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Building Information Modeling (BIM) Impact on Construction Performance

David D. John
Georgia Southern University

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BUILDING INFORMATION MODELING (BIM) IMPACT ON
CONSTRUCTION PERFORMANCE

by

DAVID DYLAN JOHN
(Under the Direction of Yunfeng (Cindy) Chen)

ABSTRACT

This study is designed to address the need for having a measure for Construction Performance on BIM-assisted construction projects. Through this study a new Construction Key Performance Indicator (CKPI) matrix is identified and created by the author. The CKPI could be used to assess BIM-assisted projects. Utilizing a sequential mixed methodology approach, academic and practitioner perspectives are assessed. A qualitative content analysis and quantitative descriptive analysis based on demographics are conducted to establish a better understanding of BIM and Construction Performance. The academic perspective is used to assess the relevance of BIMM and CKPI indicators, and the practitioner perspective is used to assess the extent to which BIM addresses the indicators. The key contributions of this study include the creation of the Construction Key Performance Indicator (CKPI) matrix and a preliminary recommendation for the creation of the BIM – Project Success Ratio (BIM-PSR) benchmark. The findings and recommendations of this study could be used by companies to help assess their current BIM adoption and identify if and how BIM should be adopted. The findings also identify existing areas of BIM infrastructure that need improvement for a more positive impact on construction performance. Academics could use the findings and recommendations to better structure courses for students and future research in BIM’s impact on Construction Performance.

INDEX WORDS: Building Information Modeling, BIM, Performance, Productivity, Construction, CKPI, BIM-PSR
BUILDING INFORMATION MODELING (BIM) IMPACT ON CONSTRUCTION PERFORMANCE

by

DAVID DYLAN JOHN

B.S., Georgia Southern University, 2016

A Thesis Submitted to the Graduate Faculty of Georgia Southern University in Partial Fulfillment of the Requirements for the Degree

MASTER OF SCIENCE

STATESBORO, GEORGIA
BUILDING INFORMATION MODELING (BIM) IMPACT ON CONSTRUCTION PERFORMANCE

by

DAVID DYLAN JOHN

Major Professor: Yunfeng (Cindy) Chen
Committee: Francisco Cubas Suazo
            Clinton D. Martin

Electronic Version Approved:
July 2018
DEDICATION

To

I dedicate this work to my Father (Dharshan John), a champion and role-model who sacrificed so much to ensure that I could pursue my Academic and professional dreams here in the United States of America. My Mother (Winifred John), who prayed each day for the favor of God to go with me and I know looks down upon me from heaven. And lastly, to all students who feel that they may not have within them the ability to persevere and complete a college degree, I dedicate this work to encourage you to stay focused till the end.
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CHAPTER 1

INTRODUCTION

1.1 Purpose of the Study

This study is put together in order to investigate Building Information Modeling (BIM) and its impact on Construction Performance. It is widely known that BIM is a growing trend in the construction industry with many researchers and practitioners attempting to gain a better understanding of its complex nature. This study will identify a BIM Maturity (BIMM) matrix and test it for academic and industry perspective. For the first time, this study will introduce a Construction Key Performance Indicator (CKPI) matrix and evaluate it for academic and industry perspective. This is done with the purpose of creating a case for a new Building Information Modeling Project Success Ratio (BIM-PSR) benchmark, to be used on BIM-assisted projects. Additionally, this study will assess how BIM is currently being utilized in industry to gain a better understanding on how BIM could be further improved to enhance productivity and performance in the practitioner’s perspective. A better understanding of BIM, construction performance, and how they interact would give insight to AEC / BIM professionals for further improvement of the BIM platform and process. For construction industry practitioners, this study is intended to equip them with the knowledge and information on where BIM has been successful in improving and increasing construction performance, while also highlighting areas that may not have seen as much success. This study will therefore give insight into the relationship between BIM and construction performance, allowing for future studies to explore the ways in which BIM could be used to enhance Construction Performance.
1.2 Research Questions

When investigating this topic, there are a few broad questions that have been kept in mind. It was imperative that during the preparation of questions, qualitative study interviews, quantitative data collection and data analysis – these questions were kept in mind in order to provide direction and focus to this study.

1. What are the key drivers for BIM adoption and implementation on a construction project?
2. What are the key areas for assessing Construction Performance?
3. Has the implementation and adoption of BIM improved productivity/performance on construction projects?

1.3 Scope of the Study

The scope of the study would be mainly focused on the Construction Industry in United States of America. The study will be conducted by interviewing and surveying AEC / BIM practitioners, AEC / BIM educators and other stakeholders of the construction industry to gain the best possible perspective on the current impact of BIM on construction performance. Foreign practitioners were included in the data collection. But, foreign practitioners are not included in the overall scope of this study. The scope of this thesis will be strictly confined to the following five components.

- What is construction performance and what factors/indicators are used to assess it
- Understanding BIM and Construction Performance from the Academic perspective
- Understanding BIM and Construction Performance from the Contractor perspective
- Understanding BIM and Construction Performance from AEC practitioner perspectives
1.4 Significance

BIM is being promoted as the ideal tool for collaboration in construction, and multiple studies investigate the need for increased understanding and efficiency of BIM in the technical and operational sense. This study is significant because it recognizes the importance of technical and operational value in the construction industry through factors/indicators of construction performance. Larger companies may use their own project data and experiences to identify the impact that BIM has on construction performance (A.Jones, 2015), this study draws on data and information from a wider variety of stakeholders and project types allowing for a broader and more meaningful understanding of how BIM impacts construction performance. The approach of this study is with the intention of providing valuable insight and findings that can be used by companies of varying size and scale for improvement of their own BIM implementation plans. A better understanding of BIM from the practitioner perspective will also allow for expansion and better utilization of BIM to improve construction performance. Academics could use these findings to better prepare their education programs and make students aware of how to drive construction performance on a construction project with the effective use of BIM.

1.5 Assumptions

The following assumptions were inherent to the pursuit of this study:

1. The 3rd party preliminary study of data extracted from interviews conducted by students in a construction graphics course were accurate and honest responses.

2. Participants interviewed responded accurately and honestly during the entire interview process, based on their own background and experiences with BIM and construction performance.
3. Participants surveyed responded accurately and honestly during the entire survey process based on their own background and experiences with BIM and construction performance.

4. Participants used their liberty to acknowledge that they do not remember or have accurate information on the questions asked during interview or survey.

5. The participants selected for the qualitative component of the study are an accurate reflection of the industry perspectives on BIM and construction performance.

1.6 Limitations

The following limitations are inherent to the pursuit of this study:

1. The qualitative component of the study was limited to the participants who volunteered, cooperated and were willing to participate in the interview component of the study.

2. The quantitative component of the study is limited to the number of participants who responded to the survey that was deployed to practitioners.

3. The study is limited by the amount of data and insight that respondents are willing to share with the researchers.

4. The study was limited by potential misinterpretation of the questions asked during interviews and surveying.

5. The study is limited by the personal biases of the researcher
CHAPTER 2

LITERATURE REVIEW

2.1 Building Information Modeling (BIM)

Building Information Modeling (BIM) is causing a major paradigm shift in the AEC industry while creating wider and newer opportunities for young professionals (Uddin & Atul, 2014). While this creates a positive drive and focus in this industry, it is also important to fully understand what BIM encompasses. BIM is expansive in nature (Turk, 2016). Turk’s study discusses the structural, functional and behavioral attributes of BIM which indicate its complex nature. There are many definitions given for BIM, one definition represents it as the replacement of 2-dimensional (2D) drawings as an architectural design with a 3-dimensional (3D) model that is entangled with contextual, data-rich building components and elements (Latiffi, Brahim, Mohd, & Fathi, 2015). Hannele, describes BIM as an emerging modeling technology which challenges the existing working procedures (Hannele, Reijo, Sami, Tarja, & Jenni, 2015). Another definition describes BIM as the combination of technologies that are expected to increase inter-organizational and inter-disciplinary collaboration in the construction industry with the expectation of improving productivity and the quality of design, construction and maintenance of buildings (Reijo & Sami, 2014). Turk, also explains BIM as a tool of automation and integration that is evolving into a tool of further specialization (Turk, 2016). This view is further supported by the expanding career options in the AEC industry as a result of BIM (Uddin & Atul, 2014). Roles such as BIM managers, BIM coordinators and BIM specialists are becoming increasingly popular and sought after for BIM assisted construction projects. While all these definitions are accurate, one of the most comprehensive definitions state that BIM is a verb or adjective phrase
that describes tools, processes and technologies that are facilitated by digital machine readable
documentation about a building, its performance, its planning, its construction and later its
operation (Sacks, Koskela, Dave, & Owen, 2010). The complex nature of BIM can be seen in a
study that identified the motivations for adopting BIM were multi-dimensional in nature
(Dongping, Heng, Guangbin, & Ting, 2016). Therefore, a limited understanding of its capability
and resultant impacts, would mean that the industry would not be maximizing the benefits of BIM
and in some instances could harm the progress and expansion of BIM.

The pursuit to better understand and define BIM has prompted studies to establish a
standard for effectively measuring and understanding Building Information Modeling Maturity
(BIMM). Chen, explores BIMM and investigated the indicators and related factors that would
capture a more comprehensive understanding of BIM as it relates to its maturity (Y. Chen, Hazar,
F., Mark, & Mihaela, 2016). The study by Chen proposes that BIMM can be grouped under
Technology, Information, Process and People. Succar, identifies the factors proposed by Chen but
also includes Policy as a factor of BIM (Succar, Sher, & Williams, 2012). Therefore, literature
review indicated that the comprehensiveness of BIMM can be measured through Information,
Technology, Process, People and Policy Management. Chen, presented a table listing the
dimensions/factors and grouped indicators under the relevant dimensions as seen in Table 2.1.1
below.
Collaboration among project participants is important for aspects of Productivity. However, it seems that software interoperability has been a significant issue in the application of BIM (Bynum, Issa, & Olbina, 2013). A critical success factor for successful implementation of BIM, is the willingness of participants to share information (Won, Lee, Dossick, & Messner, 2013). It is clear that BIM can be used as an effective platform for collaboration by changing the way construction is performed and documented (James & Meadati, 2008). For collaboration in practice, a case study showed that there was an expectation for participants on BIM projects to drive collaboration, as opposed to have an expectation of a collaborative organizational structure (Dossick & Neff, 2010). These studies refer to BIM being a platform for collaboration and as a result a means of achieving productivity. However, the studies indicate a necessity to improve
elements such as software interoperability of BIM, while also improving leadership from the participants to share information and collaborate.

The understanding of BIM should extend beyond just industry to the college education framework. There is a need for a more structured and organized BIM education (Pikas, R, & O, 2013). The collaborated industry studies on BIM and a well-structured BIM education will help with improving and maximizing the benefits of BIM.

2.2 Performance / Productivity

Construction projects worldwide have been experiencing significant cost and time overruns, with low labor productivity making poor performance of the construction industry a cause of great concern among practitioners and Academics, making productivity in construction critical (A. V. Thomas & Sudhakumar, 2014). In support of this concern, a study performed by (Odesola, 2015) suggests that the higher the construction labor productivity, the lesser the cost and time overruns. Hammad, indicated that improving productivity in construction can lead to many benefits such as time saving, cost savings, increased competitiveness and profitability for the contractor (Hammad, Omran, & Pakir, 2011).

The significance of understanding productivity in construction can also be observed in a Singaporean study (Hwang, Zhao, & Ng, 2013), where the researchers aimed to find the critical factors affecting schedule performance in order to respond to the decision by the Singaporean Government to increase and improve productivity with the aim of reducing wait time for finishing public housing projects. Literature review revealed that as a situational response, the Australian Construction industry seemed to record an increase in labor productivity during tougher economic situations (Igor, Marko, & Nikola, 2014). A labor productivity study of trends in the United States, showed contradictory information on the different methods of assessing labor productivity and
maybe indicative of a need to establish a standard measure for productivity (Nasir, Ahmed, Haas, & Goodrum, 2014).

Productivity in construction is a hot topic for study around the world. A study done on construction productivity factors in Egypt, stated that productivity for construction can be divided into three primary categories: (1) Human/Labor, (2) Industrial and (3) Management, and the findings indicated that management ranked first followed by labor and industrial (El-Gohary & Aziz, 2014). Identifying studies that had a slightly different approach, a Singaporean study which dates back to 1995 identified the construction productivity factors to be (1) Man Power, (2) Management and (3) Environment (Lim & Jahidul, 1995) while a study on labor productivity in Kuwait used four primary categories: (1) Management, (2) Technological, (3) Human/Labor and (4) External (Jarkas & Bittar, 2012). A productivity model for benchmarking construction labor productivity, highlights four factors: (1) Project Controls, (2) Site Controls, (3) Management Controls and (4) Motivation (Randolph, 2015). Some of these studies approached productivity from a broader perspective, while others evaluate it solely from a labor productivity standpoint. Because of Construction Labor Productivity (CLP) importance to the profitability of most construction projects, a study in 2014 reviewed 129 CLP related papers (Yi & Chan, 2014). This is indicative of the interest and focus of construction industry related labor productivity. It is important to identify and understand the factors that influence productivity (Mojahed & Aghazadeh, 2008). The study by Mojahed & Aghazadeh was evidence from the deep south of the United States of America and highlighted (1) Skills and experience of workforce, (2) Management, (3) Job Planning, (4) Motivation and (5) Material availability as factors that influenced productivity in construction.
Literature relating to productivity have other approaches that do not necessarily co-relate with the productivity factors discussed through many of the previously listed studies. Instead some papers discuss productivity from the approach of production systems and productivity drivers. A paper that addresses construction industry productivity systems, highlights a matrix that includes (1) Standard production, (2) Lean production, (3) Location-based management and (4) Other as production system categories which are to be assessed at the industry, firm, project and activity levels (Kenley, 2014). While the matrix by Kenley presents a framework for productivity systems assessment, it seemed to lack the level of details as highlighted by studies that discuss productivity factors. A study on the Australia construction industry by Will Chancellor, present the drivers to productivity which includes (1) Apprentices, (2) Wages, (3) Research & Development, (4) Unionization and (5) Safety Regulation (Chancellor, 2015). Chancellor, draws attention to the drivers of productivity as opposed to factors that directly affect productivity in construction. This is an important perspective when attempting to understand the broadness of assessing and discussing productivity.

A study from the UK, discusses the extensive exchange of information required to track KPI’s (Rigby, Dewick, Courtney, & Gee, 2014). The study discussed the importance of linking economic incentives to the process of benchmarking. The United Kingdom KPI working group in 2000, proposed to the Minister of Construction the following indicators Time, Cost, Quality, Client Satisfaction, Change Orders, Business performance, Health and Safety (Group, 2000). In following years, the Key Performance Indicators have been categorized into Economic, Respect for people and Environment (Excellence, 2007). Key Performance Indicators (KPI’s) were often seen as the approach taken in order to measure and quantify construction productivity on a project. The indicators identified and discussed in literature seemed to fall under two main categories of
performance indicators. Result Oriented KPI’s and Process oriented KPI’s. Many studies also referred to these indicators and productivity attributes as Critical Success Factors (CSF’s). A publication on Construction Jobsite Management (Mincks & Johnston, 2003) discusses many aspects of construction performance including: Cost Goals, schedule goals, quality goals, customer satisfaction and also touches on process related indicators such as resource management and subcontractor management. Cox describes qualitative and quantitative performance indicators (Cox, Issa, & Ahrens, 2003). The indicators described by Cox, also cover result oriented indicators such as Cost Goals, schedule goals and quality goals. The process oriented indicator of resource management was discussed by Cox while highlighting the attributes of material and labor management. Other authors who highlighted result oriented performance indicators included (P. S. P. Wong & Cheung, 2005), (Gattorna & Walters, 1996) and (Ng, Rose, Mak, & Chen, 2002). All these studies highlighted cost, schedule and quality goals as key performance indicators in construction.

A study on web-based Construction Project Management systems (Nitithamyong & Skibniewski, 2006), identified performance indicators that could be grouped under both result oriented and process oriented indicators. The study identified and discussed attributes related to cost, schedule and quality performance but also seemed to address risk improvement by reducing the number of injuries from a result oriented lens. The aspect of safety and risk can also be viewed from the perspective of process oriented performance as it relates to establishing safety and risk management procedures. A 2008 publication by the Project Management Institute highlights performance indicators: schedule goals, communication management, procurement, resource risk management, quality management, human resource management, stake holder coordination and scope clarification (PMI, 2008). According to a study that evaluated the contractor perspective;
customer satisfaction, communication and improved decision making (Ng et al., 2002) are important performance indicators.

Utilization and implementation of BIM may present an opportunity to better monitor and improve on both result oriented and process-oriented performance in construction projects. Suremann, identified key performance indicators as Quality Control, on-time completion, cost, safety, cost per unit, and man hours (Suremann, 2009). The study by Suremann was identifying the impact of BIM on construction and therefore the identified performance indicators are very relevant to the approach of this study. A case study which evaluated how to measure the benefits of BIM established some return metrics which included: number of RFI’s, percentage cost savings on Change Orders, and percentage of time saved on the duration of the project (Barlish & Sullivan, 2012). It is important to both identify the key factors that affect construction performance and accordingly develop metrics to monitor and continue improvement of construction performance through bench marking results and process enhancement. Table 2.2.1 presents the Construction KPI (CKPI) dimension and indicators that were identified through literature review.

Table 2.2.1 Construction Project Management Dimensions and Indicators

<table>
<thead>
<tr>
<th>Construction KPI (CKPI) Dimension</th>
<th>Performance Indicator</th>
</tr>
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<tbody>
<tr>
<td>KPI Result Oriented (Mincks &amp; Johnston, 2003), (Cox et al., 2003), (P. S. P. Wong &amp; Cheung, 2005), (Gattorna &amp; Walters, 1996), (Ng et al., 2002), (PMI, 2008), (Nitithamyong &amp; Skibniewski, 2006),</td>
<td>Cost Goal</td>
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<tr>
<td>KPI Process oriented (PMI, 2008), (Ng et al., 2002), (Cox et al., 2003), (Mincks &amp; Johnston, 2003), (P. S. P. Wong &amp; Cheung, 2005), (Nitithamyong &amp; Skibniewski, 2006), (Naoum, 2003)</td>
<td>Communication Management</td>
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2.3 Relationship between BIM and Productivity/ Construction Performance

Aziz, states that waste of time in construction is nearly 57% when compared to manufacturing which has a 12% waste in time (Aziz & Hafez, 2013). Additionally, the study also draws attention to the fact that productivity in the construction industry worldwide has been on the declining trend for the past 40 years, also stating that productivity in the USA construction industry has been on the decline since 1964. A whitepaper highlights a list of 33 labor factors that affect productivity of which a few included are; overtime, morale and attitude, stacking of trades, concurrent operations, Errors and omissions, Reassignment of manpower, site access, logistics, ripple effect, dilution of supervision, weather and season changes, over-manning and area practices (Intergraph, 2012). While all these factors may not be resolved through the direct application and usage of BIM, many of these factors can be addressed through improved planning and Construction Project Management (CPM).

Literature review revealed that many studies support that there is added value in BIM implementation and adoption (Boktor, Hanna, C., & Menassa, 2014). BIM enables and facilitates productivity enhancement on construction projects through the identifying of inefficiencies, finding their source and potential remedies by offering a platform for re-engineering the process (Nath, Attarzadeh, Tiong, Chidambaran, & Yu, 2015). While improvements in productivity, quality of design, construction and the maintenance of buildings is highlighted as an objective of BIM (Reijo & Sami, 2014), the study draws attention to the importance of maintaining a realistic conception in the implementation of BIM while pursuing the future oriented vision of BIM implementation. Many factors can affect and contribute towards productivity, A study conducted specifically on labor productivity (Rojas & Aramvareekul, 2003) seemed to indicate that practitioners held the belief that construction labor productivity is under their control, and that
management needs to be complemented by new technique and technologies to improve productivity. In a separate study, 82 percent of BIM users indicated that BIM had a positive impact on productivity and 79 percent of the users indicated that project outcomes were improved with fewer RFI’s and significant improvements in field coordination (Azhar, 2011). A South-Korean study focused on evaluating the Return On Investment (ROI) on the BIM-assisted D3 City project (Lee, Park, & Won, 2012) which showed that the use of BIM prevented 709 errors which would have otherwise caused negative financial impact on the project. The ROI of avoiding a week’s delay was estimated to be between 172% - 247%, while avoiding a month’s delay was estimated to be between 624%-699%, showing a significant economic impact with the use of BIM. While some studies indicate a significant and relatively quicker ROI, a study in the United Kingdom, seemed to indicate that it may take a little longer, with factors such as long run productivity and access to BIM mandated projects in the UK being the causes for a good ROI (Bryde, Broquetas, & Volm, 2013). It is possible that these differences may be due to a variety of causes such as the country of implementation, the nature and scale of the projects and method of calculation.

Improvement and monitoring of safety, quality and carbon emissions with the use of 4D applications in BIM is discussed by (Ding, Zhou, & Akinci, 2014) in view of increased information availability for decision making, while 4D applications of BIM are also discussed in the virtualization of the process for integration of codes and quality management (L. Chen & Luo, 2014) which highlights the use and potential positive impacts of BIM on productivity of a construction project. Studies have also compared construction practices such as Lean construction that focus on productivity, and shown a significant synergy between BIM and Lean construction (Rafael, Lauri, Bhargav, & Robert, 2010). In using BIM as a solution to productivity; according to a study by (Jensen & Johanneson, 2013), BIM is perceived as a tool that can diminish the
troubling lack of productivity in the Nordic countries. Effectively tracking productivity, is critical to assess progress on a project (Yelda, Frederic, Carl, & Ralph, 2013). Yelda, highlights the use of 3D imaging tools such as BIM to track earned value on a project. Another study in South-Korea indicated that the time reduction enabled by 3D based quantity take-off and estimation has resulted in higher productivity (Kim et al., 2009). Extending beyond the realm of pre-construction and the construction process, some studies show that the use of BIM in facility management has also proved to be faster and more productive (Burcin, Farrokh, Nan, & Gulben, 2012) while another study in the United Kingdom indicates that all stakeholders benefit through a construction projects lifecycle with the adoption and implementation of BIM. But, Clients followed by facility managers tend to benefit the most through the implementation of BIM (Eadie, Browne, Odeyinka, McKeown, & McNiff, 2013).

A study on BIM uses and frequency of use highlighted 25 uses of BIM and assessed the frequency and perception of the uses, which revealed a positive benefit on all the highlighted uses; showing an industry perception that supports the notion of a positive impact of BIM on productivity (Kreider, Messner, & Dubler, 2010). Another study which studied the perceived value of BIM in the U.S construction industry, highlighted that U.S practitioner perceptions indicated savings in cost and time, with increased profitability for companies that were using BIM (Burcin & Rice, 2010). A significant benefit of BIM, which is not discussed as much is its impact on Risk Management. Tomek suggests, BIM should have a positive impact on risk management, by mitigating threats and raising opportunity as companies progress from BIM implementation to post BIM implementation (Tomek & Matejka, 2014).

There are many approaches discussed through Academic studies on how to improve the impact of BIM, (Deutsch, 2011) a book titled “BIM and integrated design” highlights the
importance of leveraging people as an important means of enabling the best and most productive use of BIM. BIM is also seen as a remedy for improvement in labor productivity of the construction industry (Teicholz, 2013). Teicholz, indicated that it may be too early to measure the quantified impact of BIM on the element of labor productivity. A study on the perceived impact of BIM indicated that respondents felt that BIM is most likely to have a positive impact on the quality and on-time completion of construction projects (Suermann & Issa, 2009). While many studies highlight how improving BIM’s impact on productivity should be approached, Barlish suggests a comparison of case studies approach that compare similar projects as a means of how to identify metrics and measure the benefits of BIM (Barlish & Sullivan, 2012). The return metrics as established in the study were an assessment of the number of RFI’s, percentage cost savings on Change Orders and percentage of time saved on the duration of the project. A different study which proposes a practical framework for implementation, describes the current objectives of computer integrated construction (CIC) and BIM to be the improving of effectiveness in construction through the use of information systems and integration (Youngsoo Jung & Mihee Joo, 2011). Clearly defining that the mission of using computer technologies and processes such as BIM, is for the broader purpose of improving efficiency, which in turn leads to productivity improvements. A study by (Kihong & Taiebat, 2011) states that companies have an expectation that construction graduates bring knowledge in areas of constructability and visualization in the short term, with expectations for facility management and energy analysis in the long term. This is indicative of the expectations that companies have from Academic institutions, for the growth of BIM implementation in curricula and the hope to increase productive outputs in relation to BIM. A more comprehensive environment that trains and prepares young graduates will be beneficial to reducing
the time and costs that may need to be invested in bringing new employees up to speed with the industry use and expectations of BIM.

Additional, In-depth doctoral and thesis studies have also conducted prior research into the relationship between BIM and productivity. Ghosh conducted a case study, focused on labor productivity to develop a BIM-value framework based on geometrical information, descriptive information and workflows (Ghosh, 2015). Chelson, explored the impact of BIM on construction site productivity and concluded that every dollar spent on modeling and planning a project saved approximately $17 in construction field costs, and highlighted that the BIM process followed by the architects and owners who were studied only accomplished a small portion of what BIM has to offer (Chelson, 2010). Suermann, in his doctoral thesis highlights that owners should play a role in driving productivity in BIM and as a conclusion, states that BIM will mirror evolution in the sense that species will survive through either sudden or gradual change and that change is inevitable (Suermann, 2009). This change will demand greater collaboration as constraints increase and BIM is the AEC industries answer to collaborative information exchange. These in-depth doctoral research studies assess independent approaches to productivity through the use of BIM but, do not assess multiple productivity elements from the practitioner’s perspective. With the exception of Ghosh’s study, both the other studies were conducted approximately 7-8 years into the commencement of this thesis study and therefore could potentially see a shift in the findings and conclusions.

