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Best Practices Using Building Information Modeling in Commercial Construction

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Commercial Construction

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ABSTRACT

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Commercial Construction

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There has been an increase in adoption of building information modeling (BIM) by commercial contractors over the past few years but there is not a clear indication of current application or the frequency of each use. This research was undertaken to determine the frequency and best practices of using BIM in commercial construction.

Leading commercial contracting firms were contacted and employees were selected to complete a telephone survey that was designed to determine how they are using BIM. It was found that BIM is being used with more frequency on projects, with plans to continue to implement it even further on all projects that allow for its use. Most companies are incorporating trade contractors in their coordination meetings but are taking the lead to ensure a high standard is maintained. Trade contractors are given responsibility to resolve smaller clashes while bringing the larger problems to the clash detection meetings. The model quality being received is increasing as well the frequency of models being received from the design team; however, there is a lack of consensus as to the level of development requirement to ensure the model can be used for facilities management.

Commercial contractors are adopting building information modeling for a variety of reasons. These include client requirements, innovative technology strategies, and fear of being left behind. Overall its use improves processes within their companies. The general agreement is that BIM is having a positive impact on profitability, schedules and sales. BIM further improves the efficiency, effectiveness and competitiveness. The best practices undertaken by commercial contractors include using BIM as a sales and marketing tool, utilizing subcontractors knowledge and allowing them to resolve minor clashes, having combination of BIM teams and BIM experts and investing in training employees and further development of BIM uses.

Keywords: best practices, BIM, building information modeling, commercial construction, clash detection,

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TABLE OF CONTENTS

LIST OF TABLES ..... **xi**

LIST OF FIGURES ..... **xii**

1 INTRODUCTION **1**

1.1 Background 1

1.2 Research Problem and Purpose 4

1.3 Objectives 4

1.4 Assumptions and Limitations 4

2 LITERATURE REVIEW **6**

2.1 Building Information Modeling 6

2.1.1 BuildingSMART Alliance 7

2.1.2 Additional Descriptions of BIM 8

2.2 The BIM Model 10

2.2.1 3D Up to nD's 13

2.3 Uses of BIM 13

2.3.1 3D Modeling 14

2.3.2 Scheduling 15

2.3.3 Sequencing 15

2.3.4 Site Coordination 16

2.3.5 Cost Exercises/Estimating 16

2.3.6 Quantity Take-Offs 17

2.3.7 Clash Detection 17

2.3.8 Facilities Management 18

2.4 Top BIM General Contractors 18

3 Methodology 20
3.1 Current BIM Uses 21
3.2 Questionnaire Organization 21
3.2.1 Executive Level Questionnaire 23
3.2.2 Mid-Level Questionnaire 24
3.2.3 Field BIM Practitioner Questionnaire 26
3.3 Selection of Contractors 27
3.4 Trial Run 28
3.5 Analysis of Data 29
4 Analysis of results 30
4.1 Commercial Contractors Uses of BIM 30
4.1.1 What Contractors Are Doing 31
4.1.2 Constructability 32
4.1.3 Design Change Implications 33
4.1.4 Digital Plans Workstations 33
4.1.5 As Built Drawings 34
4.1.6 Work Plan Drawings 34
4.1.7 Laser Scanning 35
4.1.8 Operations and Manuals (OM) 36
4.1.9 Team Collaboration 36
4.1.10 Tracking Materials 36
4.1.11 Tracking Time 37
4.1.12 Site Safety 37
4.1.13 Prefabrication 37
4.1.14 Waste Reduction 38

4.1.15 Walkthroughs 38

4.1.16 Sustainability 39

4.1.17 Building Life Cycles 39

4.1.18 X-ray 40

4.1.19 Sonar 40

4.1.20 Geographic Information Systems (GIS) 40

4.1.21 Onsite Technology 41

4.2 Why They Are Using BIM and Its Benefits 41

4.3 Completion of Surveys 44

4.3.1 Participant of the Survey 44

4.3.2 Survey Questions 46

4.4 Executive Level Results 47

4.4.1 Question 1- What Are the Top Three Ways BIM is Used in Your Company? 47

4.4.2 Question 2 – How Has Each of the Above Affected Your Company? 48

4.4.3 Question 3 – What Percentage of Your Company's Projects Incorporate BIM Services? 48

4.4.4 Question 4 –How Do You Decide on Which Projects to Use BIM? 49

4.4.5 Question 5 – Do You Require Your Subcontractors to Use BIM? 50

4.4.6 Question 6 –How Has BIM Affected Profitability? 50

4.4.7 Question 7 – How Has BIM Affected Construction Time? 52

4.4.8 Question 8- How Has BIM Affected Change Orders and Litigation? 52

4.4.9 Question 9 – Why Does Your Company Value BIM? 53

4.4.10 Question 10 – Is There Anything Else You Would Like to Add About BIM That Will Benefit Our Research Into Best Practices? 53

4.5 Mid Management Level Results 54

4.5.1 Part 1 – Frequency of Uses 54
4.5.2 Question 1 – What Are the Top Three Advantages of BIM? 56
4.5.3 Question 2 – How Do You Involve Trade Contractors in Your Clash Detection Meetings? 57
4.5.4 Question 3 – Do You Use It As a Marketing Tool and If So, How? 58
4.5.5 Question 4 – How Do You Collaborate With Others Using BIM? 59
4.5.6 Question 5 – How is BIM Used On-Site? 60
4.5.7 Question 6 – How Are You Organized to Use BIM? 60
4.5.8 Question 7 – How is the BIM Process Reviewed to Create Lessons Learned? 62
4.5.9 Question 8 – What Are Your QA/QC Controls on Modeling? 62
4.5.10 Question 9 – When Do You Charge An Additional Fee for BIM Services? 63
4.5.11 Question 10 – In What Ways is Your Company Planning on Expanding Its Use of BIM? 63
4.5.12 Question 11 – What Percentages of Offices Does Your Company Have Using BIM? 64
4.5.13 Question 12 – How Long Has Your Company Been Using BIM? 64
4.5.14 Question 13 – Any Other Comments? 65
4.6 Field Practitioner Level Questions 66
4.6.1 Question 1 - What Are the Top 3 Advantages of BIM? 66
4.6.2 Question 2 - What Are the Disadvantages/ Concerns of BIM? 66
4.6.3 Question 3 - For Each of the Following Delivery Methods What Percentage of Projects Do You Receive Models From the Design Team? 68
4.6.4 Question 4 - What Percentage of Projects Do You Generate Models? 68
4.6.5 Question 5 - Of the Models Received, What Percentage of Projects Do You Have to Start From Scratch? 70
4.6.6 Question 6 - What Percentage of Projects Do You Model Your Self-Performed Work? 71

4.6.7 Question 7 - 3D Modeling 72

4.6.8 Question 8 - Do You Share Your Model With Your Trade Partners/ Subcontractors? 73

4.6.9 Question 9 - Do You Submit a Model With Your Bid? 73

4.6.10 Question 10 - Do Trade Contractors Ever Take the Lead In Clash Detection Efforts? 75

4.6.11 Question 11- Do You Use BIM to Track Variances During Construction? 76

4.6.12 Question 12 - Do You Use the Model to Produce As-Builts? 76

4.6.13 Question 13 – Any Other Comments? 78

4.7 Combined Top 3 Advantages 78

4.8 Comparison of The Eight Complete Sets 79

5 Conclusions 83

5.1 Conclusions 83

5.2 Reasons for BIM Adoption 83

5.2.1 Increase in Efficiency 83

5.2.2 Increase Competitiveness 84

5.2.3 Improved Schedules and Cost Estimates 84

5.2.4 Top Advantages as Found in the Results 84

5.3 Frequency of BIM Uses 85

5.3.1 Top Uses of BIM as Stated by Contractors 86

5.3.2 Estimating 86

5.3.3 Clash Detection 87

5.4 Best Practices 87

5.4.1 Company Organization 87

5.4.2 BIM is Used on All Projects 88

5.4.3 Subcontractors and Collaboration Meetings. 89

5.4.4 Models.......... 89

5.4.5 Invest in the Future 90

5.4.6 Marketing 90

5.4.7 Field Technology 91

5.4.8 Facilities Management 92

5.5 Recommendations for Further Research.......... 92

References 94

Appendices 99

Appendix A – Giants 300 Top BIM Contractors 100

Appendix B – Field BIM Practitioner, Mid-mangement and Executvive Questionnaires 101

Appendix C – List of Top 40 BIM Contractors 107

Appendix D – Uses of BIM Stated By Contractors' Websites 108

LIST OF TABLES

Table 2-1 Level of Detail 12

Table 4-1 Claimed Frequency of BIM Uses 55

LIST OF FIGURES

Figure 4-1 Executive Top Three Advantages 47

Figure 4-2 Percentage of Projects Using BIM 49

Figure 4-3 Are Subcontractors Required to Use BIM 51

Figure 4-4 Mid-Managers Top 3 Advantages...57

Figure 4-5 Is BIM Used for Marketing? 59

Figure 4-6 Company Structure..61

Figure 4-7 Company Structure With Combinations 61

Figure 4-8 Percentage of Offices Using BIM 64

Figure 4-9 How Long the Companies Have Been Using BIM 65

Figure 4-10 Field BIM Practitioners Top 3 Advantages 67

Figure 4-11 Percentage of Models Are Received 69

Figure 4-12 Percentage of Projects Where a Model is Received..70

Figure 4-13 Percentage of Models Needing To Be Remodeled 71

Figure 4-14 Self Performed Work 72

Figure 4-15 Do You Share Your Model 74

Figure 4-16 Percent of Companies Who Submit a Model With Their Bid 74

Figure 4-17 Subcontractors Leading Clash Detection Meetings 76

Figure 4-18 BIM Being Used to Track Variances 77

Figure 4-19 BIM Being Used to Produce As-Builts 77

Figure 4-20 Combined Top 3 Advantages of BIM 79

Figure 4-21 Comparison of Top 3 Advantages..80

1 INTRODUCTION

1.1 Background

The construction industry throughout the world had seen a major shift in the way they communicate through drawings and modeling (Rosenbloom, 2011). Technology has been at the forefront in moving the industry forward (Wsp group, 2012). Historically physical scale models were produced for structural construction projects with a key advantage being the visualization of the model, which in turn aided construction (Briggs, 1929). This advantage was lost when physical modeling became less popular. It took too much time to change the physical models when design changes were required. The industry changed to adopt hand-drafted drawings as the sole source of providing this information. The development of the personal computer led the way for the industry to use computer software to create structural drawings and assist with drafting, essentially eliminating hand drafting. Since the introduction of computer aided design (CAD) in 1963 (Sutherland, 1980; cadazz, 2004), the technology has continued to evolve into the development of virtual three-dimensional representations of the structure and we are now in the Building Information Modeling (BIM) era (Corrigan, 2010). BIM is the next natural progression from CAD and the step into the future. BIM allows the visualization aspect of modeling to be brought back into the industry, enhancing construction practice, since a model is worth a thousand drawings (McGraw-Hill, 2004). The BIM model is used within the construction industry for numerous tasks such as three-dimensional (3D) modeling, clash detection and scheduling. BIM also has the ability to be adaptable and synchronize with other software making it potentially more attractive to the industry. As a digital model is capable of different functions and BIM is continually evolving, there has been a struggle to define BIM (Jernigan, 2008; Revit forum, 2011). Recently, there have been claims that BIM can be defined as anything that is a 3D drawing (*NBIMS-US, 2012*). Others have claimed that BIM is a lot more than just a 3D model (Krygiel, 2008). For the purpose of this thesis, building information modeling (BIM) shall be defined as:

> "*A BIM is a digital representation of physical and functional characteristics of a facility. As such it serves as a shared knowledge resource for information about a facility forming a reliable basis for decisions during its lifecycle from inception onward." (NBIMS-US, 2012).*

Therefore, BIM is not only the digital model but also the process of collating and processing the data used in construction; in essence it consists of a dynamic database. As a result of this technological advancement, BIM is a current topic in the construction industry that is receiving vast attention. Contractors are adopting the software into their daily work in order to improve efficiency, advance the industry (Barton Marlow, 2012; Mortenson, 2012), and to keep pace with technology. Contractors continue to find an increased need to learn about BIM and how to implement it into their business practices. Since the technology is still relatively new, and is continually evolving, there is little consensus on how best to use BIM, how to proceed in the future uses, or how to educate the various users throughout the construction industry.

