes (Niven 2011). Abdirad et al. (2012) described these concepts in risk management context by making distinction among risk sources, risk events, and risk impacts. Measuring lead indicators helps to identify risk sources early in the processes. Therefore assessing lead and real-time indicators improves the ability to perform better in risk prevention/mitigation.

BIM assessment. According to Smith and Tardif (2009), defining metrics to assess BIM implementation is challenging due to variety of business relationships, enterprise workflow, project delivery methods, and design processes. They encourage researchers to develop different qualitative or quantitative metrics and link them to BIM objectives and goals. In this regard, Reddy (2011) describes the concept of "Gap Analysis" for BIM, which focuses on People, Process, and Platform. As Kymmell (2008) states and authors discussed in previous sections, "deliverables" are also important aspects of BIM and should be considered in the assessment. Abdirad and Pishdad-Bozorgi (2014) also emphasized on BIM assessment in integrated project delivery systems, as it can identify bottlenecks in communication and collaboration, which are critical success factors in AEC integration.

RESEARCH METHODOLOGY

This paper first develops a conceptual framework of BIM assessment based on BIM aspects, BIM goals, and types of metrics in order to use it for investigating trends of BIM assessment in construction research (

Figure **1**). The framework suggests to identify and categorize metrics based on: (1) what aspect of BIM is being assessed? (2) What BIM purpose (goal) is being assessed? And (3) what type of metric (Lead/Lag/Real-time) is developed for the assessment? In order to improve the concept of Framework 1, authors add "a whole project/constructed facility" and "BIM in industry" in BIM Aspects, because as stated in the Introduction section, some researchers assess BIM implementation to compare projects within an organization or within the industry. Similarly "improvement in a whole business" and "improvement in the industry" are added to BIM purposes. In the second step, the authors review prior research, based on the concepts of Framework 1, in order to study approaches of BIM assessment within the literature. In this regard, peer-reviewed papers within ASCE database were considered as the data sources. The authors searched two words, "BIM" and "METRIC." ASCE search engine presented 155 results (by Dec 2013). After reviewing these papers, 41 valid papers were identified and filtered. By extracting metrics from the valid papers and analyzing them, Framework 2 (

Figure **2**) was developed, and by using statistical analysis the authors investigated current trends and gaps in construction research.