Literature review has indicated that there are similarities in the factors used to measure BIM and the categories by which we assess productivity in construction. However, there needs to be a present-day study with data and information from the practitioners to verify how BIM impacts construction performance and how it can further improve its impacts on productivity.
CHAPTER 3

METHODOLOGY

3.1 Introduction

The methodology used for this study was a sequential mixed method approach using both qualitative and quantitative research methods. The qualitative approach was a content analysis and the quantitative approach was a descriptive analysis based on certain demographic groupings. Firstly, using extensive literature review, the varying Academic approaches to BIM and Construction Performance research was identified. A preliminary pilot qualitative study was conducted through 3rd party qualitative interviews by students in a construction graphics course at Georgia Southern University. The data collected through this process was utilized in developing the interview questions for the main qualitative study conducted by the author of this thesis study. The qualitative approach was used for the purpose of validating literature identified BIMM and Construction Key Performance Indicators (CKPI’s), and also to get qualitative insights into the Academic and Practitioner perspective on BIM and Construction Performance. The qualitative data was then used to build the survey that was used for the quantitative study. Literature review was again conducted following the qualitative study, to improve upon the BIM and construction performance matrices prior to quantitative survey creation and deployment. It was determined that the best approach would be to have three separate survey questionnaires that addressed the separate perspectives that were being assessed. The surveys used for the study can be found under appendix 3. The survey was then deployed to a small pilot group of 100 and then deployed for data collection. Once the data was collected, the data was screened and formatted appropriately for data analysis. Both the qualitative and quantitative study phases received independent IRB approvals.
3.2 Summary of Procedure

Step 1: Phase 1 Literature Review

Step 2: Pilot Qualitative Study with 3rd party Interviews – Construction Graphics Course

Step 3: Phase 2 Literature Review

Step 4: Developing BIM and Construction Performance matrix

Step 5: Preparation of Questionnaire for Qualitative Study

Step 6: Conducted Qualitative Study

Step 7: Phase 3 Literature Review

Step 8: Preparation of Survey Questionnaire for Quantitative Survey Study

Step 9: Conducted Quantitative Study

Step 10: Data Analysis and Completion

3.3 Developing a BIMM matrix

Using extensive literature review, BIM Maturity models and matrices were evaluated as presented by different studies. These studies were compared against the BIMM model proposed by Chen (Y. Chen, 2013). The four main factors identified in Chen’s study included technology, information, process and people. Each of these key factors of BIMM had a list of indicators and the indicators had attributes which were all listed down and used in the comparison. A full list of the factors, indicators and attributes are provided as appendix 2.

Literature review indicated that technology, information, process and people were all factors in “BIM competency sets” as presented in a study by Succar. There was also an indication for an additional factor identified as policy (Succar et al., 2012). A study from Hong Kong titled “The development of a multifunctional BIM Maturity model” by Liang also identified the
importance of the four factors identified by Chen and Succar, but introduced an additional factor referred to as protocol (Liang, Lu, Rowlinson, & Zhang, 2016). When evaluating both the policy and protocol factors as presented by Succar and Liang, it appears that many of the indicators although named and grouped differently are included within the four factors in Chen’s model.

The Indiana University created the “IU BIM Proficiency matrix” in 2009 and updated the matrix in 2015 (University, 2015). This matrix seemed to lack the comprehensive outlook on the factor relating to people but had identified indicators that can be categorized into all of the four BIM maturity factors presented by Chen. The BIM Cloud Score (BIMCS) is a cloud based BIM performance bench-mark does not indicate technology as a factor but includes information, process and people (Du, Liu, & Issa, 2014). A study titled “BIM Ecosystem” by Australian and Finnish authors identify products, processes and people (Gu et al., 2014). When analyzing the components of these factors, the fundamental characteristics presented by the study indicate that all the characteristics can be identified within Chen’s BIM maturity model.

The roadmap to the implementation of BIM suggests that the key factors of BIM maturity are technology, process and people (Khosrowshahi & Arayici, 2016). A Virtual Design and Construction (VDC) scorecard formulated and validated by the Center for Integrated Facility Engineering (CIFE) also indicated technology, process, people and also had the inclusion of measuring the performance of adoption as factors of BIM maturity (Kam, Senaratna, McKinney, Xiao, & Song, 2016). Identifying the managerial areas of BIM, a study indicated some key areas for BIM maturity which included product, application approach and work environment in addition to technology, information, process and people (He et al., 2016). It is also valuable to note that the study on the managerial areas of BIM indicated a heavy concentration towards the process factor. The application framework for BIM identified the important factors of BIM to be information,
process and people. It also discussed the existing gaps in BIM application and the potential expansion of BIM models to multiple dimensions (Ding et al., 2014). An empirical study in China evaluated the effects of BIM on collaborative design and construction and it consisted of indicators falling under all the factors: technology, information, process and people (Liu, Nederveen, & Hertogh, 2017). A study that highlighted ten years of literature research on BIM-enabled construction projects identified indicators that could be grouped under Technology, Process and People but, had no indicators highlighting the importance of Information in BIM enabled projects (Oraee, Hosseini, & Merschbrock, 2017). This is an interesting observation as much of the literature relating to BIM maturity, seems to highlight the importance of Information through providing real-time data, data richness and data accuracy.

Stepping aside from journal studies and articles, The BIM delivery cube is another potential model to be evaluated on the maturity and implementation of BIM. The cube aims to provide clarity on BIM by considering three axis identified as stakeholders, work stage and delivery component (CIRIA, 2016). The authors suggest that the cube is not intended to be comprehensive in the understanding of BIM. But, an evaluation of the cube shows evidence of indicators that can be again grouped under the key BIM maturity factors proposed by Chen. Similar to the BIM delivery cube, the Royal Institute of British Architects (RIBA) follow a matrix identified as the RIBA Plan of work (RIBA, 2013) to assist with BIM integration and implementation on construction projects. The plan of work put forward by the RIBA has 7 stages which cover the design and construction process, which identifies indicators that can be grouped under Technology, Information, Process and People spread across the different stages.

A study on BIM and standardized construction contracts recognizes the concerns related to legal risk of using BIM on construction projects and identifies changes that could help facilitate
an improvement in legal concerns of BIM implementation (Manderson, Jefferies, & Brewer, 2015). All indicators relating to legal issues in BIM can be grouped under the factors proposed by Chen. However, this study opens discussion for the potential of an independent BIM maturity factor relating to the Legal aspects of BIM implementation. Factors that drive the implementation of BIM are also important to understanding the progression of BIM to maturity. A study that analyzed the factors for influencing BIM implementation identified three of five indicators to be Top Management Support, Compatibility and Computer Self-Efficacy (Son, Lee, & Kim, 2015). The indicators as identified could also be grouped under the maturity factors proposed by Chen. It was determined that recent literature supported the factors and indicators as identified by Chen. Therefore, it was determined that the factors and indicators as identified by Chen and provided in appendix 2 would be used for the next stage of qualitative interviews.

3.4 Developing a Productivity/ Construction Performance matrix

Using a similar approach to the development of a BIM matrix, extensive literature review was performed to identify the factors which influence construction performance. A majority of the studies referred to the factors as Key Performance Indicators (KPI). Suermann evaluated the impact of BIM on construction by identifying six KPI’s listed as: Quality Control, On-time completion, Cost, Safety, Cost per unit and Man hours (Suermann, 2009). A study on measuring the benefits of BIM, identified the KPI’s as: Number of RFI’s, Change Orders = cost / total cost, and Schedule = actual / standard (Barlish & Sullivan, 2012). Similar to that of Barlish and Sullivan, an analysis of the UK construction project lifecycle listed KPI’s: Number of RFI’s, Change Orders, Overall cost, Cost of changes, Program duration and Man hours (Eadie et al., 2013). A more detailed report on construction productivity, grouped its 31 KPI’s into: Economic KPI’s, Respect
for People KPI’s and Environment KPI’s (Excellence, 2007). This would suggest that the factors for productivity are Economic, Environment and Respect for People; this is consistent with many of the other studies as the KPI’s can be grouped under one of these three factors.

A study for construction projects in Hong Kong identifies productivity as performance in relation to safety, cost, time, quality, environment, communication, functionality and client satisfaction (Yeung, Chan, Chan, & Yang, 2013). Similarly another study identified many of the popular performance indicators relating to cost, time, safety and satisfaction but also presented the factor of predictability of cost and time as a factor for performance (Skibniewski & Ghosh, 2009).

A report to the ministry of construction which identified the KPI’s for construction to be: Time, Cost, Quality, Client satisfaction, Change Orders, Business performance, Health and safety (Group, 2000). The study also highlighted the purposes of identifying KPI’s to be the clients demand for construction projects to be on time, on budget, free from defects, efficient, right the first time, safe and built by profitable companies. The study also indicated the client’s year-on-year expectation for the reduction in project costs and delivery times. Another study in 2002, approached construction productivity with a contrasting list of productivity factors which included: Risk, Project status, Decision effectiveness, Production, Cost effectiveness, Customer commitment, Stakeholders and Project management (Pillai, Joshi, & Rao, 2002). Although the indicators were in contrast to many of the indicators called out by other studies, they still could be grouped together with indicators which are similar and therefore did not indicate any additional productivity indicators for consideration. A web based approach to monitoring the performance of construction projects listed 8 performance categories which included: People, Cost, Time, Quality, Safety & Health, Environment, Client Satisfaction and Communication (Cheung, Suen, & Cheung,
This web-based performance monitoring tool also highlights many of the same performance indicators as identified in literature.

Modeling of construction productivity models in 1990 listed the factors for construction productivity to be Project controls, Site controls, Management controls and Motivation (H. R. Thomas et al., 1990). This early study on construction productivity models indicates consistency with productivity factors relating to Economic, Environment and People related factors. A study on construction productivity with a focus on Singaporean Contractors highlighted a few of the key areas of construction productivity to be Manpower, Management and Environment (Lim, 1995). Many of the recent and current literature also highlight performance indicators that fall under these factors of construction productivity, showing a positive level of consistency for published literature in relation to the topic of construction productivity performance indicators. The report presented in 1998 on the UK construction industry to John Prescott, the Deputy Prime Minister also indicated the predictability of cost and time (Egan, 1998). A book published as early as 1997, on construction project performance evaluation and benchmarking indicated consistency with most of the recent studies. However, the author had introduced experience of staff, planning period and claims as additional factors for construction productivity (Jastaniah, 1997). A study by Wong in 2004 also highlighted staff experience as a factor of productivity along with the additional inclusions of contractor experience and site management (C. H. Wong, 2004). The final matrix for construction performance factors, indicators and attributes are provided in Table 3.4.1. This table provides the full Construction Key Performance Indicator (CKPI) matrix as identified through this study and presented as a key contribution of this Thesis.
Table 3.4.1 Construction Performance Factors, Indicators and Attributes – CKPI Matrix

<table>
<thead>
<tr>
<th>Factors</th>
<th>Indicators</th>
<th>Attributes</th>
<th>References</th>
</tr>
</thead>
<tbody>
<tr>
<td>KPI (Result oriented)</td>
<td>Cost Goal</td>
<td>Meet target budget</td>
<td>(Mincks &amp; Johnston, 2003), (Cox et al., 2003), (P. S. P. Wong &amp; Cheung, 2005), (Gattorna &amp; Walters, 1996), (Ng et al., 2002)</td>
</tr>
<tr>
<td></td>
<td>Schedule Goal</td>
<td>Meet schedule goal</td>
<td>(Mincks &amp; Johnston, 2003), (Cox et al., 2003), (P. S. P. Wong &amp; Cheung, 2005), (Gattorna &amp; Walters, 1996), (Ng et al., 2002), (PMI, 2008), (Cox, 2009)</td>
</tr>
<tr>
<td></td>
<td>Quality Goal</td>
<td>Meet quality specification</td>
<td>(Mincks &amp; Johnston, 2003), (Niithamyong &amp; Skibniewski, 2006), (Gattorna &amp; Walters, 1996), (Ng et al., 2002)</td>
</tr>
<tr>
<td></td>
<td>Safety Goal</td>
<td>Meet safety goal</td>
<td>(Niithamyong &amp; Skibniewski, 2006)</td>
</tr>
<tr>
<td></td>
<td>Customer Satisfaction</td>
<td>Improve customers’ satisfaction</td>
<td>(Mincks &amp; Johnston, 2003)</td>
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<tr>
<td></td>
<td></td>
<td>Decrease total number of legal claims and litigations</td>
<td>(Ng et al., 2002)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Decrease total cost of legal claims and litigations</td>
<td>(Ng et al., 2002)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Increase number of repeat customers</td>
<td></td>
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<tr>
<td>KPI (Process oriented)</td>
<td>Communication Management</td>
<td>Information Management</td>
<td>(PMI, 2008)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Communication Frequency</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Communication Effectiveness</td>
<td></td>
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<tr>
<td></td>
<td></td>
<td>Communication Method</td>
<td></td>
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<tr>
<td></td>
<td></td>
<td>Coordination tools</td>
<td>(Ng et al., 2002), (Naoum, 2003)</td>
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<tr>
<td></td>
<td></td>
<td>Open information sharing</td>
<td>(Ng et al., 2002)</td>
</tr>
<tr>
<td></td>
<td>Resource Management</td>
<td>Material Management (e.g. waste reduction)</td>
<td>(Cox et al., 2003), (Mincks &amp; Johnston, 2003)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Labor Management (e.g. Lost time/Idle time)</td>
<td>(Cox et al., 2003)</td>
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<td></td>
<td></td>
<td>Subcontractor Management</td>
<td>(Mincks &amp; Johnston, 2003)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Effective Procurement Management</td>
<td>(PMI, 2008)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Risk (uncertainty) Management</td>
<td>(PMI, 2008)</td>
</tr>
<tr>
<td></td>
<td>Effective Schedule Control</td>
<td>Effective Schedule Control (e.g. plan, scheduling, monitor, and control of schedule)</td>
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<td>---------------------------------------------</td>
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<tr>
<td>Effective coordination of stakeholders</td>
<td>(PMI, 2008)</td>
<td>Total number of design errors</td>
<td>(Nitithamyong &amp; Skibniewski, 2006)</td>
</tr>
<tr>
<td>Improve decision-making process</td>
<td>(Ng et al., 2002), (Naoum, 2003)</td>
<td>Total number of RFI during preconstruction</td>
<td>(Nitithamyong &amp; Skibniewski, 2006)</td>
</tr>
<tr>
<td>Scope Clarification</td>
<td>(PMI, 2008)</td>
<td>Total number of RFI during construction</td>
<td>(Nitithamyong &amp; Skibniewski, 2006)</td>
</tr>
</tbody>
</table>

3.5 Data Collection

Qualitative Data Collection – Qualitative Data Collection was conducted through a preliminary qualitative study performed by students in a construction graphics course, with an in-depth qualitative study performed by the author. The in-depth qualitative study was conducted via the phone or in-person and was recorded using an audio recording device. The author was hoping to interview 10 Academics and 10 industry practitioners. Therefore, the estimated number of respondents is 20. The sample size of 20 as selected by the author is justified by the fact that qualitative research follows an in-depth study and appropriate data can be obtained from as little as 1 in-depth study (Boddy, 2016). The approach adopted to studying the data collected through the qualitative study was “Qualitative Content Analysis”. The data was transcribed and evaluated for patterns and key content highlights.
Quantitative Data Collection – The Quantitative data collection was performed using a survey designed following the qualitative study, and was performed using the Qualtrics survey platform as offered through Georgia Southern University. The study targeted distribution to a population of 5000 AEC Academics and industry practitioners. The targeted response rate was 10% and therefore expected a total of 500 survey responses. The target number was established by assessing the number of indicators presented in the study and calculating an appropriate number of responses to validate them. This approach was also adopted in the study by Chen (Y. Chen, Dib, Cox, Shaurette, & Vorvoreanu, 2016). The collected data was studied using a “Descriptive Analysis” approach. This included the use of statistical analysis tools such as SPSS software for comparison of means and validity tests to rank BIMM and Construction Performance Indicators. ANOVA tests were also conducted to compare means for certain groupings to identify if there exists a statistically significant difference in the mean scores based on certain groupings. Data storage was handled based on IRB approvals obtained for this study.
CHAPTER 4

DATA ANALYSIS

4.1 Analysis of Construction Graphics Course Data

Data was extracted from a soft preliminary 3rd party qualitative interview of construction industry practitioners conducted by students. The students conducted these interviews as part of a course assignment in a construction graphics course at Georgia Southern University. The data has been utilized for a preliminary understanding of the practitioner’s perspective on BIM and Productivity. The students asked questions from Project Managers and the questions asked have been provided under appendix 1. Eight project managers were interviewed by the students and one of the interviews were eliminated from the preliminary data analysis as there was no response to the questions asked relating to BIM and Productivity.

A majority of four out of the seven respondents indicated that strictly abiding by the schedule and monitoring schedule performance was their measure of productivity. Two other approaches on how to measure productivity was defined as testing and checking the earned value on each activity of the budget and measuring performance as defined by total weekly construction footage. One of the project managers did not seem to show an understanding of the question.

When asked if the project managers had used BIM software on their projects, three responded saying No and the other four respondents indicated that they use software such as Revit for modeling and model evaluation, while some of the project managers used Navis Works for clash detection. One of the Project managers indicated that they use only BIM software that relates to the cost estimating function and the software used was highlighted as On-Screen Takeoff and Quick Bid.
Project Managers were asked about the benefits of BIM and if it had improved productivity? The Project Managers who had utilized BIM, unanimously agreed with responses that indicated both benefits of BIM and that BIM has had an improvement on their project productivity in ways such as BIM breaks down the construction process allowing for better planning, eliminating errors in construction through model evaluation and clash detection, time savings on projects with increased competitiveness when dealing with larger general Contractors.

4.2 Analysis of Qualitative Interview Data

Academics and industry practitioners were interviewed either face-to-face or via phone/skype for the qualitative interviews. A total of 23 individuals were interviewed during the qualitative interview data collection phase. The interview participants included 12 Academics and 11 industry practitioners. The participants were divided into three categories which included Academic one-to-one interviews (7 participants), industry practitioner one-to-one interviews (4 participants), and panel discussions targeting Academic groups (5 participants) and industry groups (7 participants). These groupings were done in order to obtain a more wholesome collection of opinions.

For the Academician interviews, 7 one-to-one interviews were conducted. The years of teaching experience for the interview participants ranged between 2 – 20 years, with six of the seven Academics having over 5 years of teaching experience. The positions/titles of the Academics who participated in the interviews included faculty chair, associate professor and assistant professor. Four out of the seven Academics who were interviewed also stated that they were involved in some form of BIM related research. BIM was defined by one of the Academics as “The flow of information stored in a 3D database which concerns proper management of information concerning buildings”. This definition highlights the understanding of an information
rich model that can be used for better visualization and improved management. Another Academic described BIM as a “Process that should be and can be used during the entire lifecycle of the project. It has various processes including simulation and also serves as a repository”. This definition of BIM seemed to have the focus on the process oriented nature of BIM. A more people and management oriented definition of BIM was described as “An intelligent functionality added to the current design and facility management processes that is helpful for all stakeholders involved in the construction project. An Academic who also counts 35 years of industry experience as an owner/developer highlighted the technology advancement and multi-dimensional nature of BIM and defined it as “A tool for visualization, clash detection and the occasional use of virtual and augmented reality to manage a 3D database that includes as-built drawings that are linked to facility management processes”. It was also stated that the Academic was utilizing BIM’s capabilities of digital scanning and utility assessment and failure monitoring for the purpose of better and improved facility management. It was observed in the qualitative data analysis that the definitions for BIM provided from the Academic perspective included information, technology, people and process which are the factors of BIM maturity as proposed by Chen (Yunfeng, Chen et al., 2016).

Academics discussed many drivers of BIM and highlighted complexity of project, delivery method, improved efficiency, and information management. Competitiveness and the belief that the use of BIM would save time and cost was also highlighted as a potential driver of BIM from the Academic perspective. One of the Academics stated that stakeholders are the main drivers of BIM and listed out the stakeholders they believed would drive the implementation of BIM to be: superintendents, designers, contractors, engineers, architects, specialty trades, software/hardware companies and insurance companies. The drivers of BIM as viewed by the
Academics seemed to lean mostly towards the type of project, the benefits of utilizing BIM and the people involved in a project. The interviewed Academics were then asked to rank the BIM maturity factors as highlighted by Chen, and the rankings indicated that the BIM factors believed to have the most positive impact on construction performance would be in the order of: People, Process, Information and Technology.

The interviewees were provided with a list of construction performance indicators that were identified through literature review and asked for feedback on what they felt were the key areas of construction performance. The construction performance areas that were highlighted by the Academics included: construction time, construction cost, labor efficiency, client satisfaction, worker morale, quality management, communication, construction re-work, number of RFI’s, site management and decision making. When asked about some of the negative impacts of BIM on construction projects, Academics provided feedback that indicated the importance of technology and modeling accuracy. Interoperability issues that are currently prevalent in the implementation and utilization of BIM can sometimes result in productivity losses for the project/company. People were highlighted consistently as a potential avenue for negative impacts from BIM. The Academics discussed in training of personnel who are using BIM and the negative impact that can be sometimes observed on BIM-assisted projects due to lower levels of competency. Another aspect of how BIM could negatively impact a construction project due to people was in reference to the stakeholder buy-in on the use of BIM for their construction projects.

Four industry practitioners were interviewed one-to-one for the qualitative component of the study. The experience of the practitioners ranged from 3 years to 25 years and included a general contractor, construction manager, and subcontractor and BIM consultant. One of the industry practitioners described BIM as “A newer way in how engineering should be done and is
supposed to be able to clarify what happens on the construction site”. This definition leaned more toward a process oriented lens on BIM. Another industry practitioner defined BIM as “Taking all building envelopes, structural, MEP components and other disciplines on a construction project and combining it to one model to identify how they all relate to one another.” This practitioner’s definition shows the industry perspective and importance on BIM being used as a collaborative tool surrounding the stakeholders of a project. An industry practitioner with over 25 years of industry experience but had never been part of a BIM assisted project defined BIM as, “a modeling system that can be used to visualize and figure out the conflicts and issues”. With a limited exposure to BIM, the practitioner perceived the extent of BIM to be a technological advancement that helped to improve the visualization of a building. In contrast, the BIM consultant who had been a participant in over 600 BIM assisted projects, defined BIM as “a process that enables improved communication through leveraging a 3D model with the basic philosophy of shifting the traditional figure it out when we build, to a figure it out in a computer.” This explanation and description of BIM showcases the value placed on using the advancing technology to gather more information in a computer aided environment to model, analyze and make decision on a construction project. Similar to the definitions provided by the interviews conducted with Academics, the analysis of the data collected from the interviews with industry practitioners also indicate that the definitions lean towards the main factors of information, technology, policy and people. These factors are again in line with the BIM maturity factors as proposed by Chen (Yunfeng. Chen et al., 2016). When asked to rank the four BIM maturity factors based on their perceived impact on construction performance, the industry practitioners ranked People and Process as the top two BIMM factors. Information and Technology were ranked third and fourth.
Similar to the process followed with the Academics, industry practitioners indicated that the most important construction performance indicators were: labor efficiency, construction cost, construction time, RFI’s, profitability, material wastage, site management, construction re-work and decision making. While there is consistence on a majority of the construction performance indicators, those that were not highlighted by the Academics but were highlighted by industry practitioners were profitability and material wastage. The performance indicators that were highlighted by the Academics and not by the industry practitioners included: client satisfaction, worker morale, quality management and communication. This may have changed if there were more interview participants in the one-on-one interviews for the industry practitioners. But, is still an interesting observation when comparing the Academic and industry practitioner perspectives.

Industry practitioners had a range of opinions as it related to the negative impacts of implementing BIM on a construction project. The sub-contractor highlighted that BIM does not seem to effectively and efficiently lay out everything. The sub-contractor also provided details and examples of when the model had inaccuracies when compared to the initial drawings and as a result created some construction time delays and logistical challenges on the construction project. The construction manager stated that BIM is like any other tool that is used in construction and is only as good as the people who are using it. BIM should never be viewed as an “easy-fix button” on a project and stakeholders working on a BIM assisted project must recognize that the level of complexity and the challenges of a construction project are still the same. The construction manager also provided examples of challenges in communication with the use of BIM being kept in real-time and also challenges with stakeholder buy-in and how it could negatively impact a construction project and its progress. The BIM consultant however, stated that there can be no negative impacts of utilizing BIM on a construction project if it is planned and implemented
correctly. The BIM consultant elaborated this view by stating that BIM should not be viewed as “All or nothing” and that sometimes in the short-sighted view, construction time and cost maybe affected but the return on investment is exponential in the long-run.

Four panel interviews were conducted. Two of the panels consisted of industry practitioners and the other two panels consisted of Academics. The two industry practitioner panels consisted of a total of 7 participants who represented two general contracting companies. The titles of the participants included VDC manager / coordinator, assistant VDC manager / coordinator and VDC intern. The industry practitioner panelist’s years of experience ranged from less than one year to 15 years of industry experience. Collectively the departments represented by the panelists had worked on nearly 90 BIM assisted construction projects. The Academic panels consisted of a total of 5 participants. The titles of the participants included faculty chair, assistant professor, associate professor, senior lecturer and temporary instructor. The Academic panel had teaching experience ranging from 3 years to 18 years and collectively account for 57 years of teaching experience.

An industry panel defined BIM as, “a visual communication problem solving tool – a process which is more than a software, a process that is data centric with the use of a 3D model database and has the ability to find problems before construction takes place.” This definition describes the visual nature of BIM and also highlights the fact that BIM is a process that is rich in information. The second industry panel, defined BIM as, “a 3D model that is interoperable using different platforms to talk to each other and used with different stakeholders.” This definition again highlights the importance of collaboration between stakeholders as observed in the one-to-one interviews. The first of the two Academic panels stated that BIM in reality should be referred to as “Building Information Management” the reasoning for this opinion was that BIM is an
extension of the “typical old stuff” that goes into a construction project. The first Academic panel also held the view that most companies seem to be using BIM as a marketing tool and that it is a “tool that can go beyond software/visualization and goes into the constructability, logistics and integration of stakeholders. Again, this definition also points towards the direction of BIM being understood as a technologically driven information rich process which enables greater collaboration and interaction between stakeholders on a construction project. The second Academic panel defined BIM as “a 3D image that is generated to show you what the building will look like after it is built. The model also enables you to tie on your scheduling, inventory management, materials and is initially used to sell the project. BIM has unlimited attributes and capabilities that you could assign as elements within a system.” This definition describes BIM as evolving and growing with many capabilities. Again, we find that the definitions provided by the four panels again seem consistent with Chen’s, BIM maturity factors of information, technology, process and people (Yunfeng. Chen et al., 2016). Some of the drivers for BIM implementation as discussed in the panel discussions included complexity of project, size of project, client, money, industry trend, competitiveness and project delivery method. Panelists ranked the four BIM maturity factors and identified people, followed by process, information and technology. The rankings of the BIM maturity factors are consistent when comparing the panels to the ono-to-one interviews of both the Academic and industry practitioners.

A list of construction performance indicators were presented to the panelists and they were asked to select the top 5 performance indicators from their perspective as a panel. The listed indicators were combined, and the following construction performance indicators were listed: construction re-work, communication, client satisfaction, quality management, profitability,
construction safety, construction time, construction cost, decision making, labor efficiency and material wastage.

The negative impacts of BIM were discussed with the panelists. Industry practitioners indicated that the most challenging part of BIM implementation is the initial setup and the efforts required to extract the relevant information to start the process. One of the industry panelists stated that it was challenging to marry the client’s expectations to what BIM can deliver and it was summarized as the “Hollywood BIM.” The second industry panel stated that it used to be challenging to justify BIM related budgetary expenses but over time, people have begun to see the positive impact and it is no longer a big challenge. The Academic panelists highlighted that a potential negative effect of BIM is that many companies / sub-contractors may not be working with BIM and this could cause certain negative impacts in relation to choice/options of sub-contractors when working on a BIM assisted project. A different Academic panel stressed that the biggest challenge and negative impact of BIM would be in relation to design and modeling errors. The Academic described it as “garbage in and garbage out.” Further explained, the Academic panelists also highlighted that many of the young professionals are getting over dependent on the technology and therefore lack the knowledge and competence of industry veterans.

Word clouds were generated to summarize the qualitative interview data collected as it relates to the definition of BIM, drivers for BIM and indicators for assessing construction performance. The word clouds generated from the data are provided below.
As observed in figure 4.2.1, we can see the key words generated include: communication, information, process, management, software, stakeholders and other words that remain in alignment with the indicators covered under the BIMM factors of Technology, Information, Process and People. Other elements that can be observed from the definitions word cloud include modeling, database, imagery and visualization.
The Drivers for Building Information Modeling as described by interview participants were also used to generate a summary word cloud in figure 4.2.2. Some highlights observed include: money, owners, project requirement, project complexity, design-build delivery, improving coordination and efficiency. Stakeholders of a construction project including designers, Contractors, engineers, architects, specialty Contractors and other AEC professionals and their companies were also listed in the drivers and observed in the summary word cloud.
Construction Performance indicators that were identified by the interview participants are presented in figure 4.2.3. Some of the key performance indicators that were highlighted in the summary word cloud include: construction re-work, construction RFI’s, construction cost, construction time, construction quality and labor efficiency. Other performance indicators that appeared on the word cloud touched on performance indicators such as client/customer satisfaction, safety, site management and profitability.

In summary, the qualitative interviews conducted with Academics and industry practitioners’ provided deeper insight into how BIM is perceived and defined. A list of top priority
construction performance indicators were highlighted during the interviews and were used to further improve on the list of construction performance indicators and factors that were used in the quantitative survey. A list of common themes emerged through the qualitative study which indicated the importance of Accuracy, Training, Competence, Collaboration and Customer Satisfaction. Most of these themes relate to People and Process factors for a more mature BIM implementation. The main finding of the qualitative study is that the definitions and descriptions of BIM are consistent with the BIM maturity factors identified by Chen (Y. Chen et al., 2014). The BIM factors ranked by the most positive impact on construction performance to least impact on construction performance are People, Process, Information and Technology.

4.3 Analysis of Quantitative Survey Data: All categories

The quantitative study was conducted with data collection done through a Qualtrics survey. The survey was deployed on the 8th of February 2018 and remained open for data collection until 11:59 PM on the 31st of May 2018. The survey was deployed to nearly 8,000 potential participants including academics and AEC professionals around the world. Contacts for the survey were obtained through LinkedIn contacts, communication with AEC industry professional organizations and through other publicly available contact directories and databases. Additionally, efforts were taken to circulate the survey through AEC industry forums on LinkedIn, Facebook and other social media platforms.

The survey design allowed for practitioners to self-select themselves into three core groups which included Academics, General Contractor / Construction Manager and Other AEC Professionals. Depending on the participant’s selection, the participant was re-directed to a survey designed specifically for that category. At the conclusion of data collection, a total of 498 individuals had participated in the survey. Of this 498 participants, 137 participants identified
themselves as Academics, 164 participants self-selected into the Contractors / Construction Manager category and 198 participants identified themselves as AEC practitioners from other backgrounds such as Owner / Developer, Architect / Engineer, Subcontractor, Consultant, and Software vendor.

![Survey Participant Breakdown](image)

**Figure 4.3.1 – Survey Participant Breakdown**

This quantitative data analysis will present the overall rankings of identified BIMM indicators, Construction Project Success indicators and Construction Project Management indicators. Once the overall means and rankings are presented, further analysis is done on each category for greater insights into the separate Academic, Contactor and other AEC professional perspectives. The means and rankings were broken down for analysis by category and presented in table 4.3.1. The categories examined are Academics, Contractors and other AEC practitioners.
Table 4.3.1 – BIMM Indicator Ranking by Category

<table>
<thead>
<tr>
<th>BIMM Indicator</th>
<th>Academics, N = 137</th>
<th>Contractors, N = 163</th>
<th>Other AEC, N = 198</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Mean</td>
<td>S/D</td>
<td>Rank</td>
</tr>
<tr>
<td>Software Application</td>
<td>5.35</td>
<td>1.20</td>
<td>7</td>
</tr>
<tr>
<td>Interoperability</td>
<td>5.34</td>
<td>1.44</td>
<td>8</td>
</tr>
<tr>
<td>Hardware Equipment</td>
<td>4.74</td>
<td>1.31</td>
<td>26</td>
</tr>
<tr>
<td>Hardware Upgrade</td>
<td>4.31</td>
<td>1.39</td>
<td>28</td>
</tr>
<tr>
<td>Information Delivery Method</td>
<td>5.72</td>
<td>1.21</td>
<td>6</td>
</tr>
<tr>
<td>Information Assurance</td>
<td>5.28</td>
<td>1.37</td>
<td>14</td>
</tr>
<tr>
<td>Data Richness</td>
<td>5.79</td>
<td>1.19</td>
<td>4</td>
</tr>
<tr>
<td>Real Time Data</td>
<td>5.28</td>
<td>1.30</td>
<td>13</td>
</tr>
<tr>
<td>Information Accuracy</td>
<td>5.88</td>
<td>1.13</td>
<td>2</td>
</tr>
<tr>
<td>Graphics</td>
<td>5.30</td>
<td>1.07</td>
<td>12</td>
</tr>
<tr>
<td>Geo-spatial Capability</td>
<td>5.17</td>
<td>1.07</td>
<td>19</td>
</tr>
<tr>
<td>Work Flow</td>
<td>5.72</td>
<td>1.20</td>
<td>5</td>
</tr>
<tr>
<td>Document and Modeling Standard</td>
<td>5.93</td>
<td>1.10</td>
<td>1</td>
</tr>
<tr>
<td>Information Security</td>
<td>5.20</td>
<td>1.30</td>
<td>17</td>
</tr>
<tr>
<td>Process and Technology Innovation</td>
<td>5.33</td>
<td>1.23</td>
<td>9</td>
</tr>
<tr>
<td>Strategic Planning</td>
<td>5.23</td>
<td>1.33</td>
<td>16</td>
</tr>
<tr>
<td>Lifecycle Process</td>
<td>5.32</td>
<td>1.21</td>
<td>11</td>
</tr>
<tr>
<td>Change Management</td>
<td>5.28</td>
<td>1.17</td>
<td>15</td>
</tr>
<tr>
<td>Risk Management</td>
<td>5.07</td>
<td>1.22</td>
<td>22</td>
</tr>
<tr>
<td>Standard Operating Process</td>
<td>5.04</td>
<td>1.21</td>
<td>24</td>
</tr>
<tr>
<td>Quality Control</td>
<td>5.79</td>
<td>1.15</td>
<td>3</td>
</tr>
<tr>
<td>Specifications</td>
<td>5.33</td>
<td>1.15</td>
<td>10</td>
</tr>
<tr>
<td>Senior Leadership</td>
<td>5.07</td>
<td>1.30</td>
<td>23</td>
</tr>
<tr>
<td>Role and Responsibility</td>
<td>5.14</td>
<td>1.16</td>
<td>21</td>
</tr>
<tr>
<td>Reward System</td>
<td>4.34</td>
<td>1.26</td>
<td>27</td>
</tr>
<tr>
<td>Competency Profile</td>
<td>5.15</td>
<td>1.05</td>
<td>20</td>
</tr>
<tr>
<td>Training Program</td>
<td>5.18</td>
<td>1.14</td>
<td>18</td>
</tr>
<tr>
<td>Training Delivery Method</td>
<td>5.00</td>
<td>1.23</td>
<td>25</td>
</tr>
</tbody>
</table>

*The numbers in bold indicate ranking among the Top Ten in its category.

Table 4.3.1 shows that both Academics and Contractors rank Document and Modeling Standards (DMS) as the number one indicator for BIMM, while other AEC professionals rank Software Applications as the number one indicator. However, the importance of DMS as an indicator of BIMM is also recognized by other AEC professionals as it is ranked at second place. BIMM indicators that are consistently ranked in the top ten include: Software Application, Information Delivery Method, Information Accuracy, Document and Modeling Standard, Process and Technology Innovation and Quality Control. A majority of the indicators that are consistently ranked in the top ten by all categories fall under the Technology and Information factors of BIMM as proposed by Chen (Y. Chen, 2013).
The result oriented key performance indicators as listed in table 3.4.1 were identified in the survey as Project Success indicators. The Project Success indicators were also assessed for means and ranking based on the category. These results are presented in table 4.3.2.

Table 4.3.2 – Project Success Indicator Ranking by Category

<table>
<thead>
<tr>
<th>Project Success Indicators</th>
<th>Academics N = 137</th>
<th>Contractors N = 163</th>
<th>Others N = 198</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Mean</td>
<td>S/D</td>
<td>Rank</td>
</tr>
<tr>
<td>Cost Goal</td>
<td>6.16</td>
<td>0.93</td>
<td>3</td>
</tr>
<tr>
<td>Schedule Goal</td>
<td>6.17</td>
<td>0.89</td>
<td>2</td>
</tr>
<tr>
<td>Quality Goal</td>
<td>6.18</td>
<td>0.91</td>
<td>1</td>
</tr>
<tr>
<td>Safety Goal</td>
<td>6.03</td>
<td>1.04</td>
<td>5</td>
</tr>
<tr>
<td>Customer Satisfaction</td>
<td>6.16</td>
<td>0.93</td>
<td>4</td>
</tr>
</tbody>
</table>

As shown in table 4.3.2, it is evident that all the identified result oriented performance indicators were considered relevant. All indicators scored a mean score of at least 4.94 on a 7.00 scale. The highest ranking indicator from the Academic perspective was noted to be Quality Goal, while practitioners who identified as Contractors and other AEC professionals seemed to indicate that Customer Satisfaction was the most relevant indicator for Project Success. The indicator ranked consistently at fifth place by all categories was Safety Goal. The survey questionnaire approached the questions for indicator ranking by Contractors and other AEC professionals in relevance to the achievements and accomplishments of these performance indicators on BIM assisted projects when compared to Non-BIM projects. The individual category quantitative analysis will discuss this further.

The process oriented key performance indicators on construction projects are identified and listed in table 3.4.1, were identified in the survey as Construction Project Management (CPM) performance indicators. The mean and ranking by category is presented in table 4.3.3.
The Academics who participated in the study indicated that the most relevant measure for assessing performance in Construction Project Management is Schedule Control. Contractors and other AEC professionals seemed to indicate that Earlier Detection of Problems was the top performing Construction Project Management indicator on BIM-assisted projects when compared to their Non-BIM assisted projects. These results are further analyzed and discussed in the quantitative data analysis section for each individual category.

Table 4.3.3 – Construction Project Management Indicator Ranking by Category

<table>
<thead>
<tr>
<th>CPM Performance Indicators</th>
<th>Academics N = 137</th>
<th>Contractors N = 163</th>
<th>Others N = 198</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Mean</td>
<td>S/D</td>
<td>Rank</td>
</tr>
<tr>
<td>Labor Management</td>
<td>5.88</td>
<td>0.96</td>
<td>12</td>
</tr>
<tr>
<td>Subcontractor Management</td>
<td>5.80</td>
<td>0.91</td>
<td>14</td>
</tr>
<tr>
<td>Cost Management</td>
<td>6.10</td>
<td>0.86</td>
<td>3</td>
</tr>
<tr>
<td>Schedule Control</td>
<td>6.14</td>
<td>0.81</td>
<td>1</td>
</tr>
<tr>
<td>Work Progress</td>
<td>6.04</td>
<td>0.77</td>
<td>6</td>
</tr>
<tr>
<td>Quality Management</td>
<td>6.07</td>
<td>0.95</td>
<td>5</td>
</tr>
<tr>
<td>Earlier Detection of Problems</td>
<td>6.11</td>
<td>0.90</td>
<td>2</td>
</tr>
<tr>
<td>Information Management</td>
<td>6.01</td>
<td>0.92</td>
<td>9</td>
</tr>
<tr>
<td>Communication Effectiveness</td>
<td>6.10</td>
<td>0.93</td>
<td>4</td>
</tr>
<tr>
<td>Communication Method</td>
<td>5.68</td>
<td>1.00</td>
<td>19</td>
</tr>
<tr>
<td>Communication Frequency</td>
<td>5.68</td>
<td>0.92</td>
<td>18</td>
</tr>
<tr>
<td>Coordination Tools</td>
<td>5.67</td>
<td>1.02</td>
<td>20</td>
</tr>
<tr>
<td>Open Information Sharing</td>
<td>5.78</td>
<td>1.07</td>
<td>15</td>
</tr>
<tr>
<td>Material Management</td>
<td>5.73</td>
<td>1.02</td>
<td>17</td>
</tr>
<tr>
<td>Safety Management</td>
<td>6.02</td>
<td>1.00</td>
<td>8</td>
</tr>
<tr>
<td>Joint Solutions</td>
<td>5.75</td>
<td>0.90</td>
<td>16</td>
</tr>
<tr>
<td>Leadership</td>
<td>5.85</td>
<td>1.08</td>
<td>13</td>
</tr>
<tr>
<td>Stakeholder Coordination</td>
<td>5.90</td>
<td>0.93</td>
<td>11</td>
</tr>
<tr>
<td>Decision-Making Process</td>
<td>5.98</td>
<td>0.89</td>
<td>10</td>
</tr>
<tr>
<td>Scope Clarification</td>
<td>6.04</td>
<td>0.89</td>
<td>7</td>
</tr>
</tbody>
</table>

*The numbers in bold indicate ranking among the Top Ten in its category*
4.4 Analysis of Quantitative Survey Data: Academic Participants

The survey created for the Academics was tailored more towards the perceived relevance of BIMM indicators and Construction Performance indicators. This was done in order to evaluate if the survey participants who identified as Academics would agree with the indicators identified through literature and the qualitative interview study. Some demographic information was asked of the Academics, and the breakdown of Academics who identified as USA and Non-USA are presented in figure 4.4.1.

![Pie chart showing USA vs. Non-USA Academic participation](image)

Figure 4.4.1 – USA vs. Non-USA Survey participation - Academics

85 Academics or 64% of the Academic participants identified themselves to be from the United States of America, while 48 or 36% of the participants indicated that they were Non-USA Academics. The Non-USA participation represented the following countries: China, Canada, Turkey, United Kingdom, Brazil, Denmark, Germany, Kuwait, Greece, Italy, Taiwan, India,
Australia, Colombia, New Zealand, The Netherlands, South Korea, Ireland, Lebanon, Egypt, Luxembourg and Sri Lanka.

The Position / Title of Academic respondents ranged from Ph.D candidate, instructor, senior lecturer, assistant professor, associate professor, emeritus professor, department chair, dean, vice president and retired professor. The academic experience of the respondents ranged from less than one year to 45 years. The industry experience of the Academics who responded to the survey ranged from no industry experience to 55 years of industry experience. Some of the participants indicated that they had served in academia while concurrently working as an industry practitioner.

The Academics were further assessed under selected groupings within the Academic respondent category. Based on the available demographic information provided through the survey, Academics were divided into groups based on the years of Academic work with BIM. The survey responses from these Academic groups based on the years of Academic work with BIM are presented in table 4.4.1.
The Academics were allocated to four different groups based on the number of years of academic work with BIM. The groups were: 0-2 years, 2-5 years, 5-13 years and over 13 years. There were a few BIMM indicators that were ranked consistently among the top ten and included: Information Delivery Method (IDM), Data Richness, Information Accuracy, Work Flow, Document and Modeling Standard (DMS) and Quality Control. However, it was interesting to observe a contrasting difference of rank based on the experience in number of years working with BIM.
BIM. One of the striking differences observed was in Interoperability, which was ranked as the top indicator for measuring BIMM by Academics with over 13 years of experience and was ranked at 26 by Academics with 0-2 years of working with BIM. It is also observed that as the years of experience working with BIM increased, the rank of Interoperability as an indicator to measure BIMM also increased. An ANOVA test was conducted to assess any statistical difference between the mean rankings based on the Academics years of experience working with BIM. The condition for statistical significance is $P < 0.05$. Interoperability and Senior Leadership were noted as indicators with a statistically significant difference in Mean ranking. Documentation and Modeling Standard seem to have been identified as the overall top relevant measure for BIMM from the Academic’s perspective.

The level of Academic expertise was also considered for analysis in ranking of measures for BIMM. The categories included: Low Confidence, Medium Confidence, High Confidence and Expert Confidence. The results according to this grouping are presented in table 4.4.2.
Table 4.4.2 – BIMM Indicator Ranking by Academics Level of Confidence with BIM

<table>
<thead>
<tr>
<th>BIMM Indicator</th>
<th>Low Confidence N = 29</th>
<th>Medium Confidence N = 27</th>
<th>High Confidence N = 49</th>
<th>Expert Confidence N = 21</th>
<th>ANOVA</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Mean</td>
<td>S/D</td>
<td>Rank</td>
<td>Mean</td>
<td>S/D</td>
</tr>
<tr>
<td>Software Application</td>
<td>5.21</td>
<td>1.26</td>
<td>7</td>
<td>5.19</td>
<td>1.39</td>
</tr>
<tr>
<td>Interoperability</td>
<td>4.93</td>
<td>1.46</td>
<td>21</td>
<td>4.81</td>
<td>1.57</td>
</tr>
<tr>
<td>Hardware Equipment</td>
<td>4.86</td>
<td>1.13</td>
<td>24</td>
<td>4.67</td>
<td>1.52</td>
</tr>
<tr>
<td>Hardware Upgrade</td>
<td>4.21</td>
<td>1.47</td>
<td>28</td>
<td>4.33</td>
<td>1.59</td>
</tr>
<tr>
<td>IDM</td>
<td>5.31</td>
<td>1.14</td>
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<td>5.63</td>
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<td>4.96</td>
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<td>PTI</td>
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<td>Strategic Planning</td>
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<td>1.65</td>
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<td>Lifecycle Process</td>
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<td>5.04</td>
<td>1.37</td>
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<td>1.09</td>
<td>17</td>
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<td>1.20</td>
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<td>Risk Management</td>
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<td>12</td>
<td>5.04</td>
<td>1.32</td>
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<td>4.70</td>
<td>1.35</td>
</tr>
<tr>
<td>Quality Control</td>
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<td>1</td>
<td>5.59</td>
<td>1.22</td>
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<td>11</td>
<td>5.37</td>
<td>1.31</td>
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<td>Senior Leadership</td>
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<td>1.13</td>
<td>26</td>
<td>4.74</td>
<td>1.32</td>
</tr>
<tr>
<td>RR</td>
<td>4.93</td>
<td>1.10</td>
<td>20</td>
<td>4.74</td>
<td>1.38</td>
</tr>
<tr>
<td>Reward System</td>
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<td>27</td>
<td>4.19</td>
<td>1.52</td>
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<td>Competency Profile</td>
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<td>1.01</td>
<td>22</td>
<td>4.96</td>
<td>1.22</td>
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<td>Training Program</td>
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<td>4.96</td>
<td>1.39</td>
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<td>TDM</td>
<td>5.00</td>
<td>1.22</td>
<td>16</td>
<td>4.74</td>
<td>1.43</td>
</tr>
</tbody>
</table>

*The numbers in bold indicate ranking among the Top Ten in its category / ANOVA significance
* P < 0.05 indicates statistical significance between mean rankings

The BIMM indicators that ranked consistently in the top ten for all categories included: Information Delivery Method (IDM), Data Richness, Information Accuracy, Work Flow, Documentation and Modeling Standards (DMS), and Quality Control. Similar to the analysis done for years of Academic work with BIM, it can be observed that the higher the level of BIM expertise, the higher the rank of Interoperability. Documentation and Modeling Standards could be identified as the top measure for BIMM as it is the only indicator that was always ranked among
the top 3 indicators of BIMM based on the Academic’s level of expertise. The ANOVA test for statistical significance between the mean scores indicated that there is significance for Interoperability, Information Delivery Method (IDM) and Process and Technology Innovation (PTI). All these indicators met the condition for statistical significance which was $P < 0.05$.

The survey was also designed to assess the Academic’s perspective on relevance of Project Success indicators identified through literature review. The Project Success indicators that were identified and their rankings based on mean and standard deviation are presented in Table 4.4.3.

**Table 4.4.3 – Relevance of Project Success Indicators by Years of Academic Work with BIM**

<table>
<thead>
<tr>
<th>Project Success Indicators</th>
<th>0 - 2 Years N = 32</th>
<th>2 - 5 Years N = 30</th>
<th>5 - 13 Years N = 29</th>
<th>Over 13 Years N = 22</th>
<th>ANOVA</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Mean</td>
<td>S/D</td>
<td>Rank</td>
<td>Mean</td>
<td>S/D</td>
</tr>
<tr>
<td>Cost Goal</td>
<td>5.27</td>
<td>1.36</td>
<td>1</td>
<td>6.20</td>
<td>0.81</td>
</tr>
<tr>
<td>Schedule Goal</td>
<td>5.94</td>
<td>1.20</td>
<td>2</td>
<td>6.17</td>
<td>0.87</td>
</tr>
<tr>
<td>Quality Goal</td>
<td>5.78</td>
<td>1.34</td>
<td>4</td>
<td>6.50</td>
<td>0.84</td>
</tr>
<tr>
<td>Safety Goal</td>
<td>5.69</td>
<td>1.38</td>
<td>6</td>
<td>6.10</td>
<td>1.03</td>
</tr>
<tr>
<td>Customer Satisfaction</td>
<td>5.97</td>
<td>1.36</td>
<td>2</td>
<td>6.23</td>
<td>0.90</td>
</tr>
<tr>
<td>Total Number of Change Orders</td>
<td>4.88</td>
<td>1.29</td>
<td>13</td>
<td>4.90</td>
<td>0.96</td>
</tr>
<tr>
<td>Total Cost of Change Orders</td>
<td>5.06</td>
<td>1.32</td>
<td>12</td>
<td>5.17</td>
<td>1.05</td>
</tr>
<tr>
<td>Total Cost of Rework</td>
<td>5.59</td>
<td>1.29</td>
<td>7</td>
<td>5.70</td>
<td>1.24</td>
</tr>
<tr>
<td>Total Cost of Punch List Items</td>
<td>5.06</td>
<td>1.22</td>
<td>11</td>
<td>5.27</td>
<td>1.14</td>
</tr>
<tr>
<td>Total Number of Near Misses</td>
<td>4.34</td>
<td>1.19</td>
<td>14</td>
<td>5.07</td>
<td>1.01</td>
</tr>
<tr>
<td>Total Number of Site Accidents</td>
<td>5.53</td>
<td>1.34</td>
<td>9</td>
<td>5.73</td>
<td>1.31</td>
</tr>
<tr>
<td>Total Number of Legal Claims and Litigations</td>
<td>5.22</td>
<td>1.46</td>
<td>10</td>
<td>5.17</td>
<td>1.26</td>
</tr>
<tr>
<td>Total Cost of Legal Claims and Litigations</td>
<td>5.59</td>
<td>1.32</td>
<td>8</td>
<td>5.70</td>
<td>1.34</td>
</tr>
<tr>
<td>Total Number of Repeat Customers</td>
<td>5.75</td>
<td>1.34</td>
<td>6</td>
<td>5.87</td>
<td>1.28</td>
</tr>
</tbody>
</table>

The numbers in bold indicate ranking among the Top Five in its category  
* P < 0.05 indicates statistical significance between mean rankings

The ranking of Project Success indicators were again analyzed based on the Academic’s years of Academic experience with BIM and were grouped as: 0-2 years, 2-5 years, 5-13 years and over 13 years of experience. The Project Success indicators that were identified consistently in the top five indicators were: Cost Goal, Schedule Goal, Quality Goal and Customer Satisfaction. The cut-off point for relevance is a 4.00 mean score. The lowest recorded mean score is 4.84 for Total Number of Near Misses but is still sufficient to be considered relevant for measuring Project Success. Therefore, based on the Academics perspective all of the 14 identified indicators are
considered relevant for assessing / measuring Project Success on a construction project. The ANOVA test for significance between mean scores indicated that there was no statistically significant difference in mean scores for Project Success indicators based on the Academic years of experience working with BIM.

The relevance of Project Success indicators as ranked by the Academics were also evaluated based on the Academics level of confidence with BIM. This was done to cross check for any significant differences from the analysis done for years of experience in Academic work with BIM. The confidence levels were grouped as: Low Confidence, Medium Confidence, High Confidence and Expert Confidence. The mean scores and standard deviations based on the groupings for confidence with BIM are presented in table 4.4.4 and are discussed below.

Table 4.4.4 – Relevance of Project Success Indicators by Level of Confidence with BIM

<table>
<thead>
<tr>
<th>Project Success Indicators</th>
<th>Low Confidence N = 59</th>
<th>Medium Confidence N = 57</th>
<th>High Confidence N = 49</th>
<th>Expert Confidence N = 21</th>
<th>ANOVA</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Mean S.D Rank</td>
<td>Mean S.D Rank</td>
<td>Mean S.D Rank</td>
<td>Mean S.D Rank</td>
<td>F</td>
</tr>
<tr>
<td>Cost Goal</td>
<td>6.47 0.86 2</td>
<td>5.98 1.34 6</td>
<td>6.16 0.85 2</td>
<td>8.48 0.81 3</td>
<td>.927</td>
</tr>
<tr>
<td>Schedule Goal</td>
<td>6.14 0.85 3</td>
<td>5.60 1.27 3</td>
<td>6.14 0.82 3</td>
<td>5.67 0.68 2</td>
<td>1.562</td>
</tr>
<tr>
<td>Quality Goal</td>
<td>6.03 0.84 4</td>
<td>6.04 1.29 1</td>
<td>6.20 0.84 1</td>
<td>8.37 0.80 1</td>
<td>1.841</td>
</tr>
<tr>
<td>Safety Goal</td>
<td>5.97 1.02 6</td>
<td>5.81 1.27 7</td>
<td>6.08 1.08 5</td>
<td>6.29 0.85 5</td>
<td>.619</td>
</tr>
<tr>
<td>Customers Satisfaction</td>
<td>6.21 0.94 1</td>
<td>5.64 1.29 1</td>
<td>6.14 0.89 4</td>
<td>5.58 0.74 4</td>
<td>.432</td>
</tr>
<tr>
<td>Total Number of Change Orders</td>
<td>4.72 1.05 14</td>
<td>4.78 1.37 14</td>
<td>5.24 0.59 13</td>
<td>5.10 1.04 14</td>
<td>1.427</td>
</tr>
<tr>
<td>Total Cost of Change Orders</td>
<td>4.83 0.97 13</td>
<td>5.00 1.44 13</td>
<td>5.43 1.00 10</td>
<td>5.36 1.16 12</td>
<td>1.750</td>
</tr>
<tr>
<td>Total Cost of Rework</td>
<td>5.25 0.91 9</td>
<td>5.81 1.27 7</td>
<td>5.90 1.08 6</td>
<td>6.05 1.07 8</td>
<td>.800</td>
</tr>
<tr>
<td>Total Cost of Punch List Items</td>
<td>5.03 0.87 11</td>
<td>5.22 1.22 11</td>
<td>5.33 1.07 11</td>
<td>5.62 0.52 11</td>
<td>1.165</td>
</tr>
<tr>
<td>Total Number of Near Misses</td>
<td>5.00 0.86 12</td>
<td>5.11 1.23 12</td>
<td>5.31 1.14 12</td>
<td>5.24 0.89 12</td>
<td>4.75</td>
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<tr>
<td>Total Number of Site Abandonments</td>
<td>5.66 1.17 7</td>
<td>5.74 1.26 9</td>
<td>5.84 1.37 7</td>
<td>6.29 0.85 5</td>
<td>.654</td>
</tr>
<tr>
<td>Total Number of Legal Claims and Litigations</td>
<td>5.07 1.10 10</td>
<td>5.44 1.25 10</td>
<td>5.18 1.23 14</td>
<td>5.81 1.03 9</td>
<td>1.626  .172</td>
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<tr>
<td>Total Cost of Legal Claims and Litigations</td>
<td>5.62 1.21 8</td>
<td>5.96 1.26 4</td>
<td>5.51 1.37 9</td>
<td>6.05 0.97 7</td>
<td>1.119  .350</td>
</tr>
<tr>
<td>Total Number of Repeat Customers</td>
<td>5.97 0.98 5</td>
<td>5.96 1.26 4</td>
<td>5.67 1.30 8</td>
<td>5.76 0.83 10</td>
<td>.464</td>
</tr>
</tbody>
</table>

*The numbers in bold indicate ranking among the Top Five in its category
* P < 0.05 indicates statistical significance between mean rankings

The Project Success indicators that consistently ranked among the top five included: Schedule Goal, Quality Goal and Customer Satisfaction. In comparison, the only indicator not consistently identified in the top 5 is Cost Goal. While the mean score of the Cost Goal for
Academics with medium confidence in BIM was the same as the mean scores for Total Cost of Legal Claims and Litigations and also the indicator identified as Total Number of Repeat Customers, the Cost Goal indicator was ranked in sixth place for that category based on the standard deviation. The cut-off mark in mean score for relevance is 4.00 and the lowest mean score is 4.72 for Total number of Change Orders as ranked by Academics with low confidence in BIM. The ANOVA test returned no significance between the means scores for any of the Project Success indicators based on the Academics level of confidence with BIM. Based on the mean scores and the ANOVA test, all identified Project Success indicators are considered relevant.

As part of creating and testing a Construction Performance matrix and assessing the impact of BIM on Construction Performance, indicators for Construction Project Management (CPM) were also identified and presented in the survey for ranking. The indicators with their mean and ranking are presented in table 4.4.5.
Table 4.4.5 – Relevance of CPM Indicators by Years of Academic Work with BIM

<table>
<thead>
<tr>
<th>Construction Project Management Indicators</th>
<th>0 - 2 Years N = 32</th>
<th>2 - 5 Years N = 30</th>
<th>5 - 13 Years N = 29</th>
<th>Over 13 Years N = 22</th>
<th>ANOVA</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Mean</td>
<td>S/D</td>
<td>Rank</td>
<td>Mean</td>
<td>S/D</td>
</tr>
<tr>
<td>Labor Management</td>
<td>5.01</td>
<td>1.20</td>
<td>8</td>
<td>5.63</td>
<td>1.13</td>
</tr>
<tr>
<td>Subcontractor Management</td>
<td>5.72</td>
<td>1.14</td>
<td>13</td>
<td>5.70</td>
<td>1.02</td>
</tr>
<tr>
<td>Cost Management</td>
<td>6.00</td>
<td>1.16</td>
<td>2</td>
<td>6.10</td>
<td>1.06</td>
</tr>
<tr>
<td>Schedule Control</td>
<td>6.06</td>
<td>1.01</td>
<td>1</td>
<td>6.30</td>
<td>0.65</td>
</tr>
<tr>
<td>Work Progress</td>
<td>5.97</td>
<td>1.06</td>
<td>3</td>
<td>6.10</td>
<td>0.51</td>
</tr>
<tr>
<td>Quality Management</td>
<td>5.91</td>
<td>1.15</td>
<td>4</td>
<td>5.97</td>
<td>1.19</td>
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<td>Earlier Detection of Problems</td>
<td>5.88</td>
<td>1.16</td>
<td>5</td>
<td>6.33</td>
<td>0.84</td>
</tr>
<tr>
<td>Information Management</td>
<td>5.81</td>
<td>1.28</td>
<td>11</td>
<td>5.97</td>
<td>0.85</td>
</tr>
<tr>
<td>Communication Effectiveness</td>
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<td>1.20</td>
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<td>6.27</td>
<td>0.83</td>
</tr>
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<td>5.63</td>
<td>1.03</td>
</tr>
<tr>
<td>Communication Frequency</td>
<td>5.53</td>
<td>1.11</td>
<td>20</td>
<td>5.73</td>
<td>0.94</td>
</tr>
<tr>
<td>Coordination Tools</td>
<td>5.56</td>
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<td>19</td>
<td>5.63</td>
<td>1.00</td>
</tr>
<tr>
<td>Open Information Sharing</td>
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<td>5.78</td>
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<td>5.67</td>
<td>1.12</td>
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<td>Safety Management</td>
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<td>1.32</td>
<td>6</td>
<td>5.97</td>
<td>1.16</td>
</tr>
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<td>Joint Solutions</td>
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<td>1.10</td>
<td>16</td>
<td>5.90</td>
<td>0.96</td>
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<tr>
<td>Leadership</td>
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<td>5.90</td>
<td>1.06</td>
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<td>6.13</td>
<td>0.82</td>
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<td>Decision-Making Process</td>
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<td>6.23</td>
<td>0.77</td>
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<td>1.26</td>
<td>10</td>
<td>6.23</td>
<td>0.77</td>
</tr>
</tbody>
</table>

*The numbers in bold indicate ranking among the Top Ten in its category
* P < 0.05 indicates statistical significance between mean rankings

The Construction Project Management (CPM) indicators that were consistently ranked among the top ten included: Cost Management, Work Progress, Earlier Detection of Problems, Communication Effectiveness, Safety Management and Scope Clarification. Schedule Control was ranked among the top 2 indicators under all groups except the Academics who identified within the group for 5-13 years of Academic experience and work with BIM. This group ranked Schedule Control at the 11th place and therefore it did not rank consistently among all groups to be placed in the top ten. The cut-off mean score for relevance of CPM indicators is 4.00, and the lowest mean score was 5.53 for communication frequency. The ANOVA test indicated that there was no significant difference between the means scores for CPM based on the years of Academic
work with BIM. Therefore, all identified CPM indicators are considered relevant for assessing Construction / Project Management performance. The relevance of CPM indicators were also analyzed based on the Academics confidence with BIM. The mean score and ranking for this analysis can be seen in table 4.4.6.

Table 4.4.6 – Relevance of CPM Indicators by Academics Level of Confidence with BIM

<table>
<thead>
<tr>
<th>Construction Project Management Indicators</th>
<th>Low Confidence N = 59</th>
<th>Medium Confidence N = 27</th>
<th>High Confidence N = 49</th>
<th>Expert Confidence N = 21</th>
<th>ANOVA</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Mean</td>
<td>S/D</td>
<td>Rank</td>
<td>Mean</td>
<td>S/D</td>
</tr>
<tr>
<td>Labor Management</td>
<td>5.72</td>
<td>0.96</td>
<td>11</td>
<td>5.74</td>
<td>0.94</td>
</tr>
<tr>
<td>Subcontractor Management</td>
<td>5.59</td>
<td>1.02</td>
<td>17</td>
<td>5.81</td>
<td>0.96</td>
</tr>
<tr>
<td>Cost Management</td>
<td>6.00</td>
<td>0.96</td>
<td>2</td>
<td>6.07</td>
<td>0.83</td>
</tr>
<tr>
<td>Schedule Control</td>
<td>6.07</td>
<td>0.84</td>
<td>1</td>
<td>6.11</td>
<td>0.83</td>
</tr>
<tr>
<td>Work Progress</td>
<td>5.86</td>
<td>0.95</td>
<td>6</td>
<td>5.89</td>
<td>0.89</td>
</tr>
<tr>
<td>Quality Management</td>
<td>5.97</td>
<td>1.02</td>
<td>3</td>
<td>6.07</td>
<td>0.87</td>
</tr>
<tr>
<td>Earlier Detection of Problems</td>
<td>5.79</td>
<td>1.01</td>
<td>8</td>
<td>5.30</td>
<td>0.82</td>
</tr>
<tr>
<td>Information Management</td>
<td>5.90</td>
<td>0.90</td>
<td>4</td>
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<td>14</td>
<td>6.04</td>
<td>0.98</td>
</tr>
</tbody>
</table>

*The numbers in bold indicate ranking among the Top Ten in its category
* P < 0.05 indicates statistical significance between mean rankings

The CPM indicators that were consistently ranked among the top ten by Academics based on their confidence level with BIM include: Cost Management, Schedule Control, Work Progress, Quality Management, Earlier Detection of Problems and Communication Effectiveness. When compared to the analysis done for groupings based on the years of Academic experience with BIM, Safety Management and Scope Clarification did not consistently rank among the top ten relevant
indicators for CPM. The cut-off mean score was 4.00 and the lowest mean score was 5.33 for Coordination Tools. Therefore, all identified CPM indicators are considered relevant.

4.5 Analysis of Quantitative Survey Data: Contractor Participants

The survey for Contractors was designed with the objective of gaining more insights and understanding on the current usage of BIM. Through this survey, we also attempted to gain insights into the practitioner perspectives on how BIM is impacting construction and in what identified areas of Project Success and Construction Project Management (CPM). The Contractor survey had a total of 163 participants, of whom 103 identified as General Contractor (GC), 41 identified as Construction Manager (CM) and 19 identified as Other Contractors.

![Figure 4.5.1 – Contractor Survey Participation Breakdown](image)

The largest group that participated in the Contractor’s survey were General Contractors at 63% of the participants, followed by Construction Managers with 25% of the participants. Other
Contractors made up the smallest portion with 12% and mostly included Contractors who identified their work to be divided between the roles of GC and CM. The participant breakdown for the contractor survey can be seen in Figure 4.5.1.

![Bar Chart Figure 4.5.1 - Contractor Breakdown](chart.png)

**Figure 4.5.1 – Participant Breakdown for Contractor Survey**

The survey assessed the approximate time frame during which companies began to implement BIM. Figure 4.5.2 presents the breakdown of when BIM was implemented by the participant’s company. It was interesting to note that among the participants, there was a steady increase in BIM implementation from the years prior 1990 and up until 2008. From 2009, BIM implementation of companies represented by the participants continued to increase but at a reduced rate. While there is no tangible evidence for this, the reduction may be due to current contractor perceptions of BIM and the continuation of BIM implementation by companies could be driven by the various drivers for BIM such as increasing productivity, client expectations and industry competitiveness. Thirty-three of the participants indicated that their companies have not yet started

![Bar Chart Figure 4.5.2 - BIM Implementation Timeline](chart2.png)

**Figure 4.5.2 – When was BIM implemented by the Contractor**
to use BIM, and this is indicative that BIM is not yet fully used by all in industry and still has a market for BIM adoption.

![Percentage of BIM-assisted Projects](image)

**Figure 4.5.3 – Percentage of BIM-assisted Projects**

Nearly 30% of the survey participants, stated that over 75% of their projects are BIM-assisted projects. While, approximately 40% of the survey respondents stated that they had no BIM-assisted projects or used BIM on less than 30% of their projects. The breakdown percentage of BIM-assisted projects by the survey participants can be observed in figure 4.5.3. This also shows that the number and percentage of BIM-assisted projects within companies that have already implemented BIM can be further increased. While there maybe reasons for not having implemented BIM on all projects, more data and information on the impact of BIM on construction could possibly improve the case for BIM adoption and implementation on construction projects.

Survey respondents were asked to identify the building type/s for the majority of their BIM-assisted projects and the results indicated that the top 3 building types / markets that utilized BIM
were Commercial, Healthcare and Educational construction. BIM-assisted projects not identified in the survey but listed by survey respondents under the “Other” category included: Aviation, Ship building, Laboratory, Theme Parks, Stadium, Government Buildings and Historical Restoration. The building types of a majority of BIM-assisted projects are graphically presented in figure 4.5.4.

A total of 92 survey respondents indicated that their BIM-assisted projects were commercial projects, while 67 respondents indicated healthcare followed by 60 respondents indicating educational. The building types that seemed to have the least number of Contractors identify them as BIM-assisted projects were transportation and residential projects. The count for the delivery method used in a majority of the BIM-assisted construction projects indicated Design-Build (DB) to be the leading delivery method utilizing BIM followed by Construction Management (CM) at Risk and Design-Bid-Build (DBB). Other delivery methods identified by survey respondents in the other category included: Guaranteed Maximum Price (GMP), Design-
Assist and Two-Stage Procurement. The results of the delivery type utilized on a majority of BIM-assisted projects from the Contractors perspective is presented in figure 4.5.5.

![Figure 4.5.5 – Contractors’ BIM-assisted Project Delivery](image)

The number/count of participants who indicated Design-Build as the most common delivery method for BIM-assisted projects was 82, followed by 74 participants who identified Construction Management (CM) at Risk as the leading delivery method for BIM-assisted projects.

Contractors were then asked to identify the main drivers for adopting BIM on their construction projects and the majority of participants indicated the reason to be enhancing productivity. The count for participants who indicated enhancing productivity as one of the main drivers was 94, followed by competitive advantage at 68, and a leader in the industry who explores and adopts new trends at 66. Owners also seemed to be an important driver for BIM adoption by Contractors with 61 of the Contractors identifying owners as a driver. Policy and Success stories
of others using BIM had a lower count at 3 and 14 respectively. The responses to this question are graphically presented in figure 4.5.6.

![Graph showing contractors' drivers for adopting BIM](image)

**Figure 4.5.6 – Contractors’ Drivers for Adopting BIM**

The Contractors were asked to rank the BIMM indicators based on the extent to which the indicators were addressed by BIM on BIM-assisted construction projects. The first analysis for contractor rankings were done by Business Type. The Business Type groups included Construction Manager, General Contractor and Other Contractors. The mean scores and their rankings are presented in table 4.5.1.
Table 4.5.1 – BIMM Indicator Ranking by Contractors’ Business Type

<table>
<thead>
<tr>
<th>BIMM Indicator</th>
<th>Construction Manager N = 41</th>
<th>General Contractor N = 103</th>
<th>Other Contractor N = 19</th>
<th>ANOVA</th>
</tr>
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<tbody>
<tr>
<td></td>
<td>Mean</td>
<td>S/D</td>
<td>Rank</td>
<td>Mean</td>
</tr>
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<td>Software Application</td>
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<td>7</td>
<td>5.21</td>
</tr>
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<td>Interoperability</td>
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<td>1.45</td>
<td>15</td>
<td>4.98</td>
</tr>
<tr>
<td>Hardware Equipment</td>
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<td>1.32</td>
<td>17</td>
<td>4.26</td>
</tr>
<tr>
<td>Hardware Upgrade</td>
<td>4.27</td>
<td>1.18</td>
<td>16</td>
<td>4.08</td>
</tr>
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<td>Information Delivery Method</td>
<td>4.78</td>
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<td>4</td>
<td>5.11</td>
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<td>Information Assurance</td>
<td>4.31</td>
<td>1.40</td>
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<td>Data Richness</td>
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<td>1.41</td>
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<td>Graphics</td>
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<td>1</td>
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<tr>
<td>Work Flow</td>
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<td>1.20</td>
<td>12</td>
<td>4.87</td>
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<tr>
<td>Document and Modeling Standard</td>
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<td>1.31</td>
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<tr>
<td>Process and Technology Innovation</td>
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<td>Strategic Planning</td>
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<td>5</td>
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</tr>
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<td>Training Program</td>
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</tr>
<tr>
<td>Training Delivery Method</td>
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<td>1.11</td>
<td>19</td>
<td>4.11</td>
</tr>
</tbody>
</table>

*The numbers in bold indicate ranking among the Top Ten in its category / ANOVA significance
* P < 0.05 indicates statistical significance between mean rankings

BIMM indicators that consistently ranked in the top ten regardless of Business Type included: Software Application, Information Delivery Method, Information Accuracy, Graphics, Documentation and Modeling Standards and Quality Control. The indicators that were least addressed by BIM according to all Business Types were: Reward System and Lifecycle Process.
There also seemed to be more similarity in rankings between General Contractors and Other Contractors, when compared against the rankings of survey participants who identified themselves as Construction Managers. An ANOVA test was conducted to assess if there is statistical significance in the mean score based on the Contractor’s Business Type. The results indicated that Quality Control was the only BIMM indicator that had a statistically significant difference in mean scores between Business Types.

A second analysis of mean and ranking was done based on the Contractor’s experience by number of BIM-assisted projects. The groups for experience by number of projects were: 1 to 5, 6 to 15, 16 to 40, 41 to 100 and 100+ projects. The mean scores and ranks for these are presented in table 4.5.2.
Table 4.5.2 – BIMM Indicator Ranking by Contractor Experience - Number of BIM-Projects

<table>
<thead>
<tr>
<th>BIMM Indicator</th>
<th>1 to 5 Projects N = 53</th>
<th>6 to 12 Projects N = 30</th>
<th>16 to 40 Projects N = 18</th>
<th>41 to 100 Projects N = 11</th>
<th>10+ Projects N = 18</th>
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<td>4.40</td>
<td>1.69</td>
</tr>
</tbody>
</table>

*The numbers in bold indicate ranking among the Top Ten in its category

The indicators of BIMM that are consistently addressed from the contractor perspective based on the number of BIM-assisted projects include: Software Application, Graphics, and Document and Modeling Standards. Other indicators that were identified by all categories but one included: Information Delivery Method, Information Accuracy, Strategic Planning, Quality Control and Role and Responsibility. Indicators that were consistently ranked low were: Reward System and Lifecycle Process.
The final analysis of mean scores and ranking for the extent to which BIMM indicators were addressed on BIM-assisted projects was based on the number of years that the Contractors had worked with BIM. The groupings for the number of years with BIM were: 0 to 2 years, 2 to 8 years, 8 to 13 years, 13 to 20 years and 20+ years. The groupings that captured the 13 year mark were also grouped to assess if there is any observations based on the data collected for when the Contractor had implemented BIM in their companies. The mean scores and ranks for the mean scores and rankings of BIMM indicators based on the number of years working with BIM are presented in table 4.5.3.
Table 4.5.3 – BIMM Indicator Ranking by Experience in Number of Years working with BIM

<table>
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<tr>
<th>BIMM Indicator</th>
<th>0 to 2 years N = 19</th>
<th></th>
<th>2 to 8 years N = 53</th>
<th></th>
<th>8 to 15 years N = 32</th>
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<th>13 to 20 years N = 13</th>
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<td>Mean</td>
<td>S/D Rank</td>
<td>Mean</td>
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<td>Software Application</td>
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<td>1.49 3</td>
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<td>Interoperability</td>
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<td>1.91 8</td>
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<td>Hardware Equipment</td>
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<td>4.60</td>
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<td>4.72</td>
<td>1.67 15</td>
<td>4.77</td>
<td>1.92 19</td>
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<td>0.84 20</td>
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<td>Hardware Upgrade</td>
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<td>1.14 5</td>
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<td>IDM</td>
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<td>4.56</td>
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<td>5.00</td>
<td>1.22 21</td>
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<td>1.69 10</td>
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<td>4.28</td>
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<td>1.84 24</td>
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<td>4.87</td>
<td>1.23 8</td>
<td>5.03</td>
<td>1.66 9</td>
<td>5.69</td>
<td>1.26 2</td>
<td>5.60</td>
<td>0.89 7</td>
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<td>1.57 28</td>
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<td>1.38 28</td>
<td>4.23</td>
<td>2.13 25</td>
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<td>1.67 28</td>
</tr>
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<td>Competency Profile</td>
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<td>3.56</td>
<td>1.71 25</td>
<td>4.53</td>
<td>1.57 20</td>
<td>4.46</td>
<td>1.61 21</td>
<td>4.80</td>
<td>1.92 26</td>
</tr>
<tr>
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<td>4.02</td>
<td>1.59 22</td>
<td>4.13</td>
<td>1.64 23</td>
<td>4.31</td>
<td>1.44 24</td>
<td>5.40</td>
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</tr>
<tr>
<td>TDM</td>
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<td>1.34 22</td>
<td>4.00</td>
<td>1.58 24</td>
<td>4.28</td>
<td>1.71 21</td>
<td>4.15</td>
<td>1.46 26</td>
<td>5.60</td>
<td>1.14 5</td>
</tr>
</tbody>
</table>

*The numbers in bold indicate ranking among the Top Ten in its category

The BIMM indicators that were consistently ranked among the top ten as addressed on BIM-assisted projects included: Software Application, Graphics, Documentation and Modeling Standard and Quality Control. Indicators that were ranked among the top ten by all but one group included: Information Delivery Method, Strategic Planning and Role and Responsibility. A majority of the BIMM indicators that are ranked in the top ten are related to the BIMM factors of Technology and Information, while there are indicators from the Process and People factors, it
appears that there is still more room for improvement and maturity of a majority of BIMM indicators related to Process and People.

Contractors were asked to indicate the level of BIMM maturity on their BIM-assisted projects based on the BIMM indicators provided. Sixty-nine percent of the participants indicated that they believed the maturity level of their BIM adoption to be mature, while 13% indicated the level of BIM adoption to be immature. Eighteen percent of the participants indicated neutrality on if their BIM adoption was mature or immature. The breakdown for participants’ perception of BIMM is presented in figure 4.5.7.

Figure 4.5.7 – Contractors’ Perception of BIMM

Contractor responses to survey questions designed to assess Project Success on BIM-assisted projects can be observed in table 4.5.4 and table 4.5.5.
Table 4.5.4 – Project Success Indicator Ranking by Contractor - Business Type

<table>
<thead>
<tr>
<th>Project Success Indicator</th>
<th>Construction Manager N = 41</th>
<th>General Contractor N = 103</th>
<th>Other Contractor N = 19</th>
<th>ANOVA</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Mean</td>
<td>S/D</td>
<td>Rank</td>
<td>Mean</td>
</tr>
<tr>
<td>Cost Goal</td>
<td>5.07</td>
<td>0.72</td>
<td>4</td>
<td>4.97</td>
</tr>
<tr>
<td>Schedule Goal</td>
<td>5.17</td>
<td>0.74</td>
<td>3</td>
<td>5.14</td>
</tr>
<tr>
<td>Quality Goal</td>
<td>5.83</td>
<td>0.70</td>
<td>2</td>
<td>5.82</td>
</tr>
<tr>
<td>Safety Goal</td>
<td>5.00</td>
<td>0.74</td>
<td>5</td>
<td>4.90</td>
</tr>
<tr>
<td>Customer Satisfaction</td>
<td>5.88</td>
<td>0.75</td>
<td>1</td>
<td>5.92</td>
</tr>
</tbody>
</table>

* P < 0.05 indicates statistical significance between mean rankings

Table 4.5.5 – Contractor Ratio of Project Success - by Business Type

<table>
<thead>
<tr>
<th>Project Success Attributes</th>
<th>Construction Manager N = 41</th>
<th>General Contractor N = 103</th>
<th>Other Contractor N = 19</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Mean</td>
<td>S/D</td>
<td>Mean</td>
</tr>
<tr>
<td>Design Errors</td>
<td>0.60</td>
<td>0.59</td>
<td>0.54</td>
</tr>
<tr>
<td>RFI during Pre-construction</td>
<td>8.35</td>
<td>3.83</td>
<td>3.77</td>
</tr>
<tr>
<td>RFI during construction</td>
<td>0.78</td>
<td>0.77</td>
<td>0.71</td>
</tr>
<tr>
<td>Number of Change Orders</td>
<td>0.58</td>
<td>0.60</td>
<td>0.56</td>
</tr>
<tr>
<td>Cost of Change Orders</td>
<td>0.50</td>
<td>0.49</td>
<td>0.48</td>
</tr>
<tr>
<td>Cost of Re-work</td>
<td>0.30</td>
<td>0.37</td>
<td>0.35</td>
</tr>
<tr>
<td>Cost of punch list items</td>
<td>0.74</td>
<td>0.63</td>
<td>0.56</td>
</tr>
<tr>
<td>Number of near misses</td>
<td>0.66</td>
<td>0.63</td>
<td>0.55</td>
</tr>
<tr>
<td>Number of site accidents</td>
<td>0.55</td>
<td>0.56</td>
<td>0.48</td>
</tr>
<tr>
<td>Number of legal claims and litigation</td>
<td>0.48</td>
<td>0.51</td>
<td>0.47</td>
</tr>
<tr>
<td>Cost of legal claims and litigation</td>
<td>0.51</td>
<td>0.54</td>
<td>0.49</td>
</tr>
<tr>
<td>Number of repeat customers</td>
<td>0.98</td>
<td>1.06</td>
<td>1.09</td>
</tr>
</tbody>
</table>

The top 2 Project Success indicator rankings were identified to be Customer Satisfaction and Quality Goal followed by Schedule Goal and Cost Goal. Safety goals were also met based on contractor responses to the survey but, it was ranked at fifth place. An ANOVA test was conducted to assess if there was a statistical significance in the difference of mean scores between Business Types. The results indicated that none of the indicators were identified to have a statistically significant difference in mean scores based on Business Type.
The Project Success attributes were also ranked by Contractors who participated in the survey. The question was designed to assess the ratio of Project Success through the identified attributes when compared against Non-BIM assisted projects. The top ranking attribute was RFI’s during Pre-construction which showed an increase when compared to Non-BIM assisted projects. Construction Managers indicated a high ratio of 8.35, General Contractors at 3.83 and other Contractors indicated 3.77 as the ratio for Number of RFI’s during Pre-Construction. All Business Types also indicated that the second highest ratio when comparing BIM-assisted projects to Non-BIM assisted projects was repeat customers. All the ratios for repeat customers were approximately 1.00, which is indicative that there was no significant increase in repeat customers when comparing BIM to Non-BIM-assisted projects.

All other Project Success attributes that were identified seemed to have an improved and reduced ratio when comparing BIM to Non-BIM assisted projects. Cost of re-work was observed to have the best ratio when comparing BIM to Non-BIM assisted projects, with Construction Managers stating approximately 0.39, General Contractors stating 0.37 and Other Contractors listing 0.35 as the ratio for Cost of Re-work on BIM-assisted projects when compared to Non-BIM assisted projects. RFI’s during construction were stated to have a ratio between 0.71 – 0.78 on BIM-assisted projects which would mean that there is an approximately 22% - 29% reduction of RFI’s during the Construction process. The cost of change order and number of site accidents also seem to have a reduction of approximately 0.50 on BIM-assisted projects when compared to Non-BIM assisted projects. There is also a reduction in the number and cost of legal claims and litigation on BIM-assisted projects when compared to Non-BIM assisted projects.

To further examine the data collected from Contractors as it relates to the impact of BIM on Project Success, participants were grouped based on the Number of BIM-assisted projects. The
ranking of Project Success indicators can be found in table 4.5.6 and the ratios of Project Success attributes on BIM-assisted projects when compared to Non-BIM assisted projects are presented in table 4.5.7.

Table 4.5.6 – Project Success Indicator Ranking by Contractor - Number of BIM-assisted Projects

<table>
<thead>
<tr>
<th>Project Success Indicator</th>
<th>1 to 5 Projects N = 53</th>
<th>6 to 15 Projects N = 30</th>
<th>16 to 40 Projects N = 18</th>
<th>41 to 100 Projects N = 11</th>
<th>100+ Projects N = 18</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cost Goal</td>
<td>4.85 0.89 4</td>
<td>5.17 1.15 4</td>
<td>5.28 0.75 4</td>
<td>5.00 1.00 4</td>
<td>5.17 0.38 4</td>
</tr>
<tr>
<td>Schedule Goal</td>
<td>4.98 0.75 3</td>
<td>5.37 0.93 3</td>
<td>5.56 1.04 3</td>
<td>5.09 0.83 3</td>
<td>5.28 0.75 3</td>
</tr>
<tr>
<td>Quality Goal</td>
<td>5.64 0.92 2</td>
<td>6.03 0.76 1</td>
<td>5.83 0.86 2</td>
<td>5.92 0.87 1</td>
<td>6.06 0.42 2</td>
</tr>
<tr>
<td>Safety Goal</td>
<td>4.83 0.87 5</td>
<td>5.07 0.94 5</td>
<td>4.94 0.80 5</td>
<td>4.73 0.93 5</td>
<td>5.06 0.54 5</td>
</tr>
<tr>
<td>Customer Satisfaction</td>
<td>5.88 0.96 1</td>
<td>6.05 0.85 1</td>
<td>5.17 0.79 1</td>
<td>5.82 0.87 1</td>
<td>6.28 0.46 1</td>
</tr>
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</table>

Table 4.5.7 – Contractor Ratio of Project Success - by Number of BIM-assisted Projects

<table>
<thead>
<tr>
<th>Project Success Attributes</th>
<th>1 to 5 Projects N = 53</th>
<th>6 to 15 Projects N = 30</th>
<th>16 to 40 Projects N = 18</th>
<th>41 to 100 Projects N = 11</th>
<th>100+ Projects N = 18</th>
</tr>
</thead>
<tbody>
<tr>
<td>Design Errors</td>
<td>0.61</td>
<td>0.61</td>
<td>0.58</td>
<td>0.49</td>
<td>0.57</td>
</tr>
<tr>
<td>RFI during Pre-construction</td>
<td>3.51</td>
<td>10.11</td>
<td>3.15</td>
<td>2.90</td>
<td>3.71</td>
</tr>
<tr>
<td>RFI during construction</td>
<td>0.73</td>
<td>0.93</td>
<td>0.72</td>
<td>0.59</td>
<td>0.74</td>
</tr>
<tr>
<td>Number of Change Orders</td>
<td>0.60</td>
<td>0.67</td>
<td>0.55</td>
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<td>0.55</td>
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<tr>
<td>Cost of Change Orders</td>
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<td>0.51</td>
<td>0.47</td>
<td>0.42</td>
<td>0.46</td>
</tr>
<tr>
<td>Cost of Re-work</td>
<td>0.38</td>
<td>0.35</td>
<td>0.38</td>
<td>0.30</td>
<td>0.38</td>
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<tr>
<td>Cost of punch list items</td>
<td>0.65</td>
<td>0.76</td>
<td>0.60</td>
<td>0.52</td>
<td>0.60</td>
</tr>
<tr>
<td>Number of near misses</td>
<td>0.60</td>
<td>0.76</td>
<td>0.60</td>
<td>0.50</td>
<td>0.62</td>
</tr>
<tr>
<td>Number of site accidents</td>
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<td>0.61</td>
<td>0.58</td>
<td>0.46</td>
<td>0.53</td>
</tr>
<tr>
<td>Number of legal claims and litigation</td>
<td>0.49</td>
<td>0.56</td>
<td>0.51</td>
<td>0.43</td>
<td>0.48</td>
</tr>
<tr>
<td>Cost of legal claims and litigation</td>
<td>0.52</td>
<td>0.56</td>
<td>0.55</td>
<td>0.45</td>
<td>0.49</td>
</tr>
<tr>
<td>Number of repeat customers</td>
<td>0.97</td>
<td>1.24</td>
<td>1.01</td>
<td>0.87</td>
<td>1.10</td>
</tr>
</tbody>
</table>

When evaluating the results based on the number of projects, we again observe that Customer Satisfaction was the top ranking Project Success indicator that was achieved on BIM-assisted projects when compared to Non-BIM assisted projects. The other Project Success achievements were for the following indicators in order of Quality Goal, Schedule Goal, Cost Goal and Safety Goal. The ratios presented in table 4.5.7 were mostly consistent with the observations.
made on ratios expressed by the different Business Types. In some categories for number of projects, there seemed to be an increase in the number of repeat customers. For practitioners with 100+ BIM-assisted projects, the ratio indicated was approximately 1.10, which indicates an approximate 10% increase in repeat customers. For the 6 to 15 BIM-assisted project grouping the ratio was stated as high as 1.24, indicating an approximate 24% increase of repeat customers for BIM-assisted projects when compared to Non-BIM assisted projects. Data analysis was also conducted based on the number of years working with BIM. Tables 4.5.8 and 4.5.9 present the data analyzed based on the practitioners number of years working with BIM.

Table 4.5.8 – Project Success Indicator Ranking by Contractor - Number of Years with BIM

<table>
<thead>
<tr>
<th>Project Success Attributes</th>
<th>0 to 2 years N = 19</th>
<th>2 to 8 years N = 43</th>
<th>8 to 13 years N = 32</th>
<th>13 to 20 years N = 13</th>
<th>20+ years N = 8</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cost Goal</td>
<td>Mean 4.95 S/D 0.40</td>
<td>Mean 4.92 S/D 1.11</td>
<td>Mean 5.13 S/D 0.94</td>
<td>Mean 5.46 S/D 0.78</td>
<td>Mean 5.00 S/D 0.00</td>
</tr>
<tr>
<td>Schedule Goal</td>
<td>Mean 4.89 S/D 0.32</td>
<td>Mean 5.28 S/D 0.93</td>
<td>Mean 5.22 S/D 1.01</td>
<td>Mean 5.23 S/D 0.93</td>
<td>Mean 5.60 S/D 0.89</td>
</tr>
<tr>
<td>Quality Goal</td>
<td>Mean 5.58 S/D 0.77</td>
<td>Mean 5.81 S/D 0.92</td>
<td>Mean 5.78 S/D 0.91</td>
<td>Mean 6.23 S/D 0.60</td>
<td>Mean 6.00 S/D 0.00</td>
</tr>
<tr>
<td>Safety Goal</td>
<td>Mean 4.66 S/D 0.58</td>
<td>Mean 4.98 S/D 0.90</td>
<td>Mean 4.81 S/D 0.86</td>
<td>Mean 4.92 S/D 0.86</td>
<td>Mean 5.20 S/D 0.45</td>
</tr>
<tr>
<td>Customer Satisfaction</td>
<td>Mean 5.63 S/D 0.76</td>
<td>Mean 5.87 S/D 1.00</td>
<td>Mean 6.09 S/D 0.86</td>
<td>Mean 6.00 S/D 0.82</td>
<td>Mean 6.20 S/D 0.45</td>
</tr>
</tbody>
</table>

The analysis based on the number of years the practitioner worked with BIM also indicated that Customer Satisfaction was the top ranking Project Success indicator that was achieved on BIM-assisted projects. This was followed in order by Quality Goal, Schedule Goal, Cost Goal and Safety Goal.
Table 4.5.9 – Contractor Ratio of Project Success – Number of Years working with BIM

<table>
<thead>
<tr>
<th>Project Success Attributes</th>
<th>0 to 2 years N = 19</th>
<th>2 to 8 years N = 53</th>
<th>8 to 13 years N = 32</th>
<th>13 to 20 years N = 13</th>
<th>20+ years N = 5</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Mean</td>
<td>Mean</td>
<td>Mean</td>
<td>Mean</td>
<td>Mean</td>
</tr>
<tr>
<td>Design Errors</td>
<td>0.64</td>
<td>0.58</td>
<td>0.58</td>
<td>0.56</td>
<td>0.61</td>
</tr>
<tr>
<td>RFI during Pre-construction</td>
<td>3.87</td>
<td>3.22</td>
<td>3.22</td>
<td>18.60</td>
<td>3.20</td>
</tr>
<tr>
<td>RFI during construction</td>
<td>0.77</td>
<td>0.84</td>
<td>0.68</td>
<td>0.70</td>
<td>0.66</td>
</tr>
<tr>
<td>Number of Change Orders</td>
<td>0.61</td>
<td>0.64</td>
<td>0.56</td>
<td>0.49</td>
<td>0.51</td>
</tr>
<tr>
<td>Cost of Change Orders</td>
<td>0.53</td>
<td>0.50</td>
<td>0.48</td>
<td>0.43</td>
<td>0.45</td>
</tr>
<tr>
<td>Cost of Re-work</td>
<td>0.41</td>
<td>0.36</td>
<td>0.39</td>
<td>0.32</td>
<td>0.38</td>
</tr>
<tr>
<td>Cost of punch list items</td>
<td>0.68</td>
<td>0.71</td>
<td>0.58</td>
<td>0.55</td>
<td>0.60</td>
</tr>
<tr>
<td>Number of near misses</td>
<td>0.66</td>
<td>0.65</td>
<td>0.60</td>
<td>0.57</td>
<td>0.60</td>
</tr>
<tr>
<td>Number of site accidents</td>
<td>0.59</td>
<td>0.56</td>
<td>0.54</td>
<td>0.51</td>
<td>0.51</td>
</tr>
<tr>
<td>Number of legal claims and litigation</td>
<td>0.55</td>
<td>0.53</td>
<td>0.46</td>
<td>0.45</td>
<td>0.46</td>
</tr>
<tr>
<td>Cost of legal claims and litigation</td>
<td>0.57</td>
<td>0.53</td>
<td>0.51</td>
<td>0.48</td>
<td>0.47</td>
</tr>
<tr>
<td>Number of repeat customers</td>
<td>1.02</td>
<td>1.05</td>
<td>0.98</td>
<td>1.23</td>
<td>0.99</td>
</tr>
</tbody>
</table>

The practitioner responses based on the number of years working with BIM were mostly consistent with the observations made by Business Type and number of BIM-assisted projects. The number and cost of legal claims and litigation seem to decrease over time. Additionally, the number of site accidents and both the number and cost of Change Orders also seem to decrease over time. Observing the above tables based on Business Type, Number of Projects and Number of Years working with BIM, it seems that there is a positive impact on construction Project Success indicators when comparing BIM-assisted to Non-BIM assisted construction projects.

Construction Project Management (CPM) indicators that fall under the process oriented performance indicators were also ranked by the Contractors who participated in the survey. The Contractors ranking of the extent to which BIM impacts CPM can be observed in table 4.5.10.
The CPM attributes that were consistently ranked among the top ten by all Business Types included: Earlier Detection of Problems, Communication Effectiveness, Coordination Tools, Open Information Sharing, Decision Making Process and Scope Clarification. An ANOVA test for statistical difference in the mean scores indicated that: Quality Management, Information Management, Communication Effectiveness, Open Information Sharing and Scope Clarification met the condition $P < 0.05$ for statistical significance for difference between means based on Business Type of the Contractor.

The highest mean score and ranking was for Earlier Detection of Problems and was consistently ranked as the number one CPM attribute that was addressed on BIM-assisted
construction projects. Safety Management, Labor Management and Cost Management were ranked more towards the bottom 3 attributes based on Business Type. The lowest Mean score on the CPM attributes addressed through BIM is Safety Management at 4.85. This is above the 4.00 cut-off point and is therefore indicative that all CPM attributes are in some way addressed through the use of BIM. For additional evaluation and comparisons, the ranking of CPM attributes by number of BIM-assisted projects and number of years working with BIM were also considered and are presented in tables 4.5.11 and 4.5.12.

Table 4.5.11 – Contractors’ CPM Attributes Ranking - by Number of BIM-assisted Projects

<table>
<thead>
<tr>
<th>CPM Attributes</th>
<th>1 to 5 Projects N = 53</th>
<th>6 to 15 Projects N = 30</th>
<th>16 to 40 Projects N = 18</th>
<th>41 to 100 Projects N = 11</th>
<th>100+ Projects N = 18</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean</td>
<td>S/D</td>
<td>Rank</td>
<td>Mean</td>
<td>S/D</td>
<td>Rank</td>
</tr>
<tr>
<td>Labor Management</td>
<td>4.89</td>
<td>0.67</td>
<td>19</td>
<td>4.95</td>
<td>1.08</td>
</tr>
<tr>
<td>Subcontractor Management</td>
<td>5.09</td>
<td>0.66</td>
<td>15</td>
<td>5.07</td>
<td>0.87</td>
</tr>
<tr>
<td>Cost Management</td>
<td>4.94</td>
<td>0.57</td>
<td>18</td>
<td>5.00</td>
<td>0.95</td>
</tr>
<tr>
<td>Schedule Control</td>
<td>5.08</td>
<td>0.55</td>
<td>14</td>
<td>5.23</td>
<td>0.68</td>
</tr>
<tr>
<td>Work Progress</td>
<td>5.70</td>
<td>0.70</td>
<td>9</td>
<td>5.87</td>
<td>0.82</td>
</tr>
<tr>
<td>Quality Management</td>
<td>5.60</td>
<td>0.74</td>
<td>10</td>
<td>5.97</td>
<td>0.85</td>
</tr>
<tr>
<td>Earlier Detection of Problems</td>
<td>5.91</td>
<td>0.69</td>
<td>1</td>
<td>6.37</td>
<td>0.61</td>
</tr>
<tr>
<td>Information Management</td>
<td>5.64</td>
<td>0.76</td>
<td>9</td>
<td>5.97</td>
<td>0.76</td>
</tr>
<tr>
<td>Communication Effectiveness</td>
<td>5.70</td>
<td>0.70</td>
<td>4</td>
<td>6.13</td>
<td>0.78</td>
</tr>
<tr>
<td>Communication Method</td>
<td>5.66</td>
<td>0.71</td>
<td>7</td>
<td>6.00</td>
<td>0.79</td>
</tr>
<tr>
<td>Communication Frequency</td>
<td>5.49</td>
<td>0.93</td>
<td>12</td>
<td>6.07</td>
<td>0.87</td>
</tr>
<tr>
<td>Coordination Tools</td>
<td>3.75</td>
<td>0.76</td>
<td>2</td>
<td>6.10</td>
<td>0.76</td>
</tr>
<tr>
<td>Open Information Sharing</td>
<td>5.70</td>
<td>0.75</td>
<td>6</td>
<td>5.97</td>
<td>0.89</td>
</tr>
<tr>
<td>Material Management</td>
<td>5.00</td>
<td>0.68</td>
<td>15</td>
<td>4.90</td>
<td>0.92</td>
</tr>
<tr>
<td>Safety Management</td>
<td>4.77</td>
<td>0.58</td>
<td>20</td>
<td>4.97</td>
<td>0.76</td>
</tr>
<tr>
<td>Joint Solutions</td>
<td>4.96</td>
<td>0.65</td>
<td>17</td>
<td>5.40</td>
<td>0.81</td>
</tr>
<tr>
<td>Leadership</td>
<td>4.98</td>
<td>0.64</td>
<td>16</td>
<td>5.07</td>
<td>0.94</td>
</tr>
<tr>
<td>Stakeholder Coordination</td>
<td>5.59</td>
<td>0.77</td>
<td>11</td>
<td>5.83</td>
<td>0.99</td>
</tr>
<tr>
<td>Decision-Making Process</td>
<td>5.66</td>
<td>0.76</td>
<td>8</td>
<td>5.93</td>
<td>0.69</td>
</tr>
<tr>
<td>Scope Clarification</td>
<td>5.74</td>
<td>0.65</td>
<td>3</td>
<td>6.13</td>
<td>0.73</td>
</tr>
</tbody>
</table>

*The numbers in bold indicate ranking among the Top Ten in its category

The attributes that were consistently ranked by the practitioners regardless of the difference in experience with number of projects included: Earlier Detection of Problems, Information Management, Communication Effectiveness, Coordination Tools, Decision Making Process and
Scope Clarification. The bottom CPM attributes seemed to be Safety Management, Labor Management, Cost Management, Material Management and Schedule Control. The lowest Mean score is 4.72 for Safety Management and therefore, with mean scores that are all above 4.00, BIM seems to have a positive impact on CPM attributes for a majority of Contractors.

Table 4.5.12 – Contractors’ CPM Attributes Ranking - by Number of Years working with BIM

<table>
<thead>
<tr>
<th>CPM Attributes</th>
<th>0 to 2 years N = 19</th>
<th>2 to 8 years N = 53</th>
<th>8 to 13 years N = 32</th>
<th>13 to 20 years N = 13</th>
<th>20+ years N = 5</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Mean</td>
<td>S/D</td>
<td>Rank</td>
<td>Mean</td>
<td>S/D</td>
</tr>
<tr>
<td>Labor Management</td>
<td>4.74</td>
<td>0.45</td>
<td>19</td>
<td>4.96</td>
<td>0.96</td>
</tr>
<tr>
<td>Subcontractor Management</td>
<td>4.89</td>
<td>0.46</td>
<td>13</td>
<td>5.23</td>
<td>0.82</td>
</tr>
<tr>
<td>Cost Management</td>
<td>4.84</td>
<td>0.37</td>
<td>15</td>
<td>5.02</td>
<td>0.82</td>
</tr>
<tr>
<td>Schedule Control</td>
<td>4.84</td>
<td>0.37</td>
<td>15</td>
<td>5.26</td>
<td>0.65</td>
</tr>
<tr>
<td>Work Progress</td>
<td>5.58</td>
<td>0.77</td>
<td>6</td>
<td>5.85</td>
<td>0.69</td>
</tr>
<tr>
<td>Quality Management</td>
<td>5.58</td>
<td>0.77</td>
<td>6</td>
<td>5.77</td>
<td>0.72</td>
</tr>
<tr>
<td>Earlier Detection of Problems</td>
<td>5.79</td>
<td>0.71</td>
<td>1</td>
<td>6.23</td>
<td>0.67</td>
</tr>
<tr>
<td>Information Management</td>
<td>5.58</td>
<td>0.77</td>
<td>6</td>
<td>5.81</td>
<td>0.81</td>
</tr>
<tr>
<td>Communication Effectiveness</td>
<td>5.63</td>
<td>0.68</td>
<td>2</td>
<td>5.91</td>
<td>0.79</td>
</tr>
<tr>
<td>Communication Method</td>
<td>5.63</td>
<td>0.68</td>
<td>2</td>
<td>5.79</td>
<td>0.79</td>
</tr>
<tr>
<td>Communication Frequency</td>
<td>5.58</td>
<td>0.77</td>
<td>6</td>
<td>5.75</td>
<td>1.00</td>
</tr>
<tr>
<td>Coordination Tools</td>
<td>5.63</td>
<td>0.76</td>
<td>4</td>
<td>6.00</td>
<td>0.78</td>
</tr>
<tr>
<td>Open Information Sharing</td>
<td>5.63</td>
<td>0.76</td>
<td>4</td>
<td>5.75</td>
<td>0.90</td>
</tr>
<tr>
<td>Material Management</td>
<td>4.89</td>
<td>0.46</td>
<td>13</td>
<td>4.94</td>
<td>0.91</td>
</tr>
<tr>
<td>Safety Management</td>
<td>4.74</td>
<td>0.45</td>
<td>19</td>
<td>4.91</td>
<td>0.74</td>
</tr>
<tr>
<td>Joint Solutions</td>
<td>4.79</td>
<td>0.43</td>
<td>17</td>
<td>5.26</td>
<td>0.84</td>
</tr>
<tr>
<td>Leadership</td>
<td>4.79</td>
<td>0.42</td>
<td>17</td>
<td>5.02</td>
<td>0.84</td>
</tr>
<tr>
<td>Stakeholder Coordination</td>
<td>5.47</td>
<td>0.84</td>
<td>12</td>
<td>5.77</td>
<td>0.89</td>
</tr>
<tr>
<td>Decision-Making Process</td>
<td>5.53</td>
<td>0.84</td>
<td>11</td>
<td>5.87</td>
<td>0.76</td>
</tr>
<tr>
<td>Scope Clarification</td>
<td>5.58</td>
<td>0.77</td>
<td>6</td>
<td>5.92</td>
<td>0.68</td>
</tr>
</tbody>
</table>

*The numbers in bold indicate ranking among the Top Ten in its category

According to the survey responses, Contractors were divided into groups based on the number of years working with BIM. The CPM attributes were ranked based on the number of years working with BIM, and the attributes that consistently ranked among the top ten included: Earlier Detection of Problems, Information Management, Communication Effectiveness, Coordination Tools and Scope Clarification. The attributes that had a lower ranking included: Safety Management, Labor Management, Cost Management, Material Management, Sub-Contractor
Management and Leadership. The lowest mean score based on the number of years working with BIM is 4.72. The cut-off point is 4.00 and therefore BIM is considered to address the CPM attributes that have been identified.

Contractors’ were asked to indicate their perception of overall Project Success and project performance on BIM-assisted projects based on the identified indicators and attributes. It was interesting to note that not a single response indicated a negative experience on Project Success or Project Management. All responses indicated either a neutral response stating “about the same” or a majority of the respondents indicated it to be moderately better or much better.

4.6 Analysis of Quantitative Survey Data: Other AEC Industry Participants

The third group that was surveyed included other AEC professionals. This category included groups for: Owner / Developer, Architect, Engineer, Sub-Contractor, Consultant and other AEC professionals. Those who self-selected other, typically identified under two or more Business Types. The largest group of participants within the category were Architects, followed by Consultants and Engineers, Sub-Contractors, Owner/Developers and Others. There seemed to be a healthy distribution among the participants as they were distributed fairly evenly and this will allow for a better comparison between the different groups. The breakdown of these participants based on the professional group they self-selected into are presented in figure 4.6.1.
Figure 4.6.1 – Other AEC Practitioners’ Survey Participation Breakdown

The survey questionnaire also assessed the time period during which the AEC practitioners’ companies had implemented BIM. The breakdown of when BIM was implemented by the AEC practitioners follow the same trend as observed for Contractors who participated in the study. BIM implementation was growing by time period up until 2008. AEC practitioners who began their BIM implementation between the years of 2005–2008, recorded the largest number of participants in this study. From 2009, BIM implementation was still increasing in the AEC industry but at a slower pace. The count for BIM adoption by time period was still larger than the years prior to 2005-2008. Similar to the Contractors who participated, there still appears to be a large group of AEC professionals who have not yet implemented BIM on their construction projects. This also provides evidence for an existing market to promote BIM tools and services within the larger AEC community. These results are presented in figure 4.6.2. The time period during which BIM was implemented gives us more insight into the trends of BIM adoption among AEC professionals and their companies.
The information presented in figure 4.6.3 represent the majority of BIM-assisted building types from the AEC practitioners’ perspective. These are similar in nature to the information
provided by Contractors who participated in the study. The top three building types that utilize BIM are Commercial, Healthcare and Educational. Building types that were identified under the “other” category for not being directly listed included: Parks and Resorts, Military, Ship Building, Stadiums, Government Buildings, Prisons, City Infrastructure and Religious Buildings.

![Figure 4.6.4 – AEC Practitioners’ BIM-assisted Project Delivery](image)

Many BIM-assisted projects that AEC Practitioners had been involved with were either Design-Bid-Build (DBB) or Design-Build (DB). This was followed by Integrated Project Delivery (IPD) and Construction Management (CM) at Risk. The AEC practitioners’ perspective reveals that there is a slight difference in the project delivery method that is used on BIM-assisted projects. Other project delivery methods used on BIM-assisted projects included: Public-Private Partnership (P3), Loss Prevention Engineering (LPE), DB-IPD Hybrid and Design-Assist.

AEC practitioners who participated in the survey were presented the BIMM indicators and asked to rank the indicators based on the extent to which they were addressed on BIM-assisted
projects. The results for the mean score and rank for all the BIMM indicators by Other AEC practitioners’ Business Type is presented in table 4.6.1.

Table 4.6.1 – BIMM Indicator Ranking by AEC Practitioners’ Business Type

<table>
<thead>
<tr>
<th>BIMM Indicators</th>
<th>Owner / Developer N = 21</th>
<th>Architect N = 41</th>
<th>Engineer N = 29</th>
<th>Subcontractor N = 26</th>
<th>Consultant N = 38</th>
<th>Others N = 34</th>
<th>ANOVA</th>
</tr>
</thead>
<tbody>
<tr>
<td>Software Application</td>
<td>5.45 ± 1.65</td>
<td>5.02 ± 0.91</td>
<td>5.63 ± 1.42</td>
<td>5.00 ± 1.92</td>
<td>6.05 ± 0.70</td>
<td>5.76 ± 0.89</td>
<td>3.054</td>
</tr>
<tr>
<td>Interoperability</td>
<td>5.19 ± 1.21</td>
<td>5.05 ± 1.55</td>
<td>4.76 ± 1.44</td>
<td>4.42 ± 1.81</td>
<td>5.45 ± 0.86</td>
<td>4.71 ± 1.36</td>
<td>2.211</td>
</tr>
<tr>
<td>Hardware Equipment</td>
<td>4.90 ± 1.41</td>
<td>5.17 ± 1.60</td>
<td>4.82 ± 1.56</td>
<td>4.12 ± 1.81</td>
<td>5.08 ± 1.19</td>
<td>4.00 ± 1.11</td>
<td>1.927</td>
</tr>
<tr>
<td>Hardware Upgrade</td>
<td>4.71 ± 1.52</td>
<td>5.07 ± 1.47</td>
<td>4.79 ± 1.53</td>
<td>3.85 ± 1.40</td>
<td>4.87 ± 1.40</td>
<td>4.59 ± 1.54</td>
<td>2.390</td>
</tr>
<tr>
<td>IDM</td>
<td>5.19 ± 1.17</td>
<td>5.22 ± 1.31</td>
<td>4.95 ± 1.23</td>
<td>4.69 ± 1.52</td>
<td>5.32 ± 0.98</td>
<td>5.09 ± 0.97</td>
<td>1.080</td>
</tr>
<tr>
<td>Information Assistance</td>
<td>5.38 ± 1.12</td>
<td>4.80 ± 1.69</td>
<td>4.47 ± 1.47</td>
<td>4.12 ± 1.58</td>
<td>5.13 ± 1.09</td>
<td>4.79 ± 1.25</td>
<td>2.783</td>
</tr>
<tr>
<td>Data Richness</td>
<td>4.81 ± 1.40</td>
<td>4.88 ± 1.60</td>
<td>4.50 ± 1.38</td>
<td>4.35 ± 1.67</td>
<td>5.52 ± 1.04</td>
<td>5.08 ± 1.20</td>
<td>2.117</td>
</tr>
<tr>
<td>Real Time Data</td>
<td>4.57 ± 1.75</td>
<td>4.85 ± 1.61</td>
<td>4.50 ± 1.67</td>
<td>4.46 ± 1.10</td>
<td>5.03 ± 1.65</td>
<td>4.43 ± 1.50</td>
<td>0.828</td>
</tr>
<tr>
<td>Information Accuracy</td>
<td>5.24 ± 1.18</td>
<td>5.15 ± 1.49</td>
<td>4.84 ± 1.44</td>
<td>4.81 ± 1.41</td>
<td>5.34 ± 0.97</td>
<td>4.83 ± 1.51</td>
<td>0.920</td>
</tr>
<tr>
<td>Graphics</td>
<td>4.86 ± 1.06</td>
<td>5.46 ± 1.07</td>
<td>5.00 ± 1.45</td>
<td>4.65 ± 1.16</td>
<td>5.42 ± 0.79</td>
<td>5.08 ± 1.28</td>
<td>2.390</td>
</tr>
<tr>
<td>Geospatial Capabilities</td>
<td>4.86 ± 1.55</td>
<td>4.71 ± 1.66</td>
<td>4.55 ± 1.46</td>
<td>4.65 ± 1.70</td>
<td>5.13 ± 0.93</td>
<td>4.85 ± 1.56</td>
<td>0.707</td>
</tr>
<tr>
<td>Work Flow</td>
<td>4.67 ± 1.59</td>
<td>5.29 ± 1.23</td>
<td>4.84 ± 1.42</td>
<td>4.69 ± 1.19</td>
<td>5.24 ± 1.10</td>
<td>5.15 ± 1.31</td>
<td>1.418</td>
</tr>
<tr>
<td>DMS</td>
<td>5.62 ± 1.07</td>
<td>6.05 ± 0.86</td>
<td>5.42 ± 1.11</td>
<td>5.15 ± 1.59</td>
<td>6.08 ± 0.67</td>
<td>5.56 ± 1.40</td>
<td>3.472</td>
</tr>
<tr>
<td>Information Security</td>
<td>3.81 ± 1.29</td>
<td>4.07 ± 1.54</td>
<td>4.11 ± 1.55</td>
<td>3.77 ± 1.45</td>
<td>4.38 ± 1.13</td>
<td>4.12 ± 1.51</td>
<td>1.379</td>
</tr>
<tr>
<td>PTI</td>
<td>5.29 ± 1.51</td>
<td>5.02 ± 1.56</td>
<td>4.76 ± 1.55</td>
<td>4.38 ± 1.50</td>
<td>5.00 ± 1.19</td>
<td>4.88 ± 1.34</td>
<td>1.163</td>
</tr>
<tr>
<td>Strategic Planning</td>
<td>4.62 ± 1.77</td>
<td>4.78 ± 1.54</td>
<td>4.42 ± 1.55</td>
<td>4.46 ± 1.42</td>
<td>4.89 ± 1.27</td>
<td>4.94 ± 1.04</td>
<td>0.806</td>
</tr>
<tr>
<td>Lifecycle Process</td>
<td>4.05 ± 1.60</td>
<td>3.76 ± 1.45</td>
<td>3.71 ± 1.52</td>
<td>3.81 ± 1.33</td>
<td>4.39 ± 1.33</td>
<td>4.32 ± 1.59</td>
<td>2.498</td>
</tr>
<tr>
<td>Change Management</td>
<td>4.62 ± 1.28</td>
<td>5.00 ± 1.38</td>
<td>4.37 ± 1.59</td>
<td>4.31 ± 1.62</td>
<td>5.03 ± 1.28</td>
<td>4.91 ± 1.40</td>
<td>1.717</td>
</tr>
<tr>
<td>Risk Management</td>
<td>4.24 ± 1.22</td>
<td>4.15 ± 1.71</td>
<td>3.82 ± 1.59</td>
<td>4.31 ± 1.47</td>
<td>4.15 ± 1.17</td>
<td>4.12 ± 1.51</td>
<td>2.488</td>
</tr>
<tr>
<td>SOP</td>
<td>4.45 ± 1.47</td>
<td>4.27 ± 1.72</td>
<td>4.13 ± 1.60</td>
<td>4.08 ± 1.67</td>
<td>4.26 ± 1.31</td>
<td>4.26 ± 1.29</td>
<td>1.695</td>
</tr>
<tr>
<td>Quality Control</td>
<td>5.05 ± 1.28</td>
<td>5.24 ± 1.10</td>
<td>4.97 ± 1.57</td>
<td>4.73 ± 1.43</td>
<td>5.55 ± 0.88</td>
<td>4.88 ± 1.51</td>
<td>2.609</td>
</tr>
<tr>
<td>Specifications</td>
<td>4.45 ± 1.43</td>
<td>4.76 ± 1.48</td>
<td>4.39 ± 1.44</td>
<td>4.42 ± 1.55</td>
<td>5.39 ± 0.92</td>
<td>4.47 ± 1.80</td>
<td>1.920</td>
</tr>
<tr>
<td>Senior Leadership</td>
<td>4.10 ± 1.51</td>
<td>4.24 ± 1.61</td>
<td>3.89 ± 1.41</td>
<td>3.62 ± 1.39</td>
<td>4.39 ± 1.24</td>
<td>4.12 ± 1.22</td>
<td>2.120</td>
</tr>
<tr>
<td>Role and Responsibility</td>
<td>4.57 ± 1.78</td>
<td>4.95 ± 1.38</td>
<td>4.68 ± 1.40</td>
<td>4.62 ± 1.55</td>
<td>5.26 ± 0.98</td>
<td>5.00 ± 1.23</td>
<td>2.245</td>
</tr>
<tr>
<td>Reward Systems</td>
<td>3.29 ± 1.28</td>
<td>3.17 ± 1.73</td>
<td>3.18 ± 1.47</td>
<td>3.00 ± 1.33</td>
<td>3.34 ± 1.28</td>
<td>3.32 ± 1.63</td>
<td>2.094</td>
</tr>
<tr>
<td>Competency Profiles</td>
<td>4.10 ± 1.37</td>
<td>4.41 ± 1.59</td>
<td>3.82 ± 1.59</td>
<td>3.81 ± 1.35</td>
<td>4.31 ± 1.35</td>
<td>3.74 ± 1.96</td>
<td>2.386</td>
</tr>
<tr>
<td>Training Program</td>
<td>3.95 ± 1.43</td>
<td>4.29 ± 1.55</td>
<td>3.84 ± 1.55</td>
<td>3.54 ± 1.39</td>
<td>4.61 ± 1.22</td>
<td>3.91 ± 1.52</td>
<td>2.535</td>
</tr>
<tr>
<td>TDM</td>
<td>3.86 ± 1.59</td>
<td>4.42 ± 1.42</td>
<td>3.76 ± 1.51</td>
<td>3.46 ± 1.42</td>
<td>4.68 ± 1.30</td>
<td>3.74 ± 1.56</td>
<td>2.022</td>
</tr>
</tbody>
</table>

*The numbers in bold indicate ranking among the Top Ten in its category / ANOVA significance
* P < 0.05 indicates statistical significance between mean rankings

The BIMM indicators that were addressed on BIM-assisted projects and consistently ranked among the top ten by all AEC Business Types included: Software Application, Information Delivery Method, Graphics, and Document and Modeling Standard. The top two indicators addressed by BIM appeared to be Software Application and Document and Modeling Standard as they consistently ranked at first or second place. The bottom most indicators which were not addressed as much through BIM were: Reward System, Information Security, Lifecycle Process,
Training Delivery Method and Risk Management. An ANOVA test to assess if there is any statistical difference for mean scores between the different Business Types indicated that: Software Application, Hardware Upgrade, Information Assurance, Document Modeling Standard (DMS), Quality Control, Specifications, Competency Profile, Training Program and Training Delivery Method (TDM) were statistically significant based on the AEC practitioner’s Business Type.

Table 4.6.2 – BIMM Indicator Ranking by AEC Practitioners’ Number of BIM-assisted Projects

<table>
<thead>
<tr>
<th>BIMM Indicators</th>
<th>1 - 5 Projects N = 35</th>
<th>5 - 15 Projects N = 30</th>
<th>16 to 40 Projects N = 27</th>
<th>41 to 100 Projects N = 21</th>
<th>100+ Projects N = 45</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Mean</td>
<td>S/D</td>
<td>Rank</td>
<td>Mean</td>
<td>S/D</td>
</tr>
<tr>
<td>Software Application</td>
<td>5.26</td>
<td>1.58</td>
<td>1</td>
<td>5.47</td>
<td>1.28</td>
</tr>
<tr>
<td>Interoperability</td>
<td>4.49</td>
<td>1.70</td>
<td>13</td>
<td>4.77</td>
<td>1.25</td>
</tr>
<tr>
<td>Hardware Equipment</td>
<td>4.20</td>
<td>1.85</td>
<td>18</td>
<td>5.07</td>
<td>1.17</td>
</tr>
<tr>
<td>Hardware Upgrade</td>
<td>4.14</td>
<td>1.78</td>
<td>9</td>
<td>4.80</td>
<td>1.13</td>
</tr>
<tr>
<td>Information Delivery Method</td>
<td>4.74</td>
<td>1.42</td>
<td>4</td>
<td>4.90</td>
<td>0.88</td>
</tr>
<tr>
<td>Information Assurance</td>
<td>4.51</td>
<td>1.62</td>
<td>12</td>
<td>4.23</td>
<td>1.19</td>
</tr>
<tr>
<td>Data Richness</td>
<td>4.49</td>
<td>1.70</td>
<td>13</td>
<td>4.60</td>
<td>1.54</td>
</tr>
<tr>
<td>Real Time Data</td>
<td>4.40</td>
<td>1.67</td>
<td>16</td>
<td>4.17</td>
<td>1.62</td>
</tr>
<tr>
<td>Information Accuracy</td>
<td>4.60</td>
<td>1.42</td>
<td>7</td>
<td>4.70</td>
<td>1.74</td>
</tr>
<tr>
<td>Graphics</td>
<td>4.83</td>
<td>1.50</td>
<td>3</td>
<td>4.93</td>
<td>1.34</td>
</tr>
<tr>
<td>Geo-spatial Capability</td>
<td>4.54</td>
<td>1.75</td>
<td>10</td>
<td>4.67</td>
<td>1.45</td>
</tr>
<tr>
<td>Work Flow</td>
<td>4.66</td>
<td>1.45</td>
<td>5</td>
<td>4.97</td>
<td>1.45</td>
</tr>
<tr>
<td>Document and Modeling Standard</td>
<td>5.20</td>
<td>1.57</td>
<td>2</td>
<td>5.57</td>
<td>1.38</td>
</tr>
<tr>
<td>Information Security</td>
<td>3.83</td>
<td>1.64</td>
<td>27</td>
<td>4.23</td>
<td>1.57</td>
</tr>
<tr>
<td>Process and Technology Innovation</td>
<td>4.49</td>
<td>1.79</td>
<td>15</td>
<td>4.53</td>
<td>1.14</td>
</tr>
<tr>
<td>Strategic Planning</td>
<td>4.54</td>
<td>1.62</td>
<td>9</td>
<td>4.10</td>
<td>1.67</td>
</tr>
<tr>
<td>Lifecycle Process</td>
<td>3.86</td>
<td>1.68</td>
<td>24</td>
<td>3.93</td>
<td>1.74</td>
</tr>
<tr>
<td>Change Management</td>
<td>4.57</td>
<td>1.52</td>
<td>8</td>
<td>4.20</td>
<td>1.36</td>
</tr>
<tr>
<td>Risk Management</td>
<td>3.94</td>
<td>1.61</td>
<td>21</td>
<td>3.90</td>
<td>1.56</td>
</tr>
<tr>
<td>Standard Operating Process</td>
<td>3.86</td>
<td>1.77</td>
<td>25</td>
<td>4.20</td>
<td>1.45</td>
</tr>
<tr>
<td>Quality Control</td>
<td>4.66</td>
<td>1.53</td>
<td>6</td>
<td>5.23</td>
<td>1.25</td>
</tr>
<tr>
<td>Specifications</td>
<td>4.51</td>
<td>1.60</td>
<td>11</td>
<td>4.73</td>
<td>1.72</td>
</tr>
<tr>
<td>Senior Leadership</td>
<td>3.86</td>
<td>1.54</td>
<td>33</td>
<td>4.00</td>
<td>1.58</td>
</tr>
<tr>
<td>Role and Responsibility</td>
<td>4.31</td>
<td>1.35</td>
<td>17</td>
<td>4.33</td>
<td>1.42</td>
</tr>
<tr>
<td>Reward System</td>
<td>3.51</td>
<td>1.67</td>
<td>28</td>
<td>3.03</td>
<td>1.71</td>
</tr>
<tr>
<td>Competency Profile</td>
<td>4.00</td>
<td>1.63</td>
<td>20</td>
<td>4.30</td>
<td>1.37</td>
</tr>
<tr>
<td>Training Program</td>
<td>3.83</td>
<td>1.59</td>
<td>26</td>
<td>4.23</td>
<td>1.74</td>
</tr>
<tr>
<td>Training Delivery Method</td>
<td>3.89</td>
<td>1.59</td>
<td>22</td>
<td>4.20</td>
<td>1.79</td>
</tr>
</tbody>
</table>

*The numbers in bold indicate ranking among the Top Ten in its category*
The mean scores and rankings were also tested based on the number of BIM-assisted projects the AEC practitioner had been involved in. These results are presented in table 4.6.2. The BIMM indicators that consistently ranked among the top ten by all groupings of project experience included: Software Application, Information Delivery Method, Graphics, Document and Modeling Standard and Quality Control. The top two BIMM indicators that were addressed on BIM-assisted projects were identified as Software Application and Document and Modeling Standards. The BIMM indicators that ranked towards the bottom include: Reward System, Information Security, Risk Management, Senior Leadership and Training Delivery Method.

When asked if the level of BIM on BIM-assisted projects other AEC professionals were involved in was mature or immature, the survey respondents indicated that 72% of AEC professionals believed their BIM adoption to be mature, while 20% indicated immature and 8% indicated neutral. These results are presented in figure 4.6.5.

Figure 4.6.5 – AEC Practitioners’ Perception of BIMM
AEC practitioners were asked to rank identified Project Success goals on their BIM-assisted projects when compared to Non-BIM projects. The Project Success areas assessed were the same as assessed through the Contractor survey, the mean score and ranking for the Project Success indicators by AEC Business Type can be found in Table 4.6.3 and the ratio of Project Success attributes when comparing BIM-assisted projects to Non-BIM assisted projects are presented in Table 4.6.4.

Table 4.6.3 – Project Success Indicator Ranking by AEC Practitioners’ Business Type

<table>
<thead>
<tr>
<th>Project Success Indicators</th>
<th>Owner / Developer N = 21</th>
<th>Architect N = 41</th>
<th>Engineer N = 38</th>
<th>Subcontractor N = 26</th>
<th>Consultant N = 38</th>
<th>Others N = 34</th>
<th>ANOVA</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cost Goal</td>
<td>5.62</td>
<td>5.37</td>
<td>5.12</td>
<td>5.29</td>
<td>5.35</td>
<td>5.35</td>
<td>F</td>
</tr>
<tr>
<td>Schedule Goal</td>
<td>5.10</td>
<td>5.37</td>
<td>5.23</td>
<td>5.24</td>
<td>5.35</td>
<td>5.35</td>
<td>Sig.</td>
</tr>
<tr>
<td>Quality Goal</td>
<td>5.81</td>
<td>5.98</td>
<td>5.96</td>
<td>5.95</td>
<td>5.97</td>
<td>5.97</td>
<td></td>
</tr>
<tr>
<td>Safety Goal</td>
<td>4.95</td>
<td>5.17</td>
<td>5.08</td>
<td>5.13</td>
<td>5.06</td>
<td>5.06</td>
<td></td>
</tr>
<tr>
<td>Customer Satisfaction</td>
<td>5.76</td>
<td>5.88</td>
<td>5.60</td>
<td>5.60</td>
<td>5.68</td>
<td>5.68</td>
<td></td>
</tr>
</tbody>
</table>

*The numbers in bold indicate ANOVA significance
* P < 0.05 indicates statistical significance between mean rankings

Table 4.6.4 – AEC Practitioners’ Ratio of Project Success - by Business Type

<table>
<thead>
<tr>
<th>Project Success Attributes</th>
<th>Owner / Developer N = 21</th>
<th>Architect N = 41</th>
<th>Engineer N = 38</th>
<th>Subcontractor N = 26</th>
<th>Consultant N = 38</th>
<th>Others N = 34</th>
<th>Mean</th>
</tr>
</thead>
<tbody>
<tr>
<td>Design Errors</td>
<td>0.58</td>
<td>0.49</td>
<td>0.60</td>
<td>0.54</td>
<td>0.52</td>
<td>0.53</td>
<td></td>
</tr>
<tr>
<td>RFI during Pre-construction</td>
<td>0.68</td>
<td>0.56</td>
<td>0.68</td>
<td>0.73</td>
<td>0.69</td>
<td>0.60</td>
<td></td>
</tr>
<tr>
<td>RFI during construction</td>
<td>0.56</td>
<td>0.44</td>
<td>0.50</td>
<td>0.53</td>
<td>0.59</td>
<td>0.51</td>
<td></td>
</tr>
<tr>
<td>Number of Change Orders</td>
<td>0.57</td>
<td>0.45</td>
<td>0.59</td>
<td>0.52</td>
<td>0.50</td>
<td>0.52</td>
<td></td>
</tr>
<tr>
<td>Cost of Change Orders</td>
<td>0.58</td>
<td>0.47</td>
<td>0.62</td>
<td>0.55</td>
<td>0.49</td>
<td>0.50</td>
<td></td>
</tr>
<tr>
<td>Cost of Re-work</td>
<td>0.53</td>
<td>0.42</td>
<td>0.61</td>
<td>0.48</td>
<td>0.45</td>
<td>0.43</td>
<td></td>
</tr>
<tr>
<td>Cost of punch list items</td>
<td>0.65</td>
<td>0.56</td>
<td>0.81</td>
<td>0.60</td>
<td>0.59</td>
<td>0.57</td>
<td></td>
</tr>
<tr>
<td>Number of near misses</td>
<td>0.52</td>
<td>0.44</td>
<td>0.56</td>
<td>0.46</td>
<td>0.46</td>
<td>0.47</td>
<td></td>
</tr>
<tr>
<td>Number of site accidents</td>
<td>0.51</td>
<td>0.43</td>
<td>0.55</td>
<td>0.46</td>
<td>0.46</td>
<td>0.47</td>
<td></td>
</tr>
<tr>
<td>Number of legal claims and litigation</td>
<td>0.50</td>
<td>0.37</td>
<td>0.55</td>
<td>0.43</td>
<td>0.41</td>
<td>0.46</td>
<td></td>
</tr>
<tr>
<td>Cost of legal claims and litigation</td>
<td>0.56</td>
<td>0.43</td>
<td>0.67</td>
<td>0.48</td>
<td>0.46</td>
<td>0.50</td>
<td></td>
</tr>
<tr>
<td>Number of repeat customers</td>
<td>0.70</td>
<td>0.68</td>
<td>0.65</td>
<td>0.66</td>
<td>0.63</td>
<td>0.63</td>
<td></td>
</tr>
</tbody>
</table>
The top two Project Success goals that are achieved on BIM-assisted projects are Customer Satisfaction and Quality Goal. These are followed by Schedule Goal, Cost Goal and Safety Goal. The lowest mean score recorded is 4.63 for Safety Goal. The cut-off point for Project Success Indicator relevance is 4.00 and therefore, all Project Success Indicators are relevant and considered to be positively impacted on BIM-assisted projects. The ANOVA test for statistical significance in difference for the mean score by Business Type, indicated that Cost Goal, Schedule Goal and Quality goal all met the condition $P < 0.05$ for statistical significance for the mean comparison between groups.

The Project Success ratios were provided by survey participants as a comparison between their BIM-assisted projects and Non-BIM assisted projects. While the Contractor survey responses indicated an increase in the Pre-Construction RFI’s, the Other AEC professionals indicate that there is a reduction in the Pre-Construction RFI’s. The number of repeat customers were also noted to be slightly higher or about the same from the data obtained through the contractor surveys. However, it appears that other AEC practitioners have a decreased number of repeat customers when comparing their BIM-assisted projects with their Non-BIM assisted projects. All other Project Success attributes seem to have been positively influenced on BIM-assisted projects as the ratios are all less than 1.00.

The data was also broken down based on the number of BIM-assisted projects that AEC practitioners have worked on. The mean scores and ranking of Project Success goals achieved on BIM-assisted projects are presented in table 4.6.5, and the ratio of Project Success based on the number of BIM-assisted projects are presented in table 4.6.6.
The Top Project Success goals that were achieved on BIM-assisted projects were Customer Satisfaction and Quality Goal. These were followed by Schedule Goal, Cost Goal and Safety Goal.

The ratios of Project Success attributes based on the number of BIM-assisted projects also indicated similarity with the analysis done for the different Business Types of AEC industry practitioners. Again, it was interesting to note that the RFI’s during Pre-construction were either less or about the same as opposed to the higher ratios seen by Contractors who participated in the study. Cost of legal claims and litigation along with the number of legal claims and litigation...
seemed to improve as the number of BIM-assisted projects increased. Additionally, other AEC professionals indicated that the ratio for number of repeat customers had decreased when comparing BIM to Non-BIM assisted projects.

Construction Project Management (CPM) attributes were ranked by the AEC practitioners. The CPM attributes of BIM-assisted projects were compared with Non-BIM assisted projects and ranked. The mean scores and ranking based on the Business Type of the AEC practitioners who participated in the study are presented in table 4.6.7. The mean scores and ranking based on the practitioners’ experience by number of projects are presented in table 4.6.8.

Table 4.6.7 – Other AEC Practitioners’ - CPM Attributes Ranking by Business Type

<table>
<thead>
<tr>
<th>CPM Attributes</th>
<th>Owner/Developer N = 21</th>
<th>Architect N = 41</th>
<th>Engineer N = 38</th>
<th>Subcontractor N = 26</th>
<th>Consultant N = 38</th>
<th>Others N = 24</th>
<th>ANOVA</th>
</tr>
</thead>
<tbody>
<tr>
<td>Labor Management</td>
<td>2.14 ± 0.27</td>
<td>5.20 ± 0.24</td>
<td>6.55 ± 0.22</td>
<td>6.96 ± 0.24</td>
<td>5.11 ± 0.27</td>
<td>5.09 ± 0.27</td>
<td>5.14 ± 0.09</td>
</tr>
<tr>
<td>Subcontractor Management</td>
<td>2.14 ± 0.27</td>
<td>5.20 ± 0.24</td>
<td>6.55 ± 0.22</td>
<td>6.96 ± 0.24</td>
<td>5.11 ± 0.27</td>
<td>5.09 ± 0.27</td>
<td>5.14 ± 0.09</td>
</tr>
<tr>
<td>Cost Management</td>
<td>2.19 ± 0.20</td>
<td>5.27 ± 0.20</td>
<td>6.48 ± 0.24</td>
<td>5.10 ± 0.24</td>
<td>5.14 ± 0.20</td>
<td>5.14 ± 0.20</td>
<td>5.14 ± 0.20</td>
</tr>
<tr>
<td>Schedule Control</td>
<td>2.14 ± 0.25</td>
<td>5.22 ± 0.22</td>
<td>6.76 ± 0.21</td>
<td>5.22 ± 0.22</td>
<td>5.24 ± 0.24</td>
<td>5.26 ± 0.24</td>
<td>5.26 ± 0.24</td>
</tr>
<tr>
<td>Work Progress</td>
<td>2.14 ± 0.27</td>
<td>5.20 ± 0.27</td>
<td>6.44 ± 0.27</td>
<td>5.14 ± 0.27</td>
<td>5.14 ± 0.27</td>
<td>5.14 ± 0.27</td>
<td>5.14 ± 0.27</td>
</tr>
<tr>
<td>Quality Management</td>
<td>2.14 ± 0.23</td>
<td>5.29 ± 0.23</td>
<td>6.44 ± 0.24</td>
<td>5.15 ± 0.24</td>
<td>5.15 ± 0.24</td>
<td>5.15 ± 0.24</td>
<td>5.15 ± 0.24</td>
</tr>
<tr>
<td>Earlier Detection of Problems</td>
<td>6.02 ± 0.50</td>
<td>5.12 ± 0.51</td>
<td>5.28 ± 0.51</td>
<td>6.08 ± 0.50</td>
<td>6.18 ± 0.50</td>
<td>6.00 ± 0.50</td>
<td>3.24 ± 0.09</td>
</tr>
<tr>
<td>Information Management</td>
<td>3.90 ± 0.34</td>
<td>6.02 ± 0.65</td>
<td>5.22 ± 0.45</td>
<td>6.00 ± 0.65</td>
<td>6.02 ± 0.65</td>
<td>3.24 ± 0.06</td>
<td>3.24 ± 0.06</td>
</tr>
<tr>
<td>Communication Effectiveness</td>
<td>2.36 ± 0.62</td>
<td>6.10 ± 0.70</td>
<td>5.23 ± 0.43</td>
<td>6.03 ± 0.43</td>
<td>6.03 ± 0.43</td>
<td>7.17 ± 0.73</td>
<td>7.26 ± 0.06</td>
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<tr>
<td>Communication Method</td>
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<td>6.03 ± 0.63</td>
<td>5.27 ± 0.43</td>
<td>6.11 ± 0.39</td>
<td>6.11 ± 0.39</td>
<td>4.68 ± 0.06</td>
<td>4.68 ± 0.06</td>
</tr>
<tr>
<td>Communication Frequency</td>
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<td>6.00 ± 0.77</td>
<td>6.00 ± 0.77</td>
<td>2.83 ± 0.17</td>
<td>2.83 ± 0.17</td>
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<tr>
<td>Coordination Tools</td>
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<td>6.02 ± 0.72</td>
<td>5.45 ± 0.45</td>
<td>6.02 ± 0.72</td>
<td>6.02 ± 0.72</td>
<td>2.83 ± 0.17</td>
<td>2.83 ± 0.17</td>
</tr>
<tr>
<td>Open Information Sharing</td>
<td>6.00 ± 0.63</td>
<td>6.02 ± 0.59</td>
<td>5.39 ± 0.51</td>
<td>6.02 ± 0.59</td>
<td>6.02 ± 0.59</td>
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<td>2.83 ± 0.17</td>
</tr>
<tr>
<td>Material Management</td>
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<td>5.05 ± 0.70</td>
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<td>4.68 ± 0.37</td>
<td>4.88 ± 0.33</td>
<td>5.16 ± 0.59</td>
<td>6.97 ± 0.76</td>
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<td>Joint Solutions</td>
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<td>5.24 ± 0.19</td>
<td>5.24 ± 0.22</td>
<td>5.24 ± 0.22</td>
<td>5.24 ± 0.22</td>
</tr>
<tr>
<td>Stakeholder Coordination</td>
<td>3.95 ± 0.59</td>
<td>5.90 ± 0.89</td>
<td>5.12 ± 0.18</td>
<td>5.81 ± 0.49</td>
<td>6.08 ± 0.49</td>
<td>5.74 ± 0.49</td>
<td>5.74 ± 0.49</td>
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<tr>
<td>Decision Making Process</td>
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<td>6.05 ± 0.77</td>
<td>5.45 ± 0.45</td>
<td>6.05 ± 0.77</td>
<td>6.05 ± 0.77</td>
<td>4.03 ± 0.05</td>
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<tr>
<td>Scope Clarification</td>
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<td>5.57 ± 0.86</td>
<td>4.82 ± 0.64</td>
<td>5.06 ± 0.57</td>
<td>5.29 ± 0.73</td>
<td>5.18 ± 0.73</td>
<td>5.18 ± 0.73</td>
</tr>
</tbody>
</table>

*The numbers in bold indicate ranking among the Top Ten in its category / ANOVA significance

* P < 0.05 indicates statistical significance between mean rankings

According to the groupings based on Business Type, the AEC practitioners consistently ranked Earlier Detection of Problems, Information Management, Communication Effectiveness, Communication Method, Communication Frequency, Coordination Tools, Open Information...
Sharing and Decision-Making Process among the Top Ten CPM attributes that saw improvements on BIM-assisted projects when compared to Non-BIM assisted construction projects. Safety Management, Labor Management, Sub-contractor Management and Material Management were the lower ranking CPM attributes. The lowest mean score for CPM attributes was 4.55 for Labor Management from the engineers’ perspective. The cut-off point for relevance as a CPM attribute with a positive impact on BIM-assisted projects is a 4.00. Therefore, all the identified CPM attributes received a mean score that indicates a positive influence on average with the use and implementation of BIM. The ANOVA test for statistical significance between AEC practitioner groups based on Business Type indicated that there is statistical significance in the mean score for all CPM indicators, except for Work Progress and Safety Management.

Table 4.6.8 – Other AEC Practitioners’ - CPM Attributes Ranking by Number of BIM Projects

<table>
<thead>
<tr>
<th>CPM Attributes</th>
<th>1 - 5 Projects N = 35</th>
<th>Mean</th>
<th>S/D</th>
<th>Rank</th>
<th>6 - 15 Projects N = 30</th>
<th>Mean</th>
<th>S/D</th>
<th>Rank</th>
<th>16 to 40 Projects N = 27</th>
<th>Mean</th>
<th>S/D</th>
<th>Rank</th>
<th>41 to 100 Projects N = 21</th>
<th>Mean</th>
<th>S/D</th>
<th>Rank</th>
<th>100+ Projects N = 45</th>
<th>Mean</th>
<th>S/D</th>
<th>Rank</th>
</tr>
</thead>
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<tr>
<td>Labor Management</td>
<td>4.94</td>
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<td>19</td>
<td></td>
<td>4.80</td>
<td>0.98</td>
<td>19</td>
<td></td>
<td>4.96</td>
<td>0.85</td>
<td>16</td>
<td></td>
<td>5.24</td>
<td>1.04</td>
<td>19</td>
<td></td>
<td>3.00</td>
<td>0.77</td>
<td>19</td>
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<td>Subcontractor Management</td>
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<td>0.77</td>
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<td>0.76</td>
<td>18</td>
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<td>4.93</td>
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<td>17</td>
<td></td>
<td>5.24</td>
<td>1.04</td>
<td>19</td>
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<td>3.00</td>
<td>0.77</td>
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<tr>
<td>Cost Management</td>
<td>5.03</td>
<td>0.99</td>
<td>15</td>
<td></td>
<td>5.07</td>
<td>0.78</td>
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<td>0.68</td>
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<td>Schedule Control</td>
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<tr>
<td>Work Progress</td>
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<td>Quality Management</td>
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<td>3</td>
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<td>0.92</td>
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<td>4.85</td>
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<td>5.48</td>
<td>1.03</td>
<td>15</td>
<td></td>
<td>5.31</td>
<td>0.97</td>
<td>11</td>
<td></td>
</tr>
</tbody>
</table>

*The numbers in bold indicate ranking among the Top Ten in its category
According to the groupings based on number of BIM-assisted projects, the AEC practitioners consistently ranked: Earlier Detection of Problems, Information Management, Communication Effectiveness, Communication Method, Communication Frequency, Coordination Tools, Open Information Sharing, Stakeholder Coordination and Decision-Making Process among the Top Ten CPM attributes. Safety Management, Labor Management, Sub-contractor Management, Scope Clarification, Leadership and Material Management were the lower ranking CPM attributes. The lowest mean score was 4.73 for Safety Management. The cut-off point for relevance as a CPM attribute with a positive impact on BIM-assisted projects is a 4.00. Therefore, all the identified CPM attributes received a mean score that indicates a positive influence on average with the use and implementation of BIM.

Other AEC practitioners who participated in the study were asked to rate their Project Success and Construction Project Management on BIM-assisted projects when compared to Non-BIM assisted projects. They were asked to compare their experience considering the identified attributes of PS and CPM. While 3 participants indicated a negative experience with the use of BIM, all other participants indicated that the Project Success and Construction Project Management on BIM-assisted projects either remained the same or was better. A majority of the respondents indicated that the impact on BIM-assisted projects was either moderately better or much better.
CHAPTER 5

FINDINGS

5.1 Findings for BIM’s Impact on Construction

The qualitative and quantitative study provides us with valuable insights into both the Academic and Practitioners’ perspectives on BIM and its impact on Construction. The Academic perspective was assessed to identify the relevance of identified BIMM and Construction Performance indicators. The Contractor and Other AEC professional perspectives were collected to assess the extent to which BIMM indicators, Project Success and Construction Project Management objectives were achieved on BIM-assisted projects. The key findings of this study in response to the research questions are as follows:

1. What are the Key Drivers for BIM adoption and implementation on a Construction Project?
   a. Increasing Construction Productivity / Performance
   b. To be competitive in Industry
   c. To be a leader in Industry: Exploring and adopting new trends
   d. Required by Owner

2. What are the key areas for assessing Construction Performance
   a. Construction Key Performance Indicators (CKPI) – Table 2.2.1
      i. Goal Oriented Performance Indicators
      ii. Result Oriented Performance Indicators

3. Has the implementation and adoption of BIM improved productivity/performance on construction projects?
   a. BIM has improved Construction Project Success and Project Performance
   b. Extent of increase/decrease in performance - Table 5.1.1 and Table 5.1.2
The Academic perspective on BIMM, indicated that there was agreement on relevance for all the identified BIMM indicators in the study. The BIMM indicators that were ranked consistently among the top ten by Academics were: Information Delivery Method, Data Richness, Information Accuracy, Work Flow, Document and Modeling Standard, and Quality Control. Of these BIMM indicators, only four of the top BIMM indicators that were listed in the top ten were also identified in the top ten by Contractors and other AEC professionals. These BIMM indicators were: Information Delivery Method, Information Accuracy, Document and Modeling Standard and Quality Control.

The Academic perspective on all Project Success indicators met the 4.00 minimum mean score requirement for relevance and are therefore accepted as appropriate indicators for Project Success. The top Project Success indicator was identified to be Quality Goal followed by Schedule Goal, Cost Goal, Customer Satisfaction and Safety Goal. The priority given in rank to these Project Success indicators are different to the rank in which Project Success goals have been achieved according to the Contractors and Other AEC practitioner perspectives. The ANOVA tests conducted indicated statistical significance in Interoperability, Senior Leadership, Hardware Upgrade, Information Delivery Method, and Process and Technology Innovation for BIMM. This means that there is a statistically significant difference in opinion for the mean score of BIMM indicators between groups.

The Construction Project Management indicators that were consistently identified among the top ten as relevant, by Academics included: Cost Management, Work Progress, Earlier Detection of Problems, Communication Effectiveness, Safety Management, Scope Clarification, Schedule Control and Quality Management. Contractors and other AEC practitioners indicated that on BIM-assisted projects - Earlier Detection of Problems, Communication Effectiveness and
Scope Clarification are among the achieved CPM indicators that were consistently ranked among the top ten. The ANOVA test for the Academic’s mean scores on Project Success and Construction Project Management indicators, highlighted that there is no statistical significance in the mean scores based on the academic groupings. The findings from the Academic perspective adds further value and validation to the BIMM, Project Success and CPM indicators/attributes that were identified and refined throughout the research process.

Some interesting findings through the analysis of Academic perspectives was that there is a difference in how indicators are perceived depending on the experience in number of years working with BIM and the level of BIM expertise. For example, Interoperability was ranked lower by Academics who were in the 0-5 years of Academic experience with BIM and ranked among the top ten for Academics with over 5 years of experience. Additionally, Academics with low and medium level of expertise had also indicated a lower rank for interoperability, while Academics with high and expert levels of expertise had ranked them considerably higher.

Contractors who participated in the study provided valuable insights both at the qualitative and quantitative phases of the study. The findings during the qualitative interviews prompted the inclusion of “Information Security” as an additional BIMM indicator. This was highlighted as an important aspect to consider for BIM Maturity and was also revealed in the quantitative study as insufficiently addressed on BIM-assisted projects.

Contractors were asked to rank the BIMM indicators based on the extent to which they were addressed on BIM assisted projects. The BIMM indicators that were noted to have been consistently ranked among the top ten in at least one of the categories analyzed included: Software Application, Information Delivery Method, Information Accuracy, Graphics, Document and Modeling Standard and Quality Control. The BIMM indicators that received a mean score of less
than 4.00 in at-least one of the groupings included: Information Security, Lifecycle Process, Standard Operating Process, Reward System, Competency Profile, Risk Management, Training Program, Training Delivery Method, Change Management, Hardware Equipment, Geo-spatial capability, Workflow, Senior Leadership and Role and Responsibility. This means that there is need for improvements in the areas covered by these BIMM indicators in pursuit of a more mature BIM for utilization on construction projects.

Contractors ranked Customer Satisfaction as the top Project Success goal that is achieved on BIM-assisted projects. This is followed by Quality Goal, Schedule Goal, Cost Goal and Safety Goal. With a mean score of more than 4.00, all of the Project Success goals seem to have seen better performance on BIM-assisted projects.

Contractors identified the top Construction Project Management attributes that were achieved on BM-assisted projects were: Earlier Detection of Problems, Communication Effectiveness, Coordination Tools, Open Information Sharing, Scope Clarification, Information Management and Decision-Making Process. With a mean score of more than 4.00 on all CPM attributes, we find that there is a positive influence for Contractors on CPM for BIM-assisted projects.

The quantified benefit on Project Success for Contractors on BIM-assisted projects when compared to Non-BIM-assisted projects are presented in table 5.1.1.
Table 5.1.1 – Impact of BIM on Construction Project Success Attributes: Contractors

<table>
<thead>
<tr>
<th>Project Success Attribute</th>
<th>Impact</th>
<th>Percentage</th>
</tr>
</thead>
<tbody>
<tr>
<td>Design Errors</td>
<td>Decrease</td>
<td>42%</td>
</tr>
<tr>
<td>RFI during Pre-construction</td>
<td>Increase</td>
<td>432%</td>
</tr>
<tr>
<td>RFI during construction</td>
<td>Decrease</td>
<td>25%</td>
</tr>
<tr>
<td>Number of Change Orders</td>
<td>Decrease</td>
<td>42%</td>
</tr>
<tr>
<td>Cost of Change Orders</td>
<td>Decrease</td>
<td>51%</td>
</tr>
<tr>
<td>Cost of Re-work</td>
<td>Decrease</td>
<td>63%</td>
</tr>
<tr>
<td>Cost of punch list items</td>
<td>Decrease</td>
<td>36%</td>
</tr>
<tr>
<td>Number of near misses</td>
<td>Decrease</td>
<td>39%</td>
</tr>
<tr>
<td>Number of site accidents</td>
<td>Decrease</td>
<td>47%</td>
</tr>
<tr>
<td>Number of legal claims and litigation</td>
<td>Decrease</td>
<td>51%</td>
</tr>
<tr>
<td>Cost of legal claims and litigation</td>
<td>Decrease</td>
<td>49%</td>
</tr>
<tr>
<td>Number of repeat customers</td>
<td>Increase</td>
<td>5%</td>
</tr>
</tbody>
</table>

As observed in the table, the majority of Project Success attributes are observed to have a positive impact on BIM-assisted projects when compared to Non-BIM assisted construction projects. The largest and most positive impact is seen at a 63% reduction in Cost of Re-work. The next largest decrease of 51% is seen in Cost of Change Orders and Number of legal claims and litigation. This is followed by a 47% decrease in number of Site Accidents and a 42% decrease in Design Errors and Number of Change Orders. A 5% increase in repeat customers can be observed on BIM-assisted projects. Interestingly, there is a 432% increase in RFI’s during Pre-Construction.

These percentages are indicative of improved internal efficiencies as it relates to the process of construction, personnel safety and risk management. The increase in RFI’s during Pre-Construction is also reflective of a finding during the qualitative study which indicates an increase in RFI’s before construction begins and as a result saving cost and time while the construction is ongoing.

ANOVA tests conducted for the contractors based on the business types indicated that there are a few indicators in BIMM and CPM with statistically significant differences in mean scores. A majority of the indicators and their mean scores were not statistically significant, which means
that there is a difference of opinion between the groups but not on a large number of the presented indicators.

Other AEC practitioners who participated in the study provided valuable insights to the impact of BIM from the perspectives of other important stakeholders on a construction project. The BIMM indicators that were consistently identified among the top ten for being addressed on BIM-assisted projects included: Software Application, Information Delivery Method, Graphics, Document and Modeling Standard and Quality Control. Most of the indicators received a mean score of at-least 4.00. However, the BIMM indicators that received less than 4.00 were: Information Security, Reward System, Training Program, Training Delivery Method, Lifecycle Process, Risk Management, Senior Leadership, Competency Profile and Standard Operating Process. While improvements can be made for all areas of the BIMM indicators, these indicators should be considered for improvement in pursuit of a more mature BIM. It also appears that based on the mean score and ranking, the utilization of BIM by other AEC industry practitioners is more mature that the utilization of BIM by Contractors.

The ranking of Project Success indicators by other AEC professionals is very similar to the rankings as indicated by the Contractors. The CPM goals that were achieved on BIM-assisted projects and ranked consistently among the top ten included: Earlier Detection of Problems, Information Management, Communication Effectiveness, Communication Method, Communication Frequency, Coordination Tools, Open Information Sharing, Decision Making Process and Stakeholder Coordination. The comparison of CPM attributes consistently ranked in the top ten between Contractors and other AEC practitioners are largely similar. However, attributes such as Communication Method, Communication Frequency and Stakeholder Coordination were among the top ten for other AEC practitioners and not for the Contractors. The
CPM attribute that was ranked consistently among the top ten by Contractors and not by other AEC practitioners was Scope Clarification. The quantified benefit on Project Success for Other AEC practitioners on BIM-assisted projects when compared to Non-BIM-assisted projects are presented in table 5.1.2.

Table 5.1.2 – Impact of BIM on Construction Project Success Attributes: Other AEC

<table>
<thead>
<tr>
<th>Project Success Attribute</th>
<th>Impact</th>
<th>Percentage</th>
</tr>
</thead>
<tbody>
<tr>
<td>Design Errors</td>
<td>Decrease</td>
<td>46%</td>
</tr>
<tr>
<td>RFI during Pre-construction</td>
<td>Decrease</td>
<td>34%</td>
</tr>
<tr>
<td>RFI during construction</td>
<td>Decrease</td>
<td>48%</td>
</tr>
<tr>
<td>Number of Change Orders</td>
<td>Decrease</td>
<td>47%</td>
</tr>
<tr>
<td>Cost of Change Orders</td>
<td>Decrease</td>
<td>46%</td>
</tr>
<tr>
<td>Cost of Re-work</td>
<td>Decrease</td>
<td>52%</td>
</tr>
<tr>
<td>Cost of punch list items</td>
<td>Decrease</td>
<td>37%</td>
</tr>
<tr>
<td>Number of near misses</td>
<td>Decrease</td>
<td>52%</td>
</tr>
<tr>
<td>Number of site accidents</td>
<td>Decrease</td>
<td>52%</td>
</tr>
<tr>
<td>Number of legal claims and litigation</td>
<td>Decrease</td>
<td>55%</td>
</tr>
<tr>
<td>Cost of legal claims and litigation</td>
<td>Decrease</td>
<td>48%</td>
</tr>
<tr>
<td>Number of repeat customers</td>
<td>Decrease</td>
<td>34%</td>
</tr>
</tbody>
</table>

The impact of BIM on Construction from the perspective of Other AEC practitioners seems to also be largely positive. The largest decrease for other AEC practitioners at 55% is for the Number of Legal Claims and Litigation. This is followed by a 52% decrease for Cost of Re-work, Number of site accidents and Number of near misses when comparing BIM-assisted projects to Non-BIM assisted projects. When compared to the Contractors, other AEC practitioners seemed to indicate that there was a 34% decrease in the number of RFI’s during pre-construction and also a 34% decrease in the number of repeat customers.

The ANOVA tests for Other AEC professionals indicated the largest number of BIMM, Project Success and Construction Project Management indicators with a highlighted statistical difference in mean score based on business type. This means that the Other AEC practitioners have
a lot of variation in opinions for the mean score and rank of the presented indicators based on their business type.

Findings indicate that the top three building types that utilize BIM are Commercial, Healthcare and Educational buildings. Additionally the main delivery method for a majority of the construction projects that utilize BIM are either Design-Build (DB) or Design-Bid-Build (DBB). As indicated by both the Contractors’ group and the Other AEC Practitioners’ group, the top driver for choosing to adopt BIM was to enhance Productivity. Competitive advantage, requirement by owners and to be a leader in industry were also highly ranked as drivers and reasons for BIM adoption on projects. Success stories of BIM and Policy were not cited by many as a key driver for BIM.
CHAPTER 6

CONCLUSIONS AND RECOMMENDATIONS

6.1 Conclusions and Recommendations

Following the qualitative and quantitative analysis, we can conclude that the Building Information Modeling Maturity (BIMM) and Construction Performance indicators and attributes identified by this study are valid. This conclusion is made with significant literature evidence that supports these indicators and attributes along with qualitative and quantitative approaches that have refined and tested them. The quantitative analysis indicated that while there are a few indicators with statistical significances in mean scores based on the groupings, all the attributes were considered relevant from the Academicians’ perspective with at least a mean score of 4.00 or above.

Following extensive literature review and the qualitative study, the BIMM indicator of Information Security should be added to the initial BIMM matrix (Yunfeng. Chen et al., 2016). Table 4.3.1 provides a summary of BIMM indicator rankings from the Academic perspective which assesses relevance. Table 4.3.1 also provides the Contractor and Other AEC practitioners’ ranking of BIMM indicators, which assesses the extent to which those indicators have been addressed on BIM-assisted projects. It appears that a majority of the indicators that are grouped under the Technology and Information factors are addressed on BIM-assisted projects, but there is still a lot of room for improvement for the Process and People factors of BIMM. This is consistent with the findings of the qualitative study, where People and Process were identified as higher ranking in importance when compared to Technology and Information BIMM factors. Most of the BIMM indicators that are ranked among the top ten by Academics appear to be ranked among the
top ten for being addressed from the contractor and other AEC practitioner perspectives. However, there also appears to be a mismatch between many of the indicators ranked at the middle and lower levels. Studies should be conducted to explore how these gaps could be bridged in order that the indicators that are ranked in importance by relevance also matchup with the extent to which it is addressed on BIM-assisted projects.

A majority of the survey respondents indicated that they believe their BIM-adoption to be mature based on the BIMM indicators presented to them. However, there appears to be multiple BIMM indicators that scored a mean score rank less than 4.00 and therefore, did not meet the criteria for being adequately addressed on BIM-assisted projects. This may be caused by a lack of knowledge and information on how BIM and its capabilities could be maximized for project adoption and implementation. A further explanation of this could be caused by the single dimensional approach that most stakeholders may have on a project as opposed to a multidimensional and collaborative approach. It is recommended that companies consider evaluating their current state of BIM understanding and adoption in order to benchmark with industry uses of BIM and accordingly evaluate the appropriate strategies and approaches to increase their BIMM.

Construction Performance Indicators and Attributes divided into goal oriented - Project Success (PS) and process oriented - Construction Project Management (CPM) are presented in table 3.4.1. These indicators and attributes were also checked and refined during the qualitative interview process. The results from the Academic perspective for the quantitative analysis again confirm that the indicators and attributes are relevant for the measuring of Project Success and Construction Project Management. All indicators and attributes for PS and CPM ranked by the Academics returned a mean score of greater than 4.00. Therefore, the Construction Performance
matrix as presented in this study is accepted as a model for assessing Construction Performance on BIM-assisted construction projects. The Construction Key Performance Indicator (CKPI) matrix is a key contribution of this thesis study. It is recommended that the performance matrix be used for BIM and Non-BIM assisted construction projects for the development of case studies and further validation of appropriate use as a method of measuring construction performance on BIM-assisted projects and possibly Non-BIM assisted projects as well.

The overall Project Success goals and their rankings as seen in table 4.3.4 were the same between Contractors and other AEC practitioners. The main ranking difference observed between Academics and the industry practitioners was customer satisfaction. While Academics ranked customer satisfaction at number four, industry practitioners indicated that with the use of BIM, customer satisfaction typically ranked in first place. The rankings for Construction Project Management also were similar between the Contractors and the other AEC practitioners. Many of the Construction Project Management attributes that were ranked among the top ten by Academics were also ranked among the top ten by industry practitioners as addressed on their BIM assisted projects. Schedule Control and Cost Management, which were ranked highly by the Academics as relevant measures of Construction Project Management did not have a high ranking from the industry practitioners’ perspective. It is recommended that BIM tools and processes for Schedule Control and Cost Management be further explored and promoted among industry practitioners.

Following the analysis, it is determined that the PS and CPM indicators/attributes can be used as a means of measuring the performance of BIM-assisted construction projects.

Contractors and Other AEC practitioners provided ratios for performance on BIM-assisted projects when compared to Non-BIM assisted projects. These ratios were converted to percentage increase or decrease and presented in tables 5.1.1 and 5.1.2. The conclusion based on the majority
of these PS attributes is that BIM has a positive impact on the Project Success and performance of a Construction Project. There is a difference in the average impact that is experienced by the Contractors and other AEC practitioners who participated in this study. The author recommends further investigation into creating a Building Information Modeling Project Success Ratio (BIM-PSR) Benchmark for Contractors and other AEC practitioners to use and assess their BIM-assisted projects. The BIM-PSR would utilize the Project Success Ratio attributes identified in this study and could potentially be an established benchmark based on building type, project size and locality of project. Companies could adopt the BIM-PSR to evaluate its own performance from project to project and also measure its performance based on the building type, project size and locality. This would create a better case for BIM adoption and also create more buy-in as a measurement for performance could be presented and justified to stakeholders. A need for a quantifiable benchmark and measure for Project Success is justified by the larger number of survey participants who indicated that the main driver for adoption of BIM was to increase productivity. The BIM-PSR could also potentially be built towards a collaborative database that feeds in project/company data and generates benchmark models based on varied factors. The key recommended benchmark factors are Building Type, Project Size and Locality.

In conclusion, this study has added to the body of knowledge by identifying for the first time and evaluating a Key Construction Performance Indicator (CKPI) matrix. The matrix indicators and attributes were tested for the impact of BIM, and it is found that BIM has a positive impact on Project Success and Construction Project Management. As a result, BIM is found to have a positive impact on both Result oriented and Process oriented Construction Performance and the Building Information Modeling Project Success Ratio (BIM-PSR) benchmark is recommended for further study and industry use.
REFERENCES

Chen, Y. (2013). Measurement Models of Building Information Modeling Maturity. (Ph.D), Purdue University, Ann Arbor.
CIRIA. (2016). BIM Delivery Cube. In B. D. Cube (Ed.), (pp. A cube developed by the CIRIA to help share and develop an understanding of BIM as the implementation of BIM grows and increases).


Appendix 1 - Questions for Initial Qualitative Analysis

1. How do you measure productivity on your projects?

2. Does your company use Building Information Modeling (BIM)? And if so, what software do you use? What does BIM mean to you and your projects?

3. If your company uses BIM, what are the benefits of BIM? For whatever benefits listed, could you explain how BIM creates those benefits?

4. If your company uses BIM, has the use of BIM improved productivity on your projects? And if so, how?

Appendix 2 – Qualitative Interview - BIM Maturity (Y. Chen, 2013)

- **Factor** of BIM maturity
  - **Indicator** of BIM maturity
    - **Attribute** of BIM maturity

- **Technology**
  - Software Application
    - Software Application
    - Software Capability
    - Software Selection
    - Software Maintenance
    - Software Upgrade
  - Interoperability
    - Software Interoperability
    - Information Loss
    - Hardware Compatibility
  - Hardware Equipment
    - Hardware
    - Hardware Selection
    - Hardware Maintenance
  - Hardware Upgrade
    - Hardware Upgrade
• **Information**
  o Information Delivery Method
    ▪ Electronic Information Delivery
    ▪ Interaction Method
  o Information Assurance
    ▪ Information Assurance
  o Data Richness
    ▪ Data Richness
    ▪ Knowledge Management
  o Real-Time Data
    ▪ Real-Time Information
  o Information Accuracy
    ▪ Information Accuracy
  o Graphics
    ▪ Graphics
  o Geospatial Capability
    ▪ Geospatial Capability
  o Work Flow
    ▪ Work flow
  o Documentation and Modeling Standards
    ▪ Documentation and Modeling Standards

• **Process**
  o Process and Tech Innovation
    ▪ Innovation Orientation
    ▪ Technology Novelty
    ▪ Technology Acquisition
  o Strategic Planning
    ▪ BIM Goals
    ▪ Collaboration Plan
  o Lifecycle Process
    ▪ Lifecycle Coverage
    ▪ Information Exchange
  o Change Management
    ▪ Technology Change Management
    ▪ Process Change Management
  o Risk Management
    ▪ Risk Management
    ▪ Model Ownership
    ▪ Level of Reliance
    ▪ Contractual Agreement
  o Standard Operating Process
• **BIM Execution Process**
  o Quality Control
    ▪ BIM Deliverables
    ▪ BIM Modeling Process
  o Specification
    ▪ Level of Development
    ▪ File Format
    ▪ File Naming Structure

• **People**
  o Senior Leadership
    ▪ Senior Leadership
  o Role
    ▪ Team Role Definition
    ▪ Work Scope Awareness
    ▪ BIM Manager
  o Reward System
    ▪ Reward System
  o Competency Profile
    ▪ Competency
    ▪ Experience
    ▪ Knowledge
    ▪ Skills
  o Training Program
    ▪ Training Program
  o Training Delivery Method
    ▪ Training Delivery Method
Appendix 3 – Survey for Academics: Impact of Building Information Modeling (BIM)

Start of Block: Part I RESPONDENT'S INFORMATION

Q1 Demographic Information

○ Your current position/title: (1)
  _______________________________________________________

○ State/Province of your current institution: (2)
  _______________________________________________________

○ Country of your current institution: (3)
  _______________________________________________________

○ Highest Degree: (4) _______________________________________________________

○ Total years of academic experience (if applicable): (5)
  _______________________________________________________

○ Total years of industrial experience (if applicable): (6)
  _______________________________________________________

Q2 Please indicate your confidence in your expertise in construction management?

○ None (1)

○ Low (2)

○ Somewhat Low (3)

○ Medium (4)

○ Somewhat High (5)

○ High (6)

○ Expert (7)
Q3 Please indicate your confidence in your expertise in BIM?

- None (1)
- Low (2)
- Somewhat Low (3)
- Medium (4)
- Somewhat High (5)
- High (6)
- Expert (7)

Q4 Please indicate how long (Y) you have worked with BIM:

- Never (1)
- 0 < Y ≤ 1 Year (2)
- 1 < Y ≤ 2 Years (3)
- 2 < Y ≤ 5 Years (4)
- 5 < Y ≤ 8 Years (5)
- 8 < Y ≤ 13 Years (6)
- 13 < Y ≤ 20 Years (7)
- 20 Years < Y (8)
Q5
Please rate the following items with respect to their relevance in measuring BIM Maturity.

BIM Maturity (BIMM) refers to the extent to which BIM is explicitly defined, managed, integrated, and optimized.

<table>
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<tr>
<th>Software Applications (1)</th>
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<td>Hardware Upgrade (4)</td>
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<td>Information Delivery Method (5)</td>
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<td>Information Assurance (6)</td>
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<td>Process and Technology Innovation (7)</td>
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Q6
Please rate the following items with respect to their relevance in measuring BIM Maturity.

BIM Maturity (BIMM) refers to the extent to which BIM is explicitly defined, managed, integrated, and optimized.

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</table>
Please rate the following items with respect to their relevance in measuring BIM Maturity.

BIM Maturity (BIMM) refers to the extent to which BIM is explicitly defined, managed, integrated, and optimized.

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<thead>
<tr>
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Q8

Please rate the following items with respect to their relevance in measuring BIM Maturity.

BIM Maturity (BIMM) refers to the extent to which BIM is explicitly defined, managed, integrated, and optimized.

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End of Block: Part II EVALUATION OF BIM

Start of Block: Part III CONSTRUCTION PERFORMANCE
Q9
Please rate the following items with respect to their relevance in measuring the project success in construction.

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Q10 Please rate the following items with respect to their relevance in measuring the project success in construction.

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End of Block: Part III CONSTRUCTION PERFORMANCE

Start of Block: Part III CONSTRUCTION PERFORMANCE (Continue)
Q11 Please rate the following items with respect to their relevance in measuring the performance of construction project management.

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Q12 Please rate the following items with respect to their relevance in measuring the performance of construction project management.

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Q13 Please rate the following items with respect to their relevance in measuring the performance of construction project management.

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End of Block: Part III CONSTRUCTION PERFORMANCE
Appendix 4 – Survey for Contractors: Impact of Building Information Modeling (BIM)

Start of Block: Part I ORGANIZATION INFORMATION

Q1 Please specify your company’s primary type of business (select one):

○ General Contractor (3)

○ Construction Manager (4)

○ Other (please specify) (8) ________________________________________________

Q2 Please indicate when (year range) your company started to use BIM (select one):

○ Not Yet (1)

○ 2015-2017 (2)

○ 2012-2014 (3)

○ 2009-2011 (4)

○ 2005-2008 (5)

○ 2000-2004 (6)

○ 1995-1999 (7)

○ 1990-1994 (8)

○ Prior to 1990 (9)
Q3 Please indicate the percentage (P) of BIM-assisted projects in your organization:

- P = 0  (1)
- 0 < P ≤ 15%  (2)
- 15% < P ≤ 30%  (3)
- 30% < P ≤ 45%  (4)
- 45% < P ≤ 60%  (5)
- 60% < P ≤ 75%  (6)
- 75% < P ≤ 90%  (7)
- P > 90%  (8)

Q4 Please specify your current position/role

______________________________________________________________________________
Q5 Please indicate the number of BIM-assisted projects in which you have been involved:

- None (1)
- 1-2 (2)
- 3-5 (3)
- 6-9 (4)
- 10-15 (5)
- 16-25 (6)
- 26-40 (7)
- 41-60 (8)
- 61-100 (9)
- 100+ (10)

Skip To: End of Survey If Please indicate the number of BIM-assisted projects in which you have been involved: = None

End of Block: Part I ORGANIZATION INFORMATION

Start of Block: Part II PROFESSIONAL PROFILE
Q6 Please indicate how long (Y) you have worked with BIM:

- $0 < Y \leq 1 \text{ Year}$ (1)
- $1 < Y \leq 2 \text{ Years}$ (2)
- $2 < Y \leq 5 \text{ Years}$ (3)
- $5 < Y \leq 8 \text{ Years}$ (4)
- $8 < Y \leq 13 \text{ Years}$ (5)
- $13 < Y \leq 20 \text{ Years}$ (6)
- $Y > 20 \text{ Years}$ (7)

Q7 Please indicate the States/Provinces for the majority of those BIM-assisted projects:

____________________________________________________________________________________

Q8 Please indicate the Countries for the majority of those BIM-assisted projects:

____________________________________________________________________________________
Q9 Please indicate the building types for the majority of those BIM-assisted projects (select all that apply):

- Commercial (1)
- Healthcare (2)
- Residential (3)
- Educational (4)
- Industrial (5)
- Institutional (6)
- Transportation (7)
- Other (please specify) (8)

____________________________________

________________________________________________________________________
Q10 Please indicate the project delivery methods used for the majority of those BIM-assisted projects (select all that apply):

☐ Design-Bid-Build (DBB) (1)
☐ Construction Management (CM) at Risk (2)
☐ Construction Management (CM) Agency (3)
☐ Design-Build (DB) (4)
☐ Integrated Project Delivery (IPD) (5)
☐ Other (Please specify) (6)
Q11 Please indicate all stakeholders who used BIM in the majority of your BIM-assisted projects (Please select all that apply).

☐ Owner/Developer (1)

☐ Architect/Engineer (2)

☐ General Contractor (3)

☐ Construction Manager (4)

☐ Subcontractor (please specify) (5)

☐ Consultant (please specify) (6)

☐ Software Vendor (please specify) (7)

☐ Other (please specify) (8)

________________________________________________
Q12 Please indicate the value (V) for the majority of those BIM-assisted projects:

- $0 < V \leq 1 \text{ million}$ (1)
- $1 \text{ million} < V \leq 5 \text{ million}$ (2)
- $5 \text{ million} < V \leq 10 \text{ million}$ (3)
- $10 \text{ million} < V \leq 20 \text{ million}$ (4)
- $20 \text{ million} < V \leq 35 \text{ million}$ (5)
- $35 \text{ million} < V \leq 50 \text{ million}$ (6)
- $50 \text{ million} < V \leq 75 \text{ million}$ (7)
- $75 \text{ million} < V \leq 100 \text{ million}$ (8)
- $100 \text{ million} < V \leq 200 \text{ million}$ (9)
- $200 \text{ million} < V \leq 500 \text{ million}$ (10)
- $500 \text{ million} < V$ (11)
- I do not know. (12)
Q13 Please identify the main drivers for choosing to adopt BIM on your projects (Please select all that apply).

☐ It is required by owners or contracts (1)

☐ Competitive Advantage (2)

☐ To be a leader in industry by exploring and adopting new trends in industry (3)

☐ To enhance productivity (4)

☐ Success stories of others using BIM (5)

☐ Policy (Please state the name of law/policy if known) (6)

☐ Other (please specify) (7)
Q14 What capabilities and functions of BIM have been used in most of those BIM-assisted projects (Please select all that apply)?

- Create drawings (1)
- Clash Detection (2)
- Quantity Takeoff (3)
- Scheduling and sequencing (4)
- Site Planning (5)
- Labor resource allocations (6)
- Equipment management (7)
- Communication (8)
- Collaboration with stakeholders (9)
- Energy analysis (10)
- Code compliance (11)
- Facility management (12)
- Virtual meeting capabilities (13)
- Costing and Budgeting (14)
- Waste management (15)
- Improve project controls (16)
Q15 What policy is used to address BIM in contract for most of those BIM-assisted projects (Choose all that apply)?

☐ Not available (1)

☐ AIA E202 BIM Protocol (2)

☐ AGC ConsensusDOCS 301 BIM Addendum (3)

☐ The market-accepted exhibits are modified for specific projects. (4)

☐ Other (5) ________________________________

☐ I do not know. (6)
Q16
Please rate the extent to which most of your BIM-assisted projects addressed the following items of BIM:

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<tr>
<td>Information Security (7)</td>
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</tbody>
</table>
Q20 Please indicate the overall BIM Maturity level for the majority of BIM-assisted projects in which you have been involved, considering all previous items.

*BIM Maturity refers to the extent to which BIM is explicitly defined, managed, integrated, and optimized.*

- [ ] Extremely Immature (1)
- [ ] Very Immature (2)
- [ ] Somewhat Immature (3)
- [ ] Neutral (4)
- [ ] Somewhat Mature (5)
- [ ] Very Mature (6)
- [ ] Extremely Mature (7)

End of Block: Part III EVALUATION OF BIM (Continue)

Start of Block: Part IV CONSTRUCTION PERFORMANCE
Q21 Please indicate the ratios (BIM-assisted projects / Non-BIM-Assisted Projects) for the following items:

(For example: by average, if most of your non-BIM-assisted projects had 100 design errors, while most of your BIM-assisted projects had 80 design errors, the ratio of total number of design errors is 0.8, which equals (80/100).)

- Ratio of total number of design errors (1)
- Ratio of total number of request for information (RFI) during Pre-Construction (2)
- Ratio of total number of RFI during Construction (3)
- Ratio of total number of change orders (4)
- Ratio of total cost of change orders (5)
- Ratio of total cost of rework (6)
Q22 Please indicate the ratios (BIM-assisted projects / Non-BIM-Assisted Projects) for the following items:

(For example: by average, if most of your non-BIM-assisted projects had total cost of $1,000 of punch list items, while most of your BIM-assisted projects has total cost of $600 of punch list items, the ratio of total cost of punch list items is 0.6, which equals ($600/$1,000).

- Ratio of total cost of punch list items (1)
- Ratio of total number of near misses (2)
- Ratio of total number of site accidents (3)
- Ratio of total number of legal claims and litigations (4)
- Ratio of total cost of legal claims and litigations (5)
- Ratio of total number of repeat customers (6)
Q23
Please compare the achievement of the following goals of your BIM-assisted projects by average, with that of your non-BIM-assisted projects.

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<thead>
<tr>
<th>Goals</th>
<th>1 (1)</th>
<th>2 (2)</th>
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<tr>
<td>Cost Goal (1)</td>
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<td>Schedule Goal (2)</td>
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<td>Safety Goal (4)</td>
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<td>Customers' Satisfaction (5)</td>
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</table>

Q24 Considering all the previous project goals, please compare the overall success of your BIM-assisted projects by average, with that of your non-BIM-assisted projects.

- Much worse (1)
- Moderately worse (2)
- Somewhat worse (3)
- About the same (4)
- Slightly better (5)
- Moderately better (6)
- Much better (7)
Q25 Please compare the performance of the following project management (PM) items of your BIM-assisted projects by average, with those of your non-BIM-assisted projects.

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<th></th>
<th>1 (1)</th>
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<td>(e.g. lost time, idle time)</td>
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<tr>
<td>Quality Management</td>
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Q26 Please compare the performance of the following project management (PM) items of your BIM-assisted projects by average, with those of your non-BIM-assisted projects.

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<td>Material Management (e.g. waste reduction) (7)</td>
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</tbody>
</table>
Q27 Please compare the performance of the following project management (PM) items of your BIM-assisted projects by average, with those of your non-BIM-assisted projects.

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<th>5 (5)</th>
<th>6 (6)</th>
<th>7 (7)</th>
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<tbody>
<tr>
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<td>o</td>
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<td>Stakeholder Coordination (4)</td>
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<tr>
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</tbody>
</table>
Q28 Considering all the previous project management (PM) items, please compare the overall PM performance for your BIM-assisted projects by average, with that of your non-BIM-assisted projects.

- Much worse (1)
- Moderately worse (2)
- Somewhat worse (3)
- About the same (4)
- Slightly better (5)
- Moderately better (6)
- Much better (7)
Q1 Please specify your company’s primary type of business (select one):

- Owner/Developer (please specify) (1)

- Architect (please specify) (2)

- Engineer (please specify) (4)

- Subcontractor (please specify) (5)

- Consultant (please specify) (6)

- Software Vendor (please specify) (7)

- Other (please specify) (8)
Q2 Please indicate when (year range) your company started to use BIM (select one):

- Not Yet (1)
- 2015-2017 (2)
- 2012-2014 (3)
- 2009-2011 (4)
- 2005-2008 (5)
- 2000-2004 (6)
- 1995-1999 (7)
- 1990-1994 (8)
- Prior to 1990 (9)
Q3 Please indicate the percentage ($P$) of BIM-assisted projects in your organization:

- $P = 0$ (1)
- $0 < P \leq 15\%$ (2)
- $15\% < P \leq 30\%$ (3)
- $30\% < P \leq 45\%$ (4)
- $45\% < P \leq 60\%$ (5)
- $60\% < P \leq 75\%$ (6)
- $75\% < P \leq 90\%$ (7)
- $P > 90\%$ (8)

Q4 Please specify your current position/role

__________________________________________________________________________
Q5 Please indicate the number of BIM-assisted projects in which you have been involved:

- None  (1)
- 1-2  (2)
- 3-5  (3)
- 6-9  (4)
- 10-15 (5)
- 16-25 (6)
- 26-40 (7)
- 41-60 (8)
- 61-100 (9)
- 100+ (10)

Skip To: End of Survey If Please indicate the number of BIM-assisted projects in which you have been involved: = None

End of Block: Part I ORGANIZATION INFORMATION

Start of Block: Part II PROFESSIONAL PROFILE
Q6 Please indicate how long (Y) you have worked with BIM:

- $0 < Y \leq 1$ Year (1)
- $1 < Y \leq 2$ Years (2)
- $2 < Y \leq 5$ Years (3)
- $5 < Y \leq 8$ Years (4)
- $8 < Y \leq 13$ Years (5)
- $13 < Y \leq 20$ Years (6)
- $Y > 20$ Years (7)

Q7 Please indicate the States/Provinces for the majority of those BIM-assisted projects:

________________________________________________________________

Q8 Please indicate the Countries for the majority of those BIM-assisted projects:

________________________________________________________________
Q9 Please indicate the building types for the majority of those BIM-assisted projects (select all that apply):

- [ ] Commercial (1)
- [ ] Healthcare (2)
- [ ] Residential (3)
- [ ] Educational (4)
- [ ] Industrial (5)
- [ ] Institutional (6)
- [ ] Transportation (7)
- [ ] Other (please specify) (8)

________________________________________________
Q10 Please indicate the project delivery methods used for the majority of those BIM-assisted projects (select all that apply):

☐ Design-Bid-Build (DBB) (1)

☐ Construction Management (CM) at Risk (2)

☐ Construction Management (CM) Agency (3)

☐ Design-Build (DB) (4)

☐ Integrated Project Delivery (IPD) (5)

☐ Other (Please specify) (6)

____________________________________________________________________________
Q11 Please indicate all stakeholders who used BIM in the majority of your BIM-assisted projects (Please select all that apply).

☐ Owner/Developer (1)
☐ Architect/Engineer (2)
☐ General Contractor (3)
☐ Construction Manager (4)
☐ Subcontractor (please specify) (5)
☐ Consultant (please specify) (6)
☐ Software Vendor (please specify) (7)
☐ Other (please specify) (8)
Q12 Please indicate the value (V) for the majority of those BIM-assisted projects:

- $0 < V \leq $1 million  (1)
- $1 million < V \leq $5 million  (2)
- $5 million < V \leq $10 million  (3)
- $10 million < V \leq $20 million  (4)
- $20 million < V \leq $35 million  (5)
- $35 million < V \leq $50 million  (6)
- $50 million < V \leq $75 million  (7)
- $75 million < V \leq $100 million  (8)
- $100 million < V \leq $200 million  (9)
- $200 million < V \leq $500 million  (10)
- $500 million < V  (11)
- I do not know.  (12)
Q13 Please identify the main drivers for choosing to adopt BIM on your projects (Please select all that apply).

☐ It is required by owners or contracts (1)

☐ Competitive Advantage (2)

☐ To be a leader in industry by exploring and adopting new trends in industry (3)

☐ To enhance productivity (4)

☐ Success stories of others using BIM (5)

☐ Policy (Please state the name of law/policy if known) (6)

☐ Other (please specify) (7)
Q14 What capabilities and functions of BIM have been used in most of those BIM-assisted projects (Please select all that apply)?

- Create drawings (1)
- Clash Detection (2)
- Quantity Takeoff (3)
- Scheduling and sequencing (4)
- Site Planning (5)
- Labor resource allocations (6)
- Equipment management (7)
- Communication (8)
- Collaboration with stakeholders (9)
- Energy analysis (10)
- Code compliance (11)
- Facility management (12)
- Virtual meeting capabilities (13)
- Costing and Budgeting (14)
- Waste management (15)
- Improve project controls (16)
Facilitate decision making (17)

Other (please specify) (18)

Q15 What policy is used to address BIM in contract for most of those BIM-assisted projects (Choose all that apply)?

Not available (1)

AIA E202 BIM Protocol (2)

AGC ConsensusDOCS 301 BIM Addendum (3)

The market-accepted exhibits are modified for specific projects. (4)

Other (5) ___________________________________________________________________________

I do not know. (6)
Q16
Please rate the extent to which most of your BIM-assisted projects addressed the following items of BIM:

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Q17
Please rate the extent to which most of your BIM-assisted projects addressed the following items of BIM:

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Q18
Please rate the extent to which most of your BIM-assisted projects addressed the following items of BIM:

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</tbody>
</table>
Q19
Please rate the extent to which most of your BIM-assisted projects addressed the following items of BIM:

<table>
<thead>
<tr>
<th></th>
<th>1 (1)</th>
<th>2 (2)</th>
<th>3 (3)</th>
<th>4 (4)</th>
<th>5 (5)</th>
<th>6 (6)</th>
<th>7 (7)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Documentation and Modeling</td>
<td>○</td>
<td>○</td>
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<td>○</td>
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<tr>
<td>Standards (1)</td>
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<tr>
<td>Quality Control (2)</td>
<td>○</td>
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<tr>
<td>Specification (3)</td>
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<tr>
<td>Competency Profile (4)</td>
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<tr>
<td>Training Program (5)</td>
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<tr>
<td>Training Delivery Method (6)</td>
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<tr>
<td>Information Security (7)</td>
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</tbody>
</table>
Q20 Please indicate the overall BIM Maturity level for the majority of BIM-assisted projects in which you have been involved, considering all previous items.

*BIM Maturity refers to the extent to which BIM is explicitly defined, managed, integrated, and optimized.*

- Extremely Immature (1)
- Very Immature (2)
- Somewhat Immature (3)
- Neutral (4)
- Somewhat Mature (5)
- Very Mature (6)
- Extremely Mature (7)

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*End of Block: Part III EVALUATION OF BIM (Continue)*

*Start of Block: Part IV CONSTRUCTION PERFORMANCE*
Q21 Please indicate the ratios (BIM-assisted projects / Non-BIM-Assisted Projects) for the following items:

(For example: by average, if most of your non-BIM-assisted projects had 100 design errors, while most of your BIM-assisted projects had 80 design errors, the ratio of total number of design errors is 0.8, which equals (80/100).)

- Ratio of total number of design errors (1)
- Ratio of total number of request for information (RFI) during Pre-Construction (2)
- Ratio of total number of RFI during Construction (3)
- Ratio of total number of change orders (4)
- Ratio of total cost of change orders (5)
- Ratio of total cost of rework (6)
Q22 Please indicate the ratios (BIM-assisted projects / Non-BIM-Assisted Projects) for the following items:

(For example: by average, if most of your non-BIM-assisted projects had total cost of $1,000 of punch list items, while most of your BIM-assisted projects has total cost of $600 of punch list items, the ratio of total cost of punch list items is 0.6, which equals ($600/$1,000).

- Ratio of total cost of punch list items (1)
- Ratio of total number of near misses (2)
- Ratio of total number of site accidents (3)
- Ratio of total number of legal claims and litigations (4)
- Ratio of total cost of legal claims and litigations (5)
- Ratio of total number of repeat customers (6)
Q23 Please compare the achievement of the following goals of your BIM-assisted projects by average, with that of your non-BIM-assisted projects.

<table>
<thead>
<tr>
<th>Goal</th>
<th>1 (1)</th>
<th>2 (2)</th>
<th>3 (3)</th>
<th>4 (4)</th>
<th>5 (5)</th>
<th>6 (6)</th>
<th>7 (7)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cost Goal (1)</td>
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<td>Schedule Goal (2)</td>
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<tr>
<td>Quality Goal (3)</td>
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<tr>
<td>Safety Goal (4)</td>
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<tr>
<td>Customers' Satisfaction (5)</td>
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</tbody>
</table>

Q24 Considering all the previous project goals, please compare the overall success of your BIM-assisted projects by average, with that of your non-BIM-assisted projects.

- Much worse (1)
- Moderately worse (2)
- Somewhat worse (3)
- About the same (4)
- Slightly better (5)
- Moderately better (6)
- Much better (7)
Q25 Please compare the performance of the following project management (PM) items of your BIM-assisted projects by average, with those of your non-BIM-assisted projects.

<table>
<thead>
<tr>
<th></th>
<th>1 (1)</th>
<th>2 (2)</th>
<th>3 (3)</th>
<th>4 (4)</th>
<th>5 (5)</th>
<th>6 (6)</th>
<th>7 (7)</th>
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</thead>
<tbody>
<tr>
<td>Labor Management (e.g. lost time, idle time)</td>
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<td>○</td>
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<td>○</td>
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<tr>
<td>Subcontractor Management</td>
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<tr>
<td>Cost Management</td>
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<td>Schedule Control</td>
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<td>Work Progress</td>
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<tr>
<td>Earlier Detection of Problems</td>
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Q26 Please compare the performance of the following project management (PM) items of your BIM-assisted projects by average, with those of your non-BIM-assisted projects.

<table>
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<tr>
<th>Information Management (1)</th>
<th>1 (1)</th>
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<tr>
<td>Material Management (e.g. waste reduction) (7)</td>
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</table>
Q27 Please compare the performance of the following project management (PM) items of your BIM-assisted projects by average, with those of your non-BIM-assisted projects.

<table>
<thead>
<tr>
<th>Item</th>
<th>1 (1)</th>
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<tr>
<td>Safety Management</td>
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</tr>
</tbody>
</table>
Considering all the previous project management (PM) items, please compare the overall PM performance for your BIM-assisted projects by average, with that of your non-BIM-assisted projects.

- Much worse (1)
- Moderately worse (2)
- Somewhat worse (3)
- About the same (4)
- Slightly better (5)
- Moderately better (6)
- Much better (7)

End of Block: Part IV CONSTRUCTION PERFORMANCE