The demand for BIM products has increased significantly as contractors begin to see the benefits of utilizing this technology. Recent contractor's reports (McGraw-Hill 2009, Skanska, 2011) indicate not only financial savings, but also time savings as main benefits (Holder Construction 2009) of using the software. As a result of these positive reports in the market, more contractors are beginning to adopt BIM to try to achieve similar savings. Another reason for an increase in BIM is the impact of modern technology. Computers are being viewed more often as the best option to improve construction practices; computers are faster and more efficient than historical methods, such as hand drawings and estimating using scale rules, to measure and quantify structures. In the United States, several states are requiring more of their projects to utilize BIM (State of Ohio, 2010), as do federal projects (Levy, 2012). In the UK, the government has announced that as of 2016, all government projects over £50 million will be required to use BIM software from the design stage throughout the construction process (BIM Task Force, 2012). As a result most contractors worldwide, but in particular within the USA, understand the significance of BIM and how it can create financial savings, time savings and offer the ability to utilize the most current and advanced technologies. This has led to contractors working on implementing BIM into their business practices and to evolve their business approach as the software advances. With all of the advancements and progressions of technology in recent years, software has improved to allow the industry to change and adopt BIM.

Despite many contractors claiming to be implementing BIM, there is little evidence as to what contractors are actually using BIM for, including those that are claiming to be industry leaders in BIM utilization (Barton Marlow, 2012; Holder Construction, 2009; Hunt Construction Group, 2012; Webcor, 2011; Walsh Group, 2012). Various general contracting companies have stated on their websites and in their company literature some of the ways they are using BIM. However, there is little evidence to support these claims and to determine how often these practices are being used. There are many suggestions of potential ways that the digital model can be used, integrated and manipulated, but there is little information about how companies are actually adopting these new practices.

With all of the claims by contractors to be industry leaders in BIM utilization, it is important to understand which uses of the digital model are common practice throughout the industry. With the construction industry in a constant state of change it is important to determine what the current best practices within the industry are. This provided clarification as to where the construction industry is with regards to BIM use, provide a reference point for the rest of the contractors within the industry to determine how to proceed with BIM adoption, and determine which uses are most effective and pertinent to their field of expertise.

1.2 Research Problem and Purpose

The lack of evidence of contractor's claims regarding the use of BIM required further research to determine where the commercial construction industry was currently sitting with regards to BIM implementation. The aim of this research was to therefore provide an understanding of how commercial general contractors currently best utilized building information modeling within their construction practices.

1.3 Objectives

The objectives of this research are:

- To determine how commercial general contractors are using BIM
- To determine the frequency of potential BIM uses
- To determine the best practices for using BIM in commercial construction

1.4 Assumptions and Limitations

This research targeted leading BIM users in the construction industry, and therefore a random sample of contractors was not taken from the population. This limited the statistical analysis that could be performed on the results. It was assumed that companies with higher self-reported BIM revenues inherently suggested a greater number of projects utilizing BIM, and therefore greater experience with BIM. A list of these leading commercial construction companies with the highest BIM revenue is reported annually (bdcnetwork, 2011), and served as the starting point for this research. It should be noted that there are inevitably other companies successfully utilizing BIM that are not included in this list. However, this list still provides a comprehensive look at some of the largest contractors who are adopting BIM. One assumption made with this research is that the commercial construction companies with large BIM revenues are utilizing methods that represent the best practices currently being adopted within the construction industry. Certainly by targeting the companies with a great deal of experience in utilizing BIM, the current best practices of using BIM should collectively be identified.

2 LITERATURE REVIEW

The term ‘Best practices’ is defined as “ a method or technique that has consistently shown results superior to those achieved with other means, and that is used as a benchmark” (Business Dictionary, 2012). In order to understand the best practices of general contractors who are adopting BIM into their businesses, a careful look within the available literature was undertaken to identify various applications of BIM, ascertain which contractors are achieving superior results, and which functions these contractors are stating they are using. This involved researching industry journals, industry and contractors’ websites, textbooks, current discussion boards on construction and business websites, and forums such as LinkedIn, which provided insight into the research topic. Through reading and researching the literature, the current uses of BIM within the industry were identified, insights into possible uses of BIM were obtained and areas that were lacking information were highlighted. These findings are discussed in this chapter.

2.1 Building Information Modeling

It is important to recognize that the construction industry is still trying to understand how to best adopt BIM and how to define BIM. The purpose of this thesis is to obtain an understanding of this. Estimates show that in 2009 only 50% of general contractors claimed to have adopted some form of BIM into their business practices (McGraw Hill, 2009). By 2012 the number of users had increased to 74% (PR Newswire, 2012), which indicated a substantial rise in BIM usage. However, there were many general contractors still hesitant to fully adopt BIM (Benham, 2012), which may reflect the difficulty in adopting a practice that is not fully understood. With this in mind, the concept of BIM was explored to provide a common understanding of what BIM actually is

The construction industry has seen a recent surge in BIM usage (McGraw Hill, 2012). However, despite the increase in popularity, there appeared to be ambiguity when it came to defining what BIM is (Jernigan, 2008). Generally, the confusion revolved around the significance of BIM and whether or not it was simply a more advanced CAD program. Several different definitions were identified in textbooks, manuals, general contractors' websites and national organizations such as the Association of General Contractors (AGC). The definition of BIM that was previously identified for this thesis was taken from the buildingSMART alliance.

2.1.1 BuildingSMART Alliance

The National Institute of Building Sciences has a council called the "buildingSMART alliance" (wbdg, 2012). The purpose of this alliance is to consolidate the construction industry with regards to BIM by creating standards (NBIM Charter, 2008). However, the construction industry "does not yet have the open standards and infrastructure in place to capture, organize, distribute, and mine that information" (NBIMS-US, 2012). By producing a standard BIM definition for the industry, individuals and teams can then work together and understand the direction of BIM. The buildingSMART alliance works throughout the world attempting to coordinate the BIM efforts within each country and enable international collaboration (NIBS, 2012). Their goal is to make information sharing more easily accessible throughout the industry, thus enabling a better construction process as well as finished articles. (NBIMS-US, 2012).

The buildingSMART alliance was often referred to and appeared to be a key element in understanding BIM. Their definition of BIM is comprehensive and has been influential with BIM use throughout the United States. For these reasons it was selected as the definition of BIM to be used in this thesis. The Natural Institute of Building Sciences (NIBS) definition of BIM is as follows:

> *"A BIM is a digital representation of physical and functional characteristics of a facility. As such it serves as a shared knowledge resource for information about a facility forming a reliable basis for decisions during its lifecycle from inception onward." NBIMS-US, 2012)*

This definition explains that the model contains all the information that is required about the structure and the model is used to share this information. The model is further used to represent the structure and the purposes of the structure.

2.1.2 Additional Descriptions of BIM

Other authors have also attempted to define BIM. These definitions also help to clarify what BIM is. Jernigan (2008) suggested the following definition:

> *"….The acronym BIM (Building Information Modeling) was coined in early 2002 to describe virtual design, construction, and facilities management. BIM processes revolve around virtual models that make it possible to share information throughout the entire building industry. These virtual models are embedded with data which, shared among design team members, greatly reduces errors and improves facilities. BIM offers owners the ability to become more efficient and effective by linking their business processes with their facilities….".*

This definition suggested that the whole industry is linked through the use of BIM by sharing the data that is required. The general concept was that BIM is a process and not necessarily the model alone. This suggests that by sharing the BIM data, errors will be reduced and improvements made to other areas. This definition was found to be imprecise in that it discusses simply reducing errors and other benefits of BIM. It could be argued that any software that provided these solutions could be referred to as BIM, even though they are not a dynamically linked BIM model or meet the criteria stated by the buildingSMART alliance. It did not address the fact that a BIM is data rich and dynamic in function. This thesis regards BIM and its functions of utilizing information within the model, such as for estimating, to be important and not the general process of collaboration alone.

Krygiel (2008) furthered the previous definition by adding to the concept of BIM being a process. This expanded concept helped to alleviate some views shared within the industry. There were claims that suggested that any 3D model is a BIM model (Structure Tone, 2012) and BIM is just another visualization tool that is utilized in the construction Industry. This idea is argued by explaining that BIM is more than 3D modeling (Krygiel 2008, NBIMS-US, 2012) and can be clarified with the following:

> *"…. when we refer to BIM, we are discussing the methodology or process that BIM creates…… BIM is information about the entire building and a complete set of design documents stored in an integrated database." (Krygiel, 2008)*

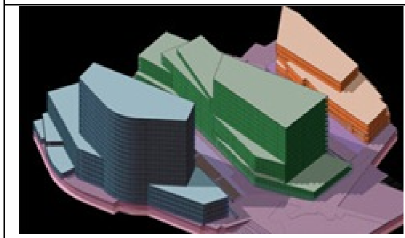
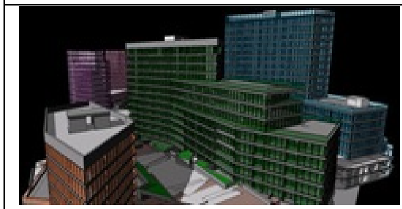
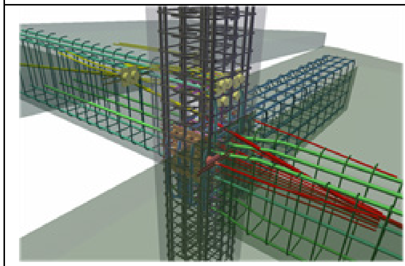
This statement referred to the design documents and integrated database, which distinguish BIM from other 3D visualization tools as well as the process of using BIM (Ryan companies, 2012; Jernigan, 2008). There are several ways to define BIM, yet Jernigan suggested that the easiest way to define BIM was by stating what BIM is not. BIM is not a single model or a single database, nor is it a replacement for people. It does not automatically calculate everything for you, since the user is still required to enter the necessary information. Otherwise, the model would produce data that is either in surplus to the requirements or not in-depth enough (Jernigan, 2008).

2.2 The BIM Model

A BIM model is produced at various levels of detail, typically referred to as LOD (All things BIM, 2008; AIA E202, 2008). There were several different definitions for LOD depending on the preference of the author. LOD may stand for "level of detail" (Vico Software 1, 2012), or "level of development" (AIA E202, 2008). For the purpose of this thesis LOD stands for 'level of detail,' since it refers to the amount of information within the model and not the development process of the model. When a model is produced, the LOD that is to be included depends on the requirement of the model and its intended use (Eastman, 2011). Fundamentally, any model consists of lines representing objects within the structure. Each model can vary in detail depending on the requirement by the architects, contractors and the client. This variance in specification for different LOD in a model leads to differing results as to what should be included in each specific model. This can cause confusion, as different users perceive different elements to be included in each LOD. Many contractors have attempted to create their own definitions of LOD (such as in DPR, 2012). In order to dispel confusion from these different definitions, the American Institute of Architects (AIA) produced E202, a document that aimed to define each level. The AIA definition aimed to include models ranging from one with basic geometric shapes, to models that have every wall type, screw, nail and equipment entered into the model. Each variance in detail level directly affects which functions a model can be used for. As an example, an architect may only be required to display a wall within their scope of work, but if a contractor plans to do any estimating from the model, they may need to enter the components that comprise the wall system. This represents two different LOD's required for the project. BIM engineers have shown reluctance to provide models at a high LOD unless required, since for each increase in LOD there is a significant corresponding increase in workload to produce the finished BIM model.

The AIA E202 document, which most contractors appear to be following, defines the model as having LOD 100, 200, 300, 400 and 500, as shown in Table 2-1 (AllthingsBIM,2008). Level 100 is the most basic level of detail and can simply be described as geometric shapes. Even with this basic level, functions such as visualization of concepts can be performed and the model can be used to provide valuable data. The more information that is added to the model (such as walls, doors, and finish details) the further up the scale the model goes. Level 300 is the middle level, and allows for cost estimating and clash detection. Level 500 is the highest level and can be used for construction estimating and facilities management, as a level 500 model includes all the necessary elements to build the structure. Since the model contains this high level of detail, it also contains a lot of the necessary information required by facility management teams to maintain the buildings. The LOD definitions did not provide a checklist of requirements for each level, but rather it provided a statement of the general requirements and a table that can be used to state which LOD is necessary for each element. The general consensus seemed to indicate that the AIA E202 document was a good grounding definition. It should be noted that the breakdown of LOD is currently in the process of being updated to provide greater clarification and a wider range of levels than the five levels outlined in AIA E202 (LinkedIn 1, 2012). For the purpose of this research the LOD definitions found in the AIA E202 were regarded to be the standard.

Table 2-1 Level of Detail

LOD	Description
	LOD 100 - Overall building massing indicative of area, height, volume, location and orientation may be modeled in three dimensions or represented by other data.
	LOD 200 - Model elements are modeled as generalized systems or assemblies with approximate quantities, size, shape, location, and orientation. Non-geometric information may also be attached to Model Elements.
	LOD 300 - Model elements are modeled as specific assemblies accurate in terms of quantity, size, shape, location, and orientation. Non-geometric information may be attached to model elements.
	LOD 400 - Model elements are modeled as specific assemblies that are accurate in terms of size, shape, location, quantity, and orientation with complete fabrications, assembly and detailing information. Non-geometric information may also be attached to model elements.
	LOD 500 - Model elements are modeled as constructed assemblies actual and accurate in terms of size, shape location, quantity, and orientation. Non-geometric information may also be attached to modeled elements.

2.2.1 3D Up to nD's

When BIM was first introduced, 3D modeling was perhaps one of the most exciting elements, as the model could be manipulated in ways previously difficult or impossible to achieve. From 3D modeling, the phrase 4D modeling was adopted to define scheduling. 5D was later adopted to define cost estimating. These three definitions for 3D, 4D and 5D are fairly consistent between different contractors. However, beyond that the definitions for 6D, 7D, 8D (Oldbury, 2012), 9D (Zyskowski, 2012), 10D, and 11D varied between different contractors. 6D can represent sustainability (elevations-bim, 2012), facilities management (Vico Software 2, 2012), accessibility (micea, 2012), and procurement and thermal properties analysis (3dbim, 2011). 7D was referred to as facilities management (elevations-bim, 2012) and operational application lifecycle (3dbim, 2011). 8D was identified as integrated project delivery (3dbim, 2011) and maintainability, 9D was for acoustics, 10D was for Security, and 11D was for heat (micea, 2012). Some contractors do not acknowledge anything above 5D and other have produced generic xD (Grady, 2012; linkedIn 2, 2012) and nD (Ghassan A, et all, 2007; micea, 2012) levels of modeling. Not all contractors utilized the same definition and there can be confusion as to what each "D" represents. Communication between different teams can be difficult if they use different definitions. For these reasons, these terms were not utilized within this research to avoid any misunderstandings. This ensured that all research participants understood what was being asked.

2.3 Uses of BIM

There are a number of common applications of BIM that were identified during the literature review, including 3D modeling, scheduling sequencing, site coordination, cost estimating, performing quantity takeoffs, facilities management, and clash detection. This section discusses these common applications of BIM. It appeared that because these uses were common practices and basic functions of BIM, that most companies would have adopted these uses or at least have been aware of them. Not all of the BIM uses utilized by general contractors are explained in this section because it was unclear which additional uses of BIM were being regularly adopted by commercial contractors. It should be noted that the literature review did not provide a single comprehensive list identifying the potential uses of BIM. One study performed by Penn State University in 2009, was comprised of an online survey to identify BIM uses (psu, 2010). This research included responses by architects, engineers, general contractors and subcontractors. Although there were 25 uses identified (psu, 2010), most of them were for the design process and beyond the basic uses previously listed, and had limited applicability to this research. Depending on the contract type, few general contractors would utilize these uses within the majority of their projects. The most common uses of BIM by commercial general contractors are each briefly discussed within this section.

2.3.1 3D Modeling

3D modeling is used to create a visualization of the structure (McCarthy, 2012; Vico Software 2, 2012) and perhaps one of the most basic uses of BIM. The plans are drawn in three dimensions, which add perspective to the drawing and also allows for different views and angels to be displayed. This provides clarification and ease compared with two dimensional paper drawings. BIM software creates 3D models, although there is a difference in the LOD in each model. 3D modeling allows for visualization of the whole structure or specific elements.

2.3.2 Scheduling

Scheduling in BIM follows the traditional practice of scheduling projects, but in a visual format and was usually referred to as 4D (Kymmell, 2008) in literature. Scheduling adds the time factor to the digital model (Levy 2012), which enables the user to see how the project is sequenced to be built. (McCarthy 2012). Through the use of BIM, each component of the structure appears in the timeframe as dictated by the schedule that allows the construction manager to organize the project. As delays or obstacles are encountered on the project, this is updated on the schedule. When components are changed or removed from the BIM model, the schedule likewise changes as it is dynamically linked to the schedule (Vico Software 4, 2012).

2.3.3 Sequencing

Sequencing follows scheduling and was used interchangeably throughout the literature (Vico Software 4, 2012). The main difference is that sequencing describes the order that is required (Scarbourgh, 2011) whereas scheduling describes the time. The model is used to determine the sequence that materials are to be brought on site, and where tools or machinery need to be located in order for an effective use of time and schedules. It can also be used to demonstrate the specific order that an installation is required to be carried out. Sequencing could be used to analyze the process of installing equipment that could only be installed in a specific order. The model would be used to produce various installation sequences until a sequence was identified that enabled the equipment to be installed successfully. This sequence could then be animated to enable the workers to follow and visualize the process (Vico Software 4, 2012).

2.3.4 Site Coordination

Site coordination is also similar to scheduling, but with an emphasis on the coordination aspect of scheduling and sequencing. The BIM model is used to coordinate the different trades on site as to when and where they are needed (Lamb E, Dean R and Khanzode A, 2009). This includes such things as space planning and ensuring cranes can fit onto site (i.e., the cranes have adequate clearance space and are able to be maneuvered without colliding with other objects). The model can also be used to demonstrate how to effectively use the site with limited space. This enables the various work teams to work concurrently and effectively with each other (Kymmell, 2008). If conflicts occur on the model, then they can be rectified prior to occurrence within the field. If used effectively, this can avoid delays on site.

2.3.5 Cost Exercises/Estimating

This was often referred as 5D and consists of the model being used to extract cost estimates based on the building components contained within the model. Quantities are extrapolated from the model and used within the estimate (Vico Software 3, 2012). If the model is adjusted to a new specification, the estimate is also changed, as long as it is dynamically linked to the model. Design changes can be easily priced and approved by the client. In order for this to be accurate, the LOD in the model is required to be about LOD 300, as all the components must be in the model. However, conceptual models are an exception to the LOD 300, as it requires generic information such as areas of walls, windows and quantities of doors. It is not material specific so a lower LOD would suffice (Bridgers & Paxton, 2012).

2.3.6 Quantity Take-Offs

Performing quantity take-offs (QTO's) is a common practice in the construction industry, even with companies that do not use BIM. QTO's are taken from drawings and estimates are used for pricing and ordering. Within the BIM model, all the components are modeled and electronic QTO's can be extrapolated using the software (Vico Software 3, 2012). To ensure that the quantity takeoffs are correct, a LOD of at least 300 is required.

2.3.7 Clash Detection

The model can be used for clash detection, to determine if any components such as structural or MEP interfere with each other (Levy, 2012) or have been planned to occupy the same space. For example, a heating duct may have been input within the model occupying the same physical place as the fire extinguishing system. However, both elements cannot occupy the same space, and therefore there is a clash. This has been a very important development for the industry and has resulted in a huge reduction of requests for change. For some large projects, the need for changes related to this type of clash could number in the thousands, and contractors were claiming they can now eliminate them almost entirely (Hunt Construction Group, 2012; Weitz company 2012; W M Jordan company, 2012). The model itself does not need to be very detailed; a LOD 300 would enable this feature to be utilized. This is one of the current common uses of BIM and has been described as the low hanging fruit (Krygiel, 2008; Lamb, Reed and Khanzode, 2009). Although useful, there are many additional reasons that contractors should be utilizing BIM and if the contractor is only using BIM for clash detection, then they are not effectively using their resources.

2.3.8 Facilities Management

There was much discussion surrounding the use of BIM for facilities management upon completion of construction. The digital model can be used in the computer-aided facilities management (CAFM) software (Messer, 2012). Various sources referred to the actual building model being used for maintenance scheduling. Contained within the model are the actual components used within the structure (Krygiel, 2008) and these can be easily located and the required data extrapolated. The facility manager can refer to the model if there is a problem within the building and quickly determine which component is within the building, when it was last repaired, and if there is a warranty. This allows facility managers to more efficiently follow the maintenance requirements of the building. An additional benefit of using a BIM model for facilities management is the ability to place a barcode or QR code on each component (ArchiCADmonkey, 2012). When the maintenance worker comes to repair the machine, they scan the code and all the handbooks and maintenance logs would be available to them on their hand held tablet.

2.4 Top BIM General Contractors

There is little information available as to which general contractors have already adopted BIM and which ones have not. This research necessitates knowing which contractors are leading BIM contractors. Therefore, an investigation was performed establishing BIM use within the construction industry with specific emphasis on commercial general contractors. The Building Design and Construction network has produced a list as part of their Giants 300 list, of the top BIM contractors, based on the contractor's self-reported BIM revenues (bdcnetwork, 2011). Apart from this list, there were no other documents or articles that provided insight into the leading BIM contractors. This list was used to target the leading BIM companies as part of this research in establishing the best practices of BIM by commercial contractors.

3 METHODOLOGY

This research aimed to establish the best practices of BIM use by general commercial contractors. From the literature review it was apparent that there was not a comprehensive list identifying potential uses of BIM by general contractors. It was therefore important as part of this research to generate such a list, prior to even going to the general contractors. It was then important to understand which of these uses of BIM commercial contractors were incorporating within their current practice and the frequency of their use. The most common BIM uses were determined by analyzing which functions were reported most frequently and which functions were perceived to be the most important. If any functions were not common between all contractors, yet were considered as innovative or advanced, these functions would be included as best practices. Not all common uses of BIM would result in best practices, since some reported functions were basic and would have been used throughout the industry. For example 3D modeling is a basic, standard practice, and all companies who use BIM software model in 3D. Therefore, a company could not be distinguished solely on 3D modeling, but their additional applications with the model, such as for sales, could produce a best practice since it makes the process run well.

The primary component of determining the frequency of BIM use involved determining how often contractors undertook each BIM function and which benefits they felt were the most important. This data was gathered through a series of questionnaires that were conducted via telephone and recorded using WebEx software. This method provided the contractors the opportunity to state the procedures of BIM that they have adopted, how often they are using them, and their general viewpoints on BIM. The data was then analyzed to produce current best practices.

3.1 Current BIM Uses

In order to determine which uses of BIM general contractors were using, further research was required. A detailed examination of contractor's websites and literature allowed for further understanding of their current practices. The most recent Giants 300 BIM list (bdcnetwork, 2011) included the top 78 commercial construction companies in self-reported BIM revenue. A copy of this list is found in Appendix A. Each of these company's websites were looked at to identify potential uses of BIM. These findings were then further used to create the BIM questionnaire.

3.2 Questionnaire Organization

For this research, a questionnaire was designed to gather both qualitative and quantitative data to enable a comprehensive understanding of the current best practices. The questionnaire that was developed can be found in Appendix B. In order to understand how BIM was implemented throughout each company, the overall questionnaire was divided into three separate smaller questionnaires targeting specific levels within each company: the executive level, mid-level management and the field BIM practitioners. By interviewing and asking the highest levels in the company about BIM and their involvement with it, the results would show if they had a basic understanding of the technology and if their involvement was vital to the functionality of BIM within the company. Asking the mid-management employees about BIM also demonstrated their knowledge and exposure to BIM, further determining how the information within each company was flowing and who was directing the BIM practices within the company. The field BIM practitioner's knowledge and daily exposure to BIM provided a basis for determining if the ideas and concepts flow throughout the company. The practitioner's knowledge of daily BIM usage was important in understanding the processes of how BIM were being performed on a daily basis.

A critical component of this research was determining how contractors were being guided with regard to BIM. From the literature review it was unclear whether the executive management were the people encouraging BIM adoption or if they were just following the trend. Since a company executive has little available time to answer lengthy questionnaires, the executive level questionnaire was designed to briefly ask questions about the company and what the respondent knew about BIM. It was specifically structured to not ask detailed questions about the uses of BIM, since these were better answered by those working directly with BIM in the company.

Depending on the size of a company, the mid-management level could vary in specific roles. Several contractors interviewed were international companies based outside the USA, and therefore their mid-management level oversaw the whole of their USA operations. For the purpose of this research, the mid-management level questionnaire was targeted towards managers above the employees working daily with BIM software.

The final target group surveyed included the employees who work with BIM on a daily basis, who are referred to in this thesis as field BIM practitioners. Depending on the size of the projects, the field BIM practitioner might only work on one or two different projects at a time, and so remain unaware of the BIM practices of the company as a whole. Due to this underexposure of BIM throughout the whole company, the questionnaire was formatted to investigate their personal thoughts about BIM use and their corresponding skillset and not necessarily all the practices undertaken within the company.

Each of the questionnaires was designed to gather both quantitative and qualitative data, as both were required to determine best practices. Much of the questionnaires targeted determining how BIM is being used within the company, the most common BIM uses, and which uses could be developed further. Additionally, the questionnaires were designed to help determine why BIM is being adopted and subsequently any common reasons for doing so, such as financial, time constraints, or other reasons associated with implementation.

3.2.1 Executive Level Questionnaire

The first two questions were designed to allow the respondent to think about the company's use of BIM and the executives understanding of the technology. It was anticipated that an executive with greater knowledge would be able to expand on personal opinions and not just select the basic definitions such as 3D, clash detection or scheduling. On the other hand, it would be evident throughout the remainder of the survey, if an executive did not fully understand BIM.

Questions 3-5 were more specific about the firm's process of deciding how to implement BIM within their business practices and how frequently BIM was used within the company. These questions were intended to invite the respondent to discuss their BIM strategy and the importance they placed on BIM. As the executive has an overview of the large scale business operations, their insights would prove vital. Differences between the strategies of the various companies would show how well they had integrated BIM into their everyday work.

Questions 6 – 8 were included to focus on three distinct aspects of BIM. This allowed for direct comparisons of views on profitability, construction time, change orders and litigation to be made. The questions allowed for comparison of the commonly stated claimed benefits. Obvious common patterns for contractors obtaining better results could be further studied.

Questions 9 – 10 allowed the respondent to state why the company values BIM and to provide additional general comments. Understanding the overall reason why BIM was valued is different from question 1, as the executive could freely express why BIM was used and limited to stating the benefits.

3.2.2 Mid-Level Questionnaire

The mid-level questionnaire was an important part of helping understand why contractors were adopting BIM and where the driving force was coming from. These questions tapped into mid managers knowledge of BIM and their company, and provided further understanding about the best practices of BIM. The questionnaire was divided into two parts, parts A and B.

Part 1 consisted of a table to be completed by the respondents, and contained a list of 26 potential BIM uses. The survey participants would enter the appropriate frequency for each use. The data collected by all mid-level management in this part of the survey could be used to assess the frequency of use within the companies of the industry BIM leaders.

Part 2 consisted of 12 questions presented in the same format as executive and field BIM practitioner questions. Their breakdown and reasoning for inclusion is as follows:

Question 1 of the mid-level survey was the same as question 1 in the executive questionnaire. This was implemented to gain further insight into the advantages of the BIM adoption and to determine if the perceived advantages of using BIM changed throughout the organization and through the level of interaction with the software.

Question 2 was included to determine how general contractors are collaborating with trade contractors. The question was left without options to allow the respondent to suggest the company's procedures without influence of possibilities.

Questions 3 - 5 asked about direct uses of BIM and were placed after questions 1 and 2 to avoid influencing the responses to question 1 and 2. By allowing the participants to state their own advantages, the data would suggest a truer reflection of their perceived benefits without being influenced by the options initiated through the survey. It was important to understand how these individuals were using BIM within the companies, as this reflects what the common BIM uses actually are. With this in mind, the questions were formatted to obtain qualitative data. By allowing the respondent to elaborate on these items, further clarity and insight into the uses of BIM was obtained.

Question 6 was included to aid in understanding the business structure of utilizing BIM within a company. This allowed for comparing common practices being adopted throughout the various companies and to determine the most common structure within the industry. This question enabled comparisons to be made between the different companies surveyed and to determine if a pattern existed or if a particular setup was unique and best.

Questions 7 – 8 referred to the organizational structure and processes of the companies. The procedures that are in place to aid with improving BIM use within a company are important. These could be a key indicator into the importance of using BIM within a company. Developing procedures are important particularly to a new process within a company structure. It is differences in processes that determine whether a company will be successful or not. These two questions in the survey were qualitative to allow the respondent to elaborate and explain how they were implementing improvements within the company. It was desired to determine if there was a common practice being developed or a practice that was superior to others. These questions were added to gain further insight into company best practices.

Question 9 was added after recognizing in the literature review that several companies stated that BIM was being used for all projects and that it was a “standard practice” within their company. It was unclear, however, whether this service was included in project costs or an additional fee was being charged. By posing question 9 in this format, contractors had the opportunity to discuss their BIM strategy with regard to costs.

Question 10 was included to determine if there was a common direction within the industry or practices that were more popular than others, since there were numerous articles discussing future uses of BIM within the industry. It was felt that because contractors understand their industry and know what the needs are, their input would be a good gauge of what will be practical in the coming years.

Questions 11 - 12 were quantitative questions, added to allow comparison between companies and individuals to be made. Patterns or common practices by size, experience or adoption rates could further be analyzed. This would in turn permit further best practices to be identified and categorized as required.

3.2.3 Field BIM Practitioner Questionnaire

Understanding the perceptions of BIM at the employee level was important since these were the people within the organization who work daily with BIM. Although they ultimately knew what they were doing with regard to using BIM, they may not have a comprehensive vision for BIM use within the company.

Question 1 was the same as the executive and mid management questionnaires. Question 1 was included within this questionnaire to understand the field BIM practitioner’s perception of the advantages of BIM. It was expected that there would be a difference in opinions throughout the whole organization but that each group might identify similar advantages.

Question 2 was included to capitalize on the interaction of the field BIM practitioners with BIM and determine if there were any disadvantages associated with BIM integration.

Questions 3-9 were included because generation of the model is a key component of BIM and understanding who is generating the models, the quality of the models received and to which LOD, is an important part of determining the best practices.

Questions 10 - 12 allowed for the respondents to answer specific questions relating to their company and how they collaborate with trade contractors and use BIM together during construction. Each question was designed to allow for comparisons to be derived and for best practices to be obtained. The final question allowed the respondents to express additional comments or ideas that they felt would add to the research, and to help understand the best practices within their company as well as within the industry.

3.3 Selection of Contractors

To understand which practices within the industry were the best practices, it was important to select the correct contractors to interview. In order to achieve the overall objective, a list of the top 40 general contractors was derived from the BD+C Giants 300 BIM contractors list, as discussed previously and found in Appendix C. The contractors in the original Giants 300 list were listed in reported descending revenue from BIM and not categorized by different sectors. The top 40 contractors that were selected followed the format of descending BIM revenue. These contractors were not randomly selected, since the research objective required the leading contractors in BIM adoption to be surveyed.

The list of selected contractors was reviewed by the thesis committee to ensure that suitable companies were being interviewed. This list of contractors included individuals and companies who had recently written and produced articles and research on the use of BIM. The top 10 contractors were then chosen to be targeted in the research and out of the remaining 30 contractors, 10 additional contractors were selected at random. Once the research pool of contractors had been finalized, contact details for their BIM departments were obtained and each company was asked to participate in the survey. Upon their agreement, arrangements were made to undertake the questionnaire.

3.4 Trial Run

To test the functionality of the survey and ensure that the questions were understandable and would provide the necessary data for analysis, the questionnaire was first sent to several industry representatives as a trial run. Since the questionnaire was required to be completed by 60 different individuals, it was imperative that the data collected would indeed provide further insight into the best practices of BIM. By creating a trial run, the answers could be reviewed and feedback acknowledged, ensuring that there were no misleading or vague questions being asked.

The trial questionnaire was first sent to a leading BIM professional for comments. This professional was selected because he is a current leader in BIM adoption, and has the current role as a BIM manager for a general contractor. He represented the mid-management level being sought, but provided feedback on all three surveys. The process was then repeated with an employee level and then again with an executive level manager. The final version of the questionnaire was updated and issued to the selected contractors based on the comments received during the trial run.

3.5 Analysis of Data

The data was collated and patterns, common responses and outliers were recorded. Any extreme outliers were reviewed and either ignored if felt irrelevant or commented on if the information was regarded as important. Trends were identified and comments that suggested best practices were also recorded. These were later reviewed to determine if the practice was considered as best.

Qualitative data was compared by reviewing the responses and looking for patterns or common thoughts or ideas. Quantitative data was collated and organized into graphs, charts or tables to allow for patterns to be observed or comparisons to be made.

4 ANALYSIS OF RESULTS

This chapter includes a summary of the BIM uses identified during the preliminary research, the results of the questionnaires, and the analysis of the results describing the trends and discussing outliers as appropriate. A table providing the preliminary findings is found in Appendix D.

4.1 Commercial Contractors Uses of BIM

To determine how each of the 78 contractors listed in the Giants 300 list are using BIM, a search of their websites was undertaken manually searching for the phrases BIM, building information modeling, and virtual design and construction (VDC). The latter phrase is currently being used interchangeably (Weitz, 2012; Lamb, reed and Khanzode, 2009) with BIM. One contractor's website stated that they do not believe in BIM as a stand-alone method, but that BIM is incorporated in VDC (Swinterton, 2012). Appendix D, shows the uses of BIM by the contractors found in the Giants 300 list. It is listed in the same order as found on the original list. The 26 uses of BIM in commercial construction listed in Appendix D are the uses of BIM identified from their websites. This list is thorough but may not be all-inclusive.

If a company stated that they were using a specific application of BIM, it was identified as such in the table. Additional information was recorded such as comments, facts, or figures that provided further insight, including information on number of projects, return on investments, or additional training being offered to employees. These results will be further discussed later in this chapter. Several contractors did not provide any information on their websites and these were recorded in the table as not having any information available. Appendix D shows a summary count of the contractors' website information of how they were commonly using BIM.

It was surprising to discover that some of these leading BIM contractors did not even include anything about their use of BIM on their websites. As stated earlier, BIM is currently a hot topic in the construction industry, and therefore it was suspected that information would be more easily accessible on their websites. The lack of advertising in their BIM use was not investigated any further. However, it should be noted that 37 of the 78 leading contractors researched did not state what they were doing with BIM. This is 47% of the top contractors in BIM not providing readily accessible information on their BIM usage and project types. This lack of information may simply be due to the websites being designated as a general corporate website, and deliberately not providing specific details of their actual construction services. Another reason could include the time and cost associated with regularly updating the website as additional BIM projects are completed.

4.1.1 What Contractors Are Doing

Based on the information obtained from the leading BIM contractor's websites, the four most common uses of BIM are 3D modeling, scheduling (4D), cost estimating (5D), and clash detection. This was not necessarily surprising, as these are arguably the most basic functions of BIM and the ones that obviously save time and cost. Modeling structures in three dimensions has evolved with the CAD industry and has been around for several years. Computer aided scheduling and cost estimating are also other tasks that have been utilized by the construction industry for many years. The ease of clash detection, on the other hand, is an application that is unique to BIM. However, this is regarded as a LOD 300 practice. This could imply that it is simply one of the easier functions to perform. This process has been claimed to be "yesterday's news" (ConstructionTech, 2011) since it is not utilizing the full power of the model and its information. Appendix D lists the 26 different uses of BIM that contractors are collectively claiming to use. These 26 uses were incorporated into the research questionnaire. A follow up question at the end of the questionnaire allowed for any additional uses to be identified by the contractors. The more common uses of BIM were explained previously as part of the literature review. An explanation of each of the more innovative uses of BIM is included within this section, since these uses required further analysis through non-published sources.

4.1.2 Constructability

At the creative thinking stage of a project many ideas and proposal are suggested, but not all suggestions are possible. By using BIM, suggestions can be simulated to simply determine if they are feasible or affordable. If any problems arise, solutions can found and adopted. Various possibilities can be shown to enable the client to choose the best option (Mortenson, 2012). This allows for ideas to be tested and fail on a computer rather than failing onsite during construction, which is more expensive.

4.1.3 Design Change Implications

BIM is a digital prototype that can be updated or altered to show the different design proposals and how different changes impact the rest of the project before it is constructed (JE Dunn, 2012). BIM can also be used to help generate the cost of each design proposal to show the client (Krygiel, 2008) the impact of the cost. The model also demonstrates impact on schedules and aesthetics of the structure and aids the client in decision making (Mortenson, 2012). As BIM is dynamic, the changes are reflected throughout the rest of the model, and the estimates, schedules and other documents can be easily updated from changes occurring in BIM. As the model is updated, analysis can be performed to show clashes and provides additional information on constructability issues that perhaps where not considered at the design conception stage.

4.1.4 Digital Plans Workstations

Digital plans workstations can be used at various stages of the project, either on or off site. Early in the design process a workstation can be created. This workstation consists of a computer with the up-to-date model. It is usually in an office space where employees can review the current model in one specific location. This enables the users whose hardware does not allow for the software to be installed to also view the model and access the data as required. This is also commonly used in design meetings if the model is to be reviewed or clashes are to be reviewed. It was observed that for several projects the whole design team, including members from different companies, was dedicated to a specific project. They were permanently in a common office building, known as co-location (Lamb, Reed and Khanzode, 2009) and used the station as a common work share point. When the workstation is located onsite, the model can be shared by all the site workers, including subcontractors. The model in the workstation contains all the current drawings, specifications and plans. Workers can review and query the model. Often there are numerous locations within a site that host a workstation for the workmen to utilize the technology.

4.1.5 As Built Drawings

The digital model can be updated throughout the construction period to represent the completed structure. The model is updated to reconcile the design drawings to form a model that represents the actual building as completed (JE Dunn, 2012). From this, the model can be used as either an as-built model to display the structure or be reviewed for future projects such as remodeling. As the model represents the actual structure, future works can be based from the model without the need to remodel the structure. An additional advantage to having the completed model stored digitally is the reduction in stored paper copies of the structure, although any desired drawings can still be easily printed.

4.1.6 Work Plan Drawings

Work plan drawings, also known as lift drawings, are drawings that contain only the detailed information required for a specific task (McCarthy, 2012). These drawings enable workers to utilize only the information specific to their task and not be required to sort through the entire project documents to find all the information they need. For example, the concrete workers would have information about the concrete slab on a single sheet including quantities, material properties, and dimensional information. The idea behind the work plan drawings is to reduce confusion by having information scattered throughout a large set of documents. The work plan concept has been utilized before BIM was introduced, but an advantage of BIM is that these drawings are automatically updated if changes are made elsewhere in the model. In conventional 2D CAD drawings, these changes would have to be completed manually.

4.1.7 Laser Scanning

Laser scanning is the process of gathering 3-dimensional information about an existing structure with the use of a laser scanner. A laser scanner is placed in a room or area that is to be measured and the scanner then emits beams in all directions. When the laser comes in contact with a surface, the distance from the scanner to the point is recorded. Whenever the laser comes in contact with a surface, this is called a point. When all the points in the room are collated, it is called a point cloud, which can then be uploaded into the BIM model. This spatial data (McCarthy, 2012) represents the exact layout of the room. It is the number of points (typically in the thousands) that improve the measurements (Skanska, 2011). Traditionally only a few points would have been collected and entered into the model. This can then be compared to the plans to determine if columns, beams and walls are in the same location as shown in the drawings. This technology can be applied to new building projects to produce as built drawings as well as for renovation projects where existing structures are required to be scanned before work can progress.

4.1.8 Operations and Manuals (OM)

Digital models are data rich and incorporate all the required information regarding equipment contained within the model, when created at an appropriate LOD. This can range from complex HVAC systems to fire protection systems, or to the hand dryers located in restrooms. Information about any electrical or mechanical equipment can be entered into the model. This allows all OM to be stored in one location, digitally. As the model is a direct representation of what is in place, the user can click on the equipment and the corresponding documents are loaded. This reduces the need to search for the correct manuals.

4.1.9 Team Collaboration

It has been stated several times that BIM improves the collaboration throughout the design team (Naumovich, 2001), a critical requirement and necessity to the design and construction process (Lamb, reed and Khanzode, 2009). As the model is shared by the design team, everyone can have the same information. A coordination meeting allows for issues to be resolved, thus improving collaboration. The model itself improves interoperability, as the design team is required to ensure it is accurate and up-to-date. This provides the most current information about the project to the entire project team.

4.1.10 Tracking Materials

Materials can be tracked offsite once they have been ordered. This ensures that any delays are spotted early in the project and allows for contingency plans. Materials can also be tracked using Radar Frequency Identification (RFID) (Levy, 2012; Skanska, 2011). RFID is a chip that emits a unique code at a specific frequency. These chips can be used to track where materials are en route to the site, where they are on the site, or where they are within the structure. QR code or barcode scanners are another similar option to track materials.

4.1.11 Tracking Time

The BIM model can be used to track the time spent by each employee on a project, the lead times for materials, or the time being spent on a specific task or phase. This information can then be added to the schedule to ensure that it is current and accurate.

4.1.12 Site Safety

The BIM model is an increasingly important asset in ensuring that the site safety is improved. The model can be used to ensure collisions with cranes or other large equipment are avoided, equipment is stored in safe places, and that the building structure itself is safe during construction by mitigating hazards that may be avoided by using a different method, sequence or location. For example, if the site contains several work areas, work teams can be positioned in specific areas to avoid hazardous undertakings in another area. There are many other solutions that increase safety and by using the model effectively they can be identified and resolved. As with all technology, it cannot guarantee a safe site, but the model is used as a tool to help improve safety.

4.1.13 Prefabrication

Prefabrication is when components are built offsite, transported to site and then added to the structure. There are many different opportunities for prefabrication within a building. They may be as simple as timber trusses being built and brought to site or as detailed as whole room pods being built, painted, finished, wired and plumbed, and then transported to site. Once on site, the prefabrication component is placed in the correct position and connected to the rest of the building. Prefabrication has been around since the 1950's and is therefore not conceptually new. However, as the structure is modeled prior to construction, there is an increased opportunity for prefabrication to occur. This can ultimately reduce costs, errors and time.

4.1.14 Waste Reduction

The construction industry is renowned for the level of waste it produces. By using BIM models a more accurate measurement can be taken to ensure that the right quantities of materials are ordered. An example of waste reduction would be moving a standard sized sheet of drywall an inch to save on purchasing an extra sheet and wasting the remainder of the board. A complete tub of paint has to still be purchased even if it is not all required, so the areas to be painted can be calculated and adjusted to encompass ordering strategies. If a mistake is made when cutting timber, the whole piece of timber is often scrapped and not reused elsewhere. These are examples of quantities that can be adjusted within the model to reduce waste of materials.

4.1.15 Walkthroughs

The BIM model is a valuable visual tool. Not only can the building be seen in 3D, but there is also the opportunity for virtual walkthroughs. This feature is almost like a video representation of what the structure would look like, both internally and externally and improves the visualization for the team and the client (Jones Lang LaSalle, 2011).

This feature can also be incorporated with virtual reality. The client and design team member can virtually walk through the building before it is completed. It can be used to ensure that there is sufficient space within rooms, codes are met, and the client is happy with the design.

4.1.16 Sustainability

Sustainability is an increasingly important achievement for buildings. Generally LEED is used to represent how small the carbon footprint (also known as green) a building is (Greenbiz, 2010). This helps the client to analyze the building's impact on the environment as well as its energy performance. Design proposals are analyzed and adjusted as required so that the finished structure can obtain the desired level of LEED certification. There are various software packages available that can be used to analyze the sustainability of the structure. By analyzing the site prior to construction, the client can determine the level of performance for the project. This analysis includes rainwater harvesting, solar studies, and energy analysis models that can be used to determine the effects of the building orientation and weather conditions for the project. A daylighting model can be used to determine natural lighting in the building and the natural resources being utilized as appropriate (Krygiel, 2008).

4.1.17 Building Life Cycles

BIM can be used to demonstrate and calculate the building life cycle, which may include performance data, repairs, maintenance, rehabilitation works, restoration, and demolishing of the structure (Greenbiz, 2010). This is similar to the facilities management aspect of BIM, but without using the model after completion of the building. It merely forecasts what the usage and time duration should be.

4.1.18 X-ray

X-ray is used on existing structures, such as those constructed with reinforced concrete, to determine where specific unknown components such as rebar are located. It can also be used to locate hidden pipes or items that are redundant and not shown on drawings. The images are then put into the model and the results and locations can be added to the model to show current in situ conditions.

4.1.19 Sonar

Sonar is similar to X-ray, except that sonar equipment is used instead to detect where underground components are located. The sonar images can be directly linked into the digital model.

4.1.20 Geographic Information Systems (GIS)

GIS can be incorporated at several stages of the model. GIS is, in very basic terms, an interactive map that can be manipulated by the user to display different data. A good example is Google maps, as it can be used to display locations of supermarkets or live traffic conditions. Within the BIM context, GIS can be used to display site plans or surrounding areas. The model can be added to the project to display traffic patterns or traffic congestion. The site can be mapped using Light Detection and Ranging (LIDAR) which can also be uploaded in the digital model (Mortenson, 2012). This data can then be downloaded directly into equipment to assist site coordination (Messer, 2012). GIS can also be used in facilities management to record locations of machinery, fire extinguishers or escape routes within the structure. Users can manipulate the model to appear as a map and these options can be recorded. This is particularly useful in large buildings or on campuses. A common concern is ensuring that BIM and GIS can work together and how this use should be adopted within the industry.

4.1.21 Onsite Technology

Construction sites are becoming more technically advanced and as such there has been an increase in the use of iPads, iPhones, workstations, tablets and apps that enable technology to be used onsite. Models can be reviewed in location, rather than the employee returning to the site office to look at the drawings to understand what is going on (McCarthy, 2012). Technology can be used to share models, track materials, determine if workers are onsite, access emails and minutes of meetings, and access important documents such as change orders. This list does not provide an extensive use of onsite technology, but this is the definition that will be used. It does not include GPS, RFID or other similar technologies, as each has already been described elsewhere in this thesis. It is merely the technology that utilizes BIM and other software.

4.2 Why They Are Using BIM and Its Benefits

Several contractors stated on their websites why they are using BIM. Skanska stated that they use BIM because it is " a way to work smarter and not harder…" (Becker, 2010). They feel that it is now a necessity to use BIM due to the benefits gained. Hunt construction state on their webpage that they are

> *"proud to be at the forefront of major game changing technology. Never before have [they] seen such a positive technical shift in the industry that is a win for both the owner and CM alike. In the years ahead, Hunt will only see these new techniques advance, and the savings both in construction time and financially, will create an entirely new and exciting construction industry." (Hunt, 2012)*

Hunt also states that they encourage every subcontractor they work with to receive training on BIM.

Of all 78 companies that were listed on Giants 300 list, only two companies actually stated how many projects they had used BIM on. The leading BIM contractor in revenue, Turner Construction, had used BIM on 147 different projects. Swinterton Construction had used BIM on 167 projects. With all of this experience in the industry, it is fair to say that BIM is being well used and not just as something that will pass (AECbytes, 2012).

Hunt construction further described their experiences with BIM on their website. They stated that on a recent job they had detected 1,200 clashes during the design phase. By correcting them before the building was being constructed, they saved time and money. Weitz construction stated on their website that they have had zero Requests for Information (RFI's) on various aspects of a project. Usually within a large project a couple of hundred could be expected. They also stated that they had zero change orders for the same project. This is also a significant decrease in the number of change orders for traditional construction practice without the use of BIM.

Various contractors stated that by using BIM they have saved a specified amount of time, money and Return On Investment (ROI). Since the contractors stated ROI often, it was apparent that the return was important to owners and investors. They wanted to ensure that any money that was put towards BIM in their projects was beneficial to them.

This included money, time and scheduling benefits. It is assumed that if there was not a significant ROI, the investment would not be made. Others stated that although it is difficult to specify the exact amounts of savings because of BIM use, the general consensus is that they saved time, money, and returned savings to the owner. Holder Construction claimed that they received a (ROI) of 3 to 5 times their initial cash investment (Holder construction, 2012). On the other side, one owner stated that ROI was not important to them, since contractors should be performing to the best. If BIM is the best method then it should be always used (Weitz, 20102).

The biggest uncertainty found in analyzing the contractor websites was the lack of continuity. With each company defining BIM their own way, recording finances in the way that best suits the company, and reporting all the possibilities of BIM, it was difficult to determine where the industry currently was with regards to current best practices. It was equally important to ignore the sales factor of the contractors' websites to determine what was actually being adopted.

By analyzing the leading BIM contractor's websites, it was discovered that there is a wide range of potential application of building information modeling. However, identifying to which extent the various applications were being used and the practicalities of such was not readily available. Therefore, the remainder of this research aimed to better understand the current industry practices and which applications were being effectively used, by contacting industry BIM leaders and asking them about their experiences with BIM.

4.3 Completion of Surveys

When the interviews were scheduled via telephone or email, a copy of the survey was emailed to each participant to allow for each participant to be prepared to discuss the questions. Each interview was conducted through the audio component of WebEx, which allowed for the discussion to be recorded. This made it possible to pay more attention to administering the interviews and capture their exact responses.

During each survey, individuals received the same opportunity to express their ideas and comments. As the survey was being conducted, each participant received the same questions in the same order and wording. When required, participants were asked to elaborate or reword their answers to be more in accordance with the question. For example a participant may have responded with a number rather than a percentage. In cases such as this, they were asked to state the percentage if possible.

Once the interviews were completed, the interviews were transcribed to allow for further analysis. The transcriptions were checked by multiple individuals to ensure accuracy and corrections were made as warranted. It should be recognized that there were a few technical difficulties that occurred during the recording process, such as the interview only being partly recorded or the recording itself being somewhat inaudible due to bad connections. In these circumstances, copies of the written notes that were scribed during the interviews were utilized.

4.3.1 Participant of the Survey

The top 20 contractors from the Giants 300 list were invited to participate in this research, as stated in Chapter 3. Several companies refused to take part due to various reasons such as company policy to not participate in research, or not having sufficient time to organize schedules to be available to participate. Others felt they were not in a position to assist the research and there were numerous non-replies. This resulted in additional companies being contacted to obtain a sufficient sample group. These additional companies were included based on recommendations and referrals from those who participated. The number of survey participants included 12 executives, 13 mid-management level and 12 field users, and represent participation on some level from the following 18 companies:

- Balfour Beatty US
- Barton Malow
- Bernards
- C W Driver
- DPR Construction
- Gilbane Building
- Hensel Phelps Construction
- Holder Construction
- Hunt Construction
- JE Dunn Construction
- Layton Construction
- McCarthy Construction
- Robins and Morton
- Rogers Obrien
- Skanska USA
- Suffolk Construction

- Swinerton Builders
- Whiting Turner

Eight of these companies were interviewed through all three levels, which enabled comparisons to be made within individual companies, and to gain an understanding of the processes involved. The additional participants provided further information, each through their respective survey level, as well as answering the final question of "any other comments." The collective results helped produce insights into the use of BIM within companies, management practices associated with utilizing BIM, and the general direction of BIM within the construction industry.

In order to ensure that a sufficient amount of companies were contacted, thus ensuring that comparisons could be made, suggestions from participants and others within the commercial field were accepted. Each company that participated utilized BIM regularly as part of their company practices.

4.3.2 Survey Questions

The survey remained unchanged during the interview process, with the exception of a final question (any other comments) added to the mid management and field BIM practitioner levels, by allowing the participants to express any additional comments or insights that could further the research. This question proved valuable as most participants felt they could share additional information. During the actual interview process, questions were clarified for the respondents as needed to ensure the survey results were comparable.

4.4 Executive Level Results

Twelve executives from different contracting firms completed this survey. There were not any changes made to the format or layout of the questionnaire during the interview process. In general there were not any difficulties with participants understanding the questions.

4.4.1 Question 1- What Are the Top Three Ways BIM is Used in Your Company?

Figure 4-1 shows that the most common response was clash detection and collaboration, which were both stated by 42% of the survey participants. Marketing, at 33%, closely followed this.

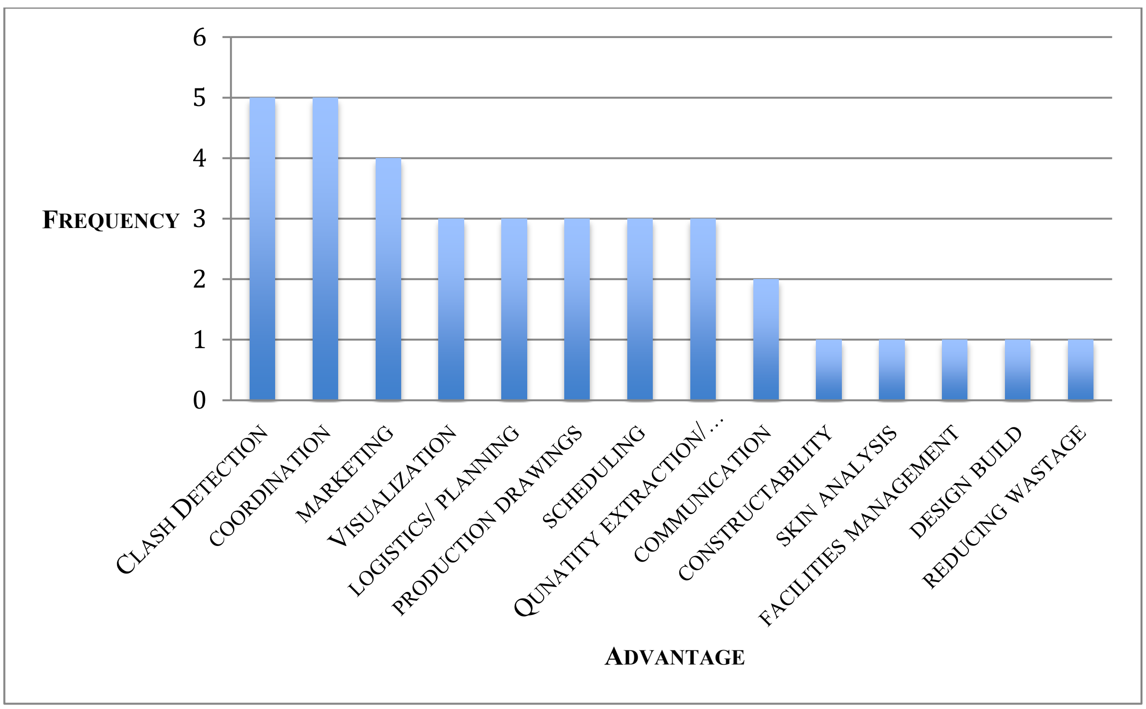


Figure 4-1 Executive Top Three Advantages

4.4.2 Question 2 – How Has Each of the Above Affected Your Company?

The common themes from the responses to this question were the benefits that were brought to their company. From the responses, BIM helps the companies become more efficient, produce tighter schedules and bring construction costs down due to reduced man hours, less rework and an increase in prefabrication. It was reported that clients were more satisfied as constraints, such as noise levels and site access, were being made through the use of BIM, which had allowed for less disturbances. The other main comment made was the impact that BIM was having on winning projects and being more competitive. Having the clients see how they were able to perform work through virtual walk through, scheduling and other BIM uses, clients were aware that the companies were competent and capable in the industry. This was reported as allowing for more work to be won in a tough economy.

4.4.3 Question 3 – What Percentage of Your Company's Projects Incorporate BIM Services?

The results of this question are found in Figure 4-2. There were three companies using BIM on all projects and three who were using it on 90% of projects. The lowest two used it on only 50% of their projects but stated that they were planning on increasing their usage of BIM. Only one individual was unaware of how many projects wee utilizing BIM. Most individuals during their conversations expressed the desire to increase BIM on projects. One participant elaborated that although BIM was on 90-95% of projects, the LOD on the projects were lower. They were using LOD 400 on 70% and LOD 500 on 10-15% of projects. Even though BIM was being used on most projects, the services that could be applied varied due to the LOD, and this should be considered for the percentages stated in Figure 4.2. Some may have only been using a 3D BIM model that was used for visualization or clash detection and others used BIM for estimating, scheduling, site layouts, cloud technology and field uses. Both were very different from each other, but would both fit the criteria of projects using BIM.

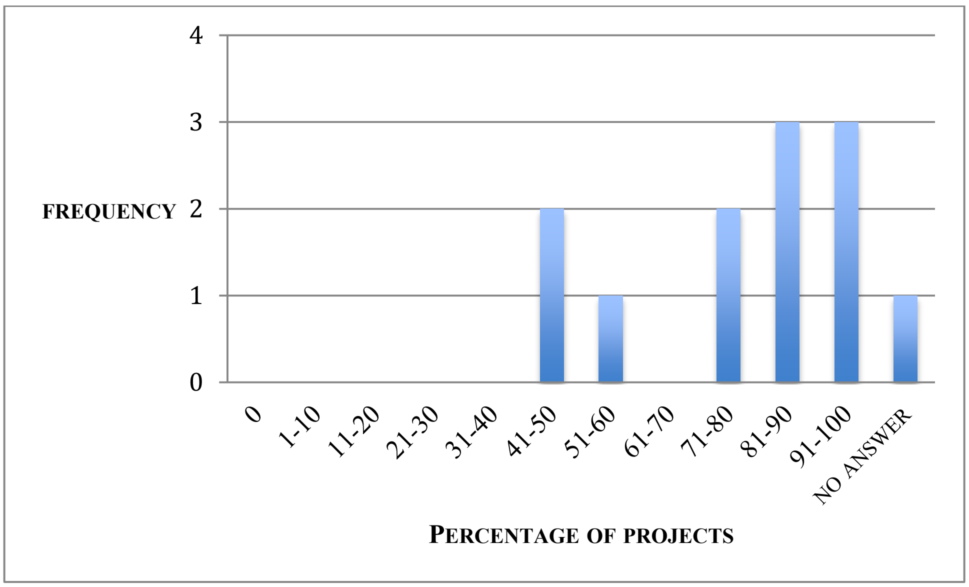


Figure 4-2 Percentage of Projects Using BIM

4.4.4 Question 4 –How Do You Decide on Which Projects to Use BIM?

There were four main reasons identified that influenced when BIM was used on projects. The first reason was the value of the project. Two participants stated that all projects over $10 Million used BIM. They also included the second reason, which was complexity, as part of their decision-making. If the project was considered to be complex, or high risk, most used BIM to assist with the projects. The third common reason identified was the return on investment (ROI); the cost of using BIM has to be viable to ensure the client's money is being wisely invested into the technology. The final common response did not have to do with which projects to use BIM on, but rather which projects should BIM not be used on. The mentality was that BIM is the way forward and should be used on all projects unless there was a specific reason not to use BIM on the project, thus excluding its use.

One respondent provided some insight and some warning that BIM should only be used if the design team was capable of using it. They warned that if there was a lack of expertise, then there was also the potential for problems arising with the use of BIM. Others stated that if they had sufficient resources, then BIM would be used on all projects. However, they were further aware of the limited resources available and the finances involved investing in BIM.

4.4.5 Question 5 – Do You Require Your Subcontractors to Use BIM?

Most contractors agreed that subcontractors were required to use BIM on a BIM project. However, not all of their projects require BIM. As a result, not all subcontractors were required to use BIM, which can be seen in Figure 4-3. Others elaborated and stated that it is impractical for some trades to use BIM, such as painters, and this was also considered.

4.4.6 Question 6 –How Has BIM Affected Profitability?

The common concern from the participants was the inability to provide an exact figure or range for how BIM has affected their profitability. Most commented on the fact that they knew it had improved profitability, however not always in a monetary sense. Depending on the contract that the company was working with, any money saved was returned to the client, thus not adding directly to their profits. Although, they were able to work on larger projects due to using BIM, they could also work a larger volume of projects as BIM shortened construction time and had more satisfied clients who then provided more projects. In this way they were able to report increased profitability. Efficiency was also a common response with regards to time, resources, materials and reduced construction costs. One respondent stated that their company used to try to track cost and money saved. The difficulty with this method was unless they built the project twice; there were no guarantees that the savings were accurate. They went on to defend their methods by stating that this is the same with any cost estimate produced and that the industry works by estimates. However, because they knew that it was saving money they stopped tracking it several years ago. Overall, the respondents had a general consensus that there was an increase in profitability, but for a variety of reasons and not purely a monetary fact. As stated by one contractor, "it isn't about the money."

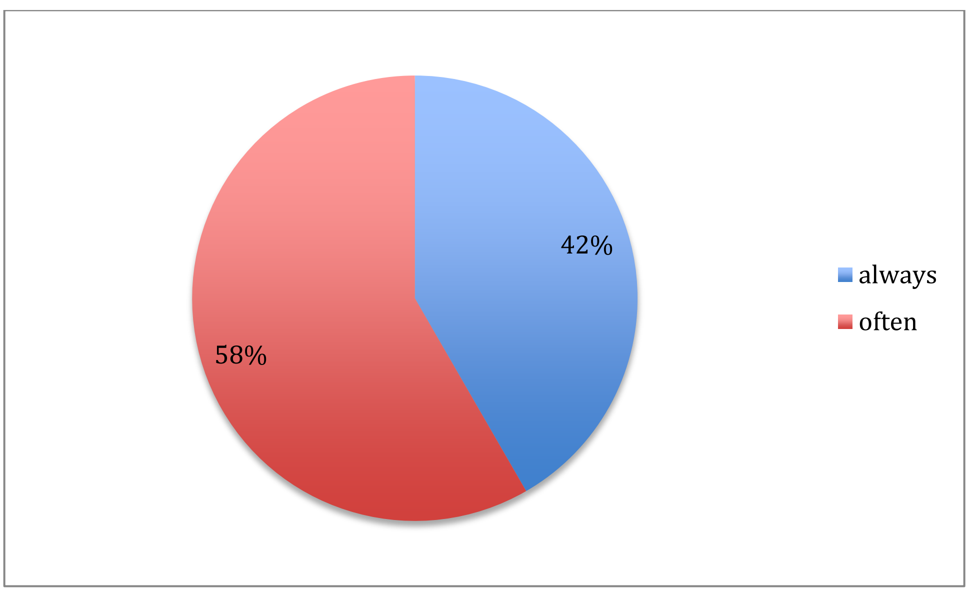


Figure 4-3 Are Subcontractors Required to Use BIM

4.4.7 Question 7 – How Has BIM Affected Construction Time?

The participants had an easier time answering this question than the previous question, because they were able to provide details of projects that had several months of scheduling or were working through difficult schedules. One of the biggest reasons for the decrease in construction time has been the increase in prefabrication. This had allowed for schedules to be shortened as well as allowing for improved safety. The other viewpoint expressed by some individuals on this question was that BIM doesn't add any time and it also allowed them to achieve schedules, not necessarily reduce schedules. The achievement of these schedules was attributed to the reduction in rework.

4.4.8 Question 8- How Has BIM Affected Change Orders and Litigation?

Most companies did not have any litigation on BIM projects and were therefore unable to state how BIM has affected litigation. However, one contractor did state that they had applied BIM to a job that had not been using the software and it cost the company a six-figure sum to implement BIM on the project. These costs were never recuperated or charged to the client. At the end of the project it was observed that by adopting BIM a problem was found and corrected, and a litigation that would have been in the seven figures was avoided. In this example, BIM had prevented litigation.

Generally most companies reported a decrease in change orders as producing models resolved the lack of information that created change orders and the models were easier to follow than more traditional methods. There were reports of very large projects producing zero change orders, which is an important step in the construction project. All projects typically aim to have zero change orders due to incorrect data. However, there was one individual who observed that any change orders that were currently being received was different from the change orders that used to be received prior to BIM. Previously, large items were included in change orders and subcontractors resolved smaller items themselves. The individual further stated that they had actually seen an increase in these smaller items coming through as change orders as subcontractors felt the model should have been correct and they were therefore not required to change it. It was not the purpose of this thesis to discuss whether the subcontractors were correct or not. However, it is important to note that there has been a change in direction from subcontractors and that this may also be seen elsewhere. Further research could determine if this is a common change throughout the industry.

4.4.9 Question 9 – Why Does Your Company Value BIM?

A variety of reasons were given in response to this question, each being a valid reason for using BIM. There was not a single common reason for using and valuing BIM. The reasons stated included efficiency, client demands, embracing the future, allowing the company to achieve its goals and enabling the company to stay relevant and innovative. They also acknowledged that there were negatives to using BIM, such as the learning curve, but felt that the industry was going this way and BIM was becoming a standard tool.

4.4.10 Question 10 – Is There Anything Else You Would Like to Add About BIM That Will Benefit Our Research Into Best Practices?

This question provided various suggestions for further research. Most comments followed the lines of individuals needing to become more educated as to what BIM actually is. One person stated that BIM is sometimes over sold as being a solution to everything. Another individual said that people don't fully understand what it is, and therefore are not using it correctly. One individual stated, "BIM will become like Microsoft Office - just everyday use." This was significant since companies are accepting BIM as an everyday tool and it should be fully adopted. There were not any individuals who participated who felt that BIM could be ignored or not worth investing in.

4.5 Mid Management Level Results

Thirteen different individuals from the mid management level of commercial contracting completed this level of the questionnaire. The only changes made to this survey was the additional question included at the end to allow for any further comments, and the specific software element of part 1 being removed.

4.5.1 Part 1 – Frequency of Uses

Each individual who participated in the mid management level was invited to complete part 1. The thirteen participants returned the completed table and their answers were analyzed to determine the frequency of each BIM use. Out of the responses received, three participants had an omission for walkthrough and this is shown in the no comment column. There was no apparent reason why all three contractors failed to complete that row in the table. These results are shown in Table 4-1. The results were weighted to allow for a ranking order to be created and the uses listed in descending order. The table has been color scaled to highlight the common responses. A darker color shows a higher frequency response. There were more than 26 uses stated, as the survey participants were able to add additional uses of BIM. In total there were 29 uses of BIM found in table. The bottom three uses were not included in the general rankings as these were the additional rankings, and not every contractor had the opportunity to select it.

Table 4-1 Claimed Frequency of BIM Uses

	Percentage used on total projects						
Tasks/uses	**91-100**	**76-90**	**51-75**	**26-50**	**1-25**	**0**	**No Comment**
Clash detection	8	3	2				
3D Modeling	8	2	3				
Team collaboration	6	4	2	1			
Constructability issues of designs	6	3	4				
Sales	5	4	2	1		1	
Site co-ordination with equipment and trades	4	4		4	1		
As built drawings	5	3	1	1	2	1	
Prefabrication	3	4	1	3	2		
Field BIM - iPads, tablets etc.	1	4	4	3	1		
Sequencing	1	3	4	5			
Digital plans workstation off-site	2	4	1	4	1	1	
Design change implications	1	3	4	2	3		
Virtual reality mock ups	2	2	4	3	1	1	
Digital plans workstation on-site	1	3	3	4	1	1	
Cloud technology	4	2	1		2	4	
Scheduling		1	3	6	3		
Cost exercises / Estimating		1	4	3	5		
Quantity takeoffs		2	2	4	5		
Walkthroughs	1	2	2	3	2		3
LEED/Green buildings	1	2	1	4	4	1	
Site safety		1	2	6	3	1	
Waste reduction	1	1	4	1	3	3	
Facilities management, EOM			5	1	6	1	
Laser scanning		1	2	6	2	2	
Lift drawings		1	4	4	1	3	
Tracking materials off and on site		2		3	4	4	
X-Ray scanning	1	1	1	1	4	5	
Global position software (GPS)		2	2		4	5	
Building life cycle				4	5	4	
Sonar scanning		1	2	1	3	6	
Tracking time spent / punch cards	2			2	2	7	
Geographic Information System (GIS)			1	2	4	6	
Model based sketching/ working drawings		1					
Quality assurance/control		1					
Surveying and layout			1				

The top five uses of BIM on most projects were clash detection, 3D modeling, team collaboration, constructability issues of designs and sales. This followed the pattern that was created when participants stated their top 3 advantages.

Waste reduction was an example of a use that could be utilized on all projects by at least one company, but was then spread fairly evenly across all brackets including never being used by at least one other company. This was surprising since BIM provides an opportunity to save materials and reduce costs. It was evident that contractors were using it, but not extensively throughout the industry. Another example of a use of BIM that had outliers was using BIM to track time spent. Seven respondents stated they have never used BIM to track time, yet two participants of the survey stated that it was used on 91-100% of their projects. It was apparent that there were advantages to using BIM for this purpose. Otherwise these companies would not be using it so frequently on their projects. Further research could determine the methods used to successfully implement tracking time through all projects.

4.5.2 Question 1 – What Are the Top Three Advantages of BIM?

The results of the advantages of using BIM, as identified by the mid managers are found in Figure 4-4. The most frequently stated advantage was coordination, stated 6 times and representing 46% of participants stating it as one of their top 3 advantages. Communication, scheduling, information in the model, and visualization were all stated by at least 25% of those surveyed.

This question provided a variety of answers, which included items that were not just physical uses of BIM. One respondent stated that an advantage was the clients' satisfaction. The individual felt this was important, because if the client was happier with the project there was a better chance of that client returning in the future.

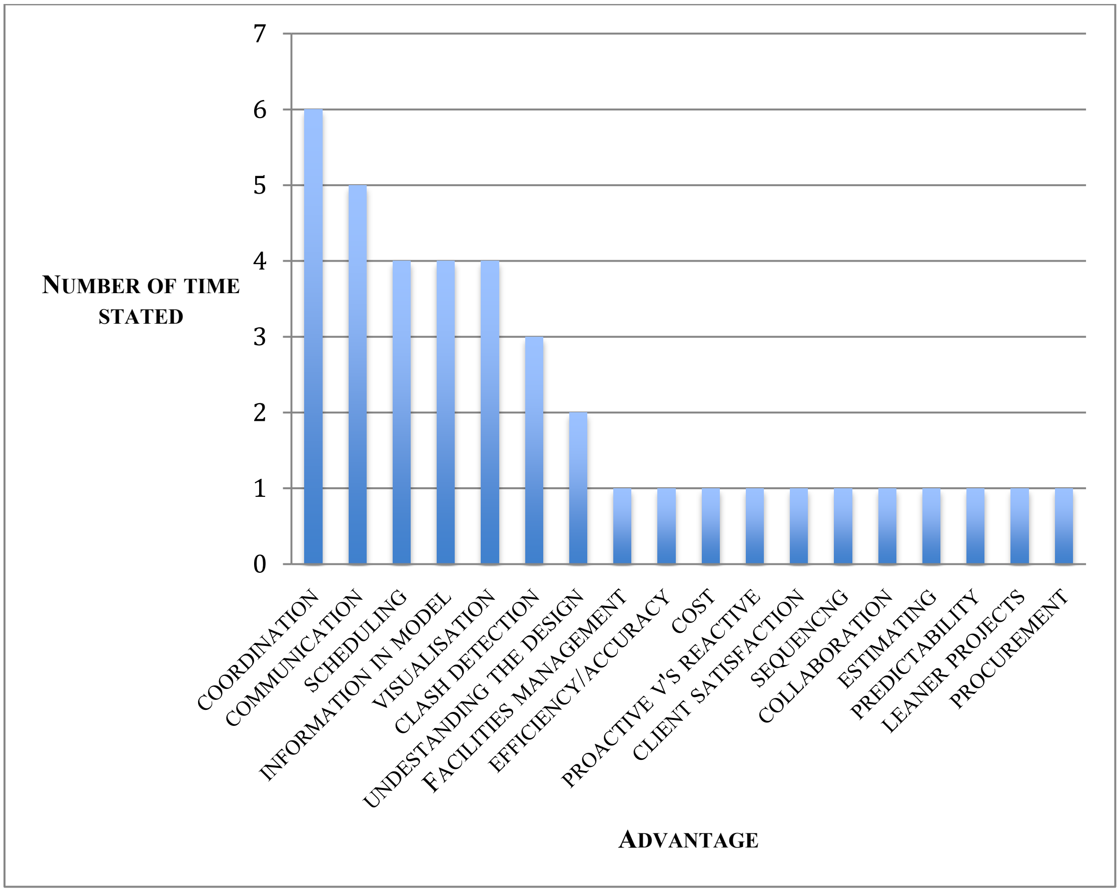


Figure 4-4 Mid-Managers Top 3 Advantages

4.5.3 Question 2 – How Do You Involve Trade Contractors in Your Clash Detection Meetings?

There was a common theme established by the survey participants with regards to trade contractors. Generally, they were under contract to attend all trade and clash detection meetings. These typically occurred early in the design process to ensure that they were fully engaged in the process. However, two respondents stated that subcontractors were required to run clash detections themselves and only bring the larger problems that require the design teams input to the clash meetings. This prevented the team from having to work on small clashes that did not require their input, and therefore utilized their time more effectively.

Another recurring observation that was mentioned by nine individuals was the significance of who runs the coordination efforts. Since not everyone offered this response and it was not directly asked, it was unclear how the other survey participants were using it. Most of the nine individuals who commented on who takes charge of the coordination efforts directly stated that the general contractor runs the meetings. One stated that the reason was to ensure that quality was being delivered to the client. Twice, different contractors referred to this point. Another stated speed as the reason and yet another stated that there was more to be learned from the process than just about clashes. This included knowing the structure intimately and addressing any additional complications not directly affecting the main subcontractor. By taking control of the meetings, the additional items could be learned without the sub contractors' agenda being the driver of the meetings.

4.5.4 Question 3 – Do You Use It As a Marketing Tool and If So, How?

Every contractor stated that they are using BIM as a marketing tool, as shown in Figure 4-5. The common reason for using BIM as a marketing tool was to demonstrate to clients, and potential clients, the capabilities of the contractors, in order to win bids. Generally it was utilized as a visualization tool for clients. However, it was also being utilized in some cases on websites and in the company literature to allow viewers to understand the company's potential. One respondent stated that they also used BIM when visiting schools in an effort to market the company to students. They felt that the technical ability sells the company and attracts the best students.

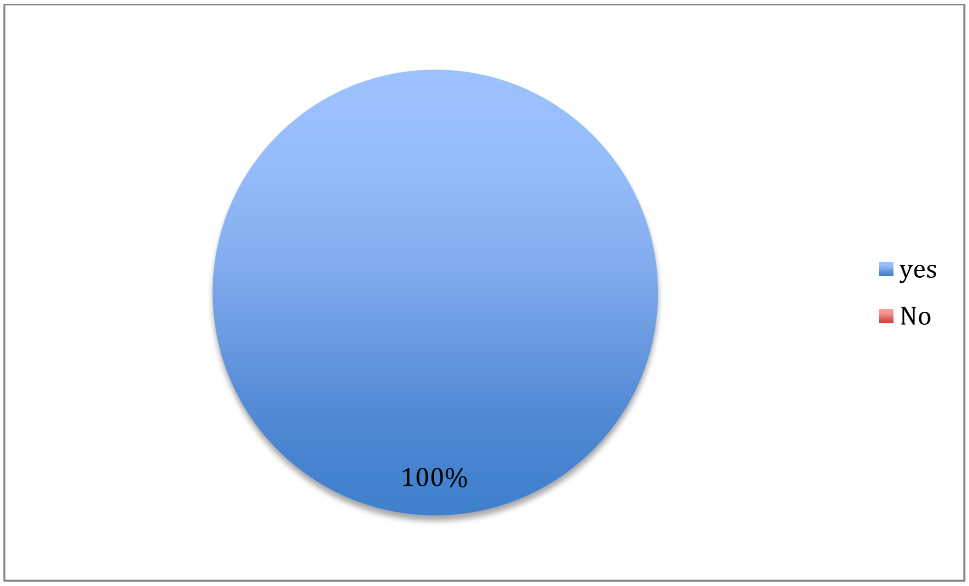


Figure 4-5 Is BIM Used for Marketing?

4.5.5 Question 4 – How Do You Collaborate With Others Using BIM?

The results of this question did not provide a clear, single method of collaboration. However, it instead provided a list of ways in which BIM was being used to assist in collaboration with others. One of the key concepts of collaboration was the use of clash detection meetings and trade coordination meetings. As the team met regularly at these meetings they knew each other better and discussed problems effectively, which is the very essence of collaboration. Several contractors stated that they shared models with other design team members, thus sharing the information. Others did not share their model, but still allowed other trades to view the model in an effort to share the information. Technology proved to be an important aspect of collaboration, whether through the BIM software, File Transfer Protocol (FTP) websites or other software allowing remote access to meetings that involved BIM, such as clash detection meetings.

4.5.6 Question 5 – How is BIM Used On-Site?

The results to this question showed two distinct areas where BIM was being applied on-site. The most referenced subject was the use of the model being uploaded onto computers, iPads and touch screen computers located in site trailers or lock boxes on site. This allowed for easy access to the model on site, and therefore further allowed for concerns and questions to be answered directly from the model.

The other main area that BIM was used on site, included field-based tasks such as site coordination, site layouts, comparing as-builts with models and quality assurance. These were tasks that were previously being completed in some other manner, but were now using BIM to complete them. It was not mentioned why BIM was being used to complete these tasks, but it could be due to the efficiency and accuracy that can be created.

4.5.7 Question 6 – How Are You Organized to Use BIM?

This question stated that the participant should select any of the means that they were using to organize their use of BIM within their company, including through a BIM team, a BIM expert, consultants, or other form. These results are shown in Figure 4-6. This provided a demonstration of total use for each sub category, but lacks the detail to show relationships between companies who were utilizing more than one method. Figure 4-7 shows how these companies truly were organized for BIM use.

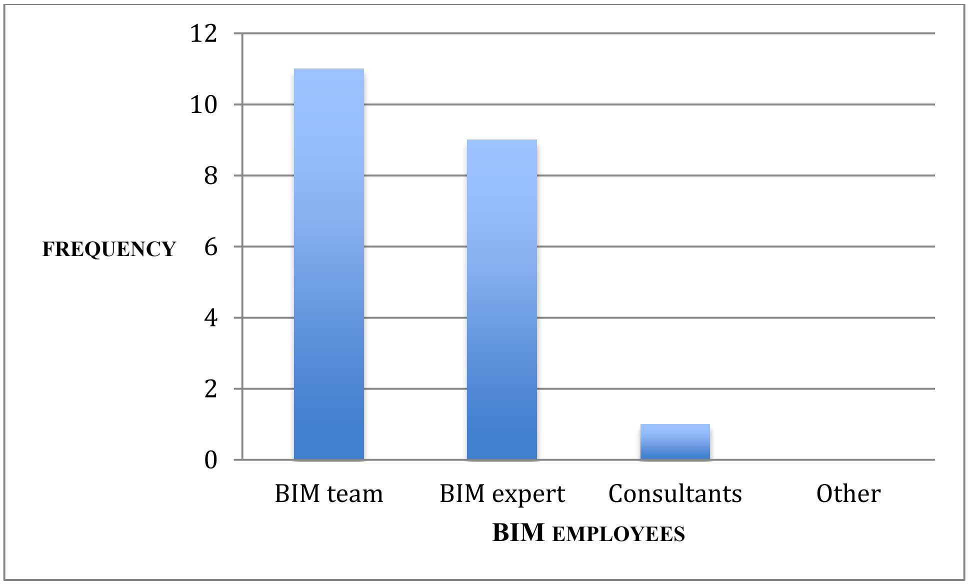


Figure 4-6 Company Structure

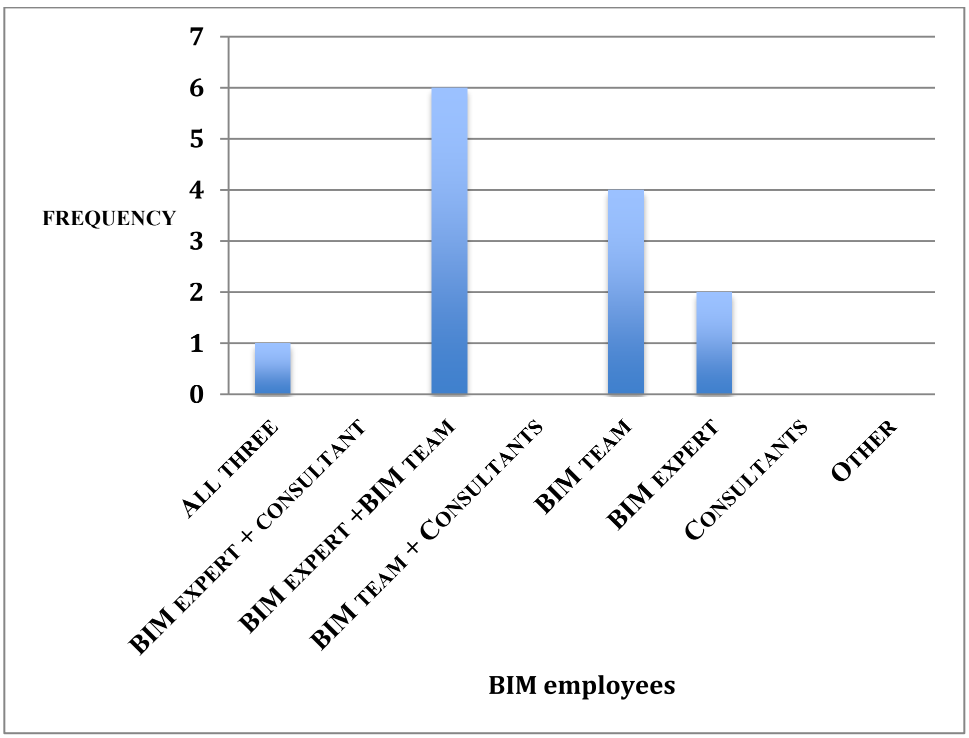


Figure 4-7 Company Structure With Combinations

Figure 4-7 shows that the most common set up was a combination of BIM experts and BIM teams. One respondent indicated that the company was currently trying to implement that setup. Consultants were only utilized when work was too large to be completed internally or if fast tracking projects was required. Generally, the industry's top users do not use consultants.

4.5.8 Question 7 – How is the BIM Process Reviewed to Create Lessons Learned?

Very few of the companies who were interviewed had any formal procedures for reviewing the BIM process to create lessons learned. Some stated that there was a debriefing at the end of a job, but did not indicate whether this was recorded and utilized later. However, three did state that they were recorded. Two of the three stated that within their company there was an intranet page dedicated to