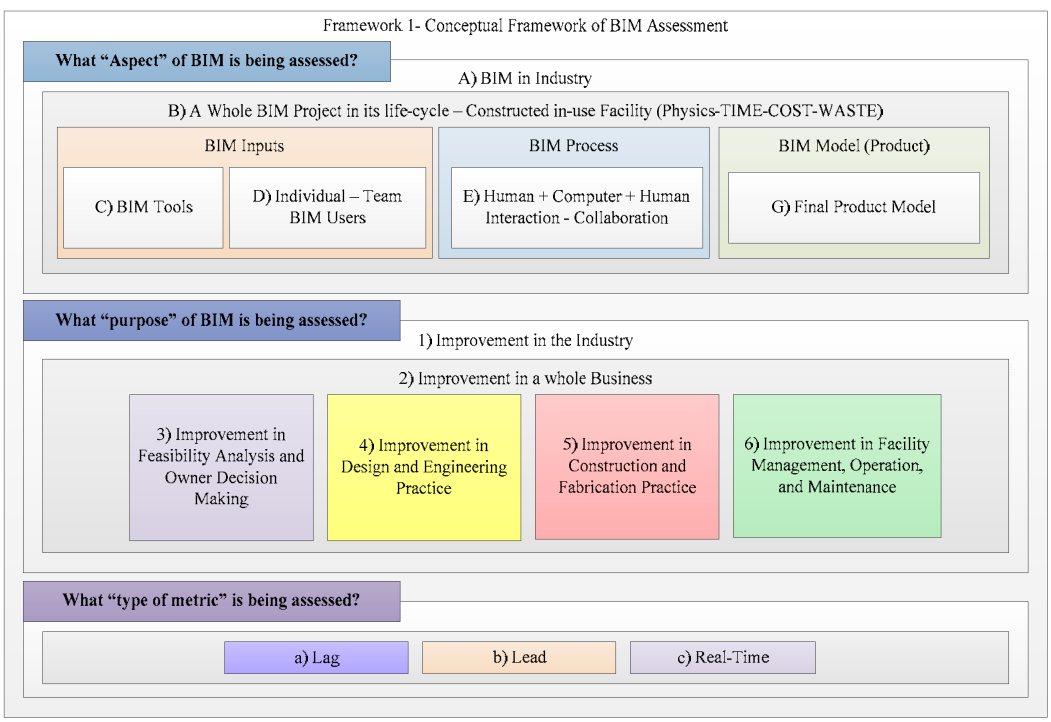


Figure 1. Conceptual Framework of investigating BIM assessment trends

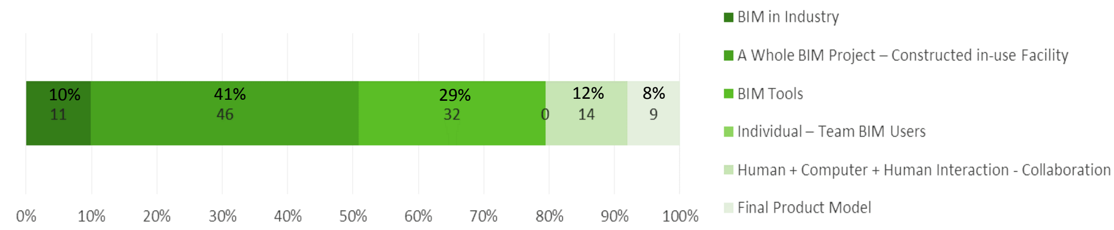
KEY FINDINGS

Basic statistical analysis on the Framework 2 shows that 112 metrics were developed in the peer-reviewed papers. Most of the metrics investigated "A whole BIM project-Constructed Facility" (41%) and "BIM in the industry" (10%) for completed projects. In regard to BIM inputs, no metric was developed for assessing individual-team BIM users. Interestingly, 29% of developed metrics measured BIM tools; however, most of the measured tools contribute to image recognition and scan of under-construction or constructed facilities (accuracy of tools/software, level of detail, etc.) (Figure 3). From the standpoint of "BIM processing," 12% of metrics focused on human-computer-human interactions. About 8% of metrics assessed final BIM model from the standpoints of its accuracy and fitness for purpose. From the BIM purpose standpoints, 65% of metrics measured improvements in construction and fabrication phase. About 12% of metrics investigated the improvements in business at organizational level and 9 % of metrics measured it at the industry level. No metric was found to measure impacts of BIM in Feasibility analysis and decision making phases and only 2% of metrics measured improvements related to facility management (Figure 3). About 17% of metrics were considered as Lead and Real-time indicators and about 83 percent of metrics were used as Lag Indicators.

Parts of Framework 2- Framework of Metrics

Reference	Metrics	Why Used?	Aspect of BIM	Purpose of BIM	Type of Metric
Clevenger and Khan (2013)	Material Waste	Show impacts of design to fabrication BIM on a project.	B	5	a
	# RFIs in Rebar detailing/install		E	5	a
	Schedule Change: Rebar detailing/Install		B	5	a
	Cost change of rebar detailing/ install		B	5	a
Bae, Golparvar-Fard, and White (2013)	Accuracy of the localization method	Using photographs for localization in an augmented reality format.	C	5	a
	Speed of using a 3D point-cloud model		C	5	a
Eybpoosh, Akinci, and Bergés (2012)	# Deviating Components for each Type of Deviation	Comparisons between Point Clouds and Building Information Models	B	5	a-b
	Distance between points in a scanned data and their pairs in BIM		B	5	a-b
Senescu, Haymaker, Meza, and Fischer (2013)	Frequency of value-adding information transfer between designers	Assess Design Process Communication	E	4	a-b
	Number of statements about design trends.		E	4	a-b
	Number of complete and accurate design options.		E	4	a-b
	Number of expressions of confusion.		E	4	a-b

Figure 2. Parts of Framework 2- Framework of Metrics



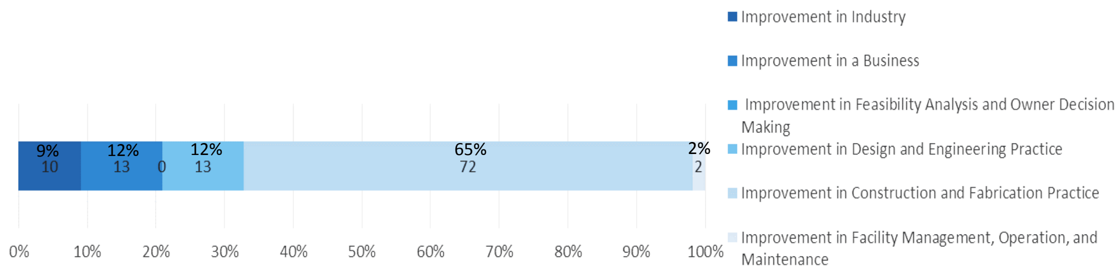


Figure 3. Number and Percentage of the Metrics that measured each of BIM Aspects and BIM Purposes

DISCUSSION AND CONCLUSION

By a comprehensive review and analysis of the peer-reviewed publications within ASCE database, this paper investigated trends of assessing BIM implementation within academia. According to the findings, most research has focused on measuring "A whole project – constructed facility", which is an "After BIM" assessment approach. Such an assessment only reflects achievements of BIM in form of final project duration, cost, and waste, and does not reflect improvable areas/risks within an in-progress project (processes and inputs). This shows that involvement of academic researchers in early stages of BIM adoption and BIM processes is very limited and only BIM outcomes are reported. Therefore, there is an extensive gap in research on Real-time BIM Assessment (e.g. BIM Processing: human-technology interactions and bottlenecks, human collaboration, modeling performance), and BIM Inputs Assessment (e.g. assessing individual and team users of BIM). Moreover, assessing improvements of BIM implementation in pre-construction stages (e.g. feasibility analysis and design development) and post-construction stages (e.g. facility operation and management) is also underrated in the literature. Metrics should be developed to assess different BIM aspects (Tools, Users, Interactions, and Models) in order to make improvements in early design and decision-making processes, and also in facility operations and management. Such trends in prior research reflect that the researchers mostly intended to demonstrate benefits of BIM adoption and improvements in BIM projects vs. non-BIM projects. This research demonstrates that future research on BIM would seek more efficient BIM implementation (BIM projects vs. BIM projects) in form of high-performance tools, users, interactions, and processes.

To present limitations of this research, the authors indicate that although ASCE database is one of the major databases in this field, findings of this paper may not reflect trends of research within other research databases. Furthermore, due to page limits, only parts of the Framework 2 were presented to reflect the research method, and to depict future of a more comprehensive framework of metrics. For future research, according to the research method, a framework of metrics (or a model) can be developed to assess BIM project in Pre-BIM, Real-Time BIM, and After BIM stages and also for different disciplines of design, construction and fabrication, and facility management. Such a framework, would be a valuable tool to measure inputs, processes, and outputs, and improves BIM implementation processes. This paper is a part of an ongoing research. In future, authors will investigate other databases, organizational reports and white papers to study trends and gaps, and also to develop a finalized framework of BIM assessment.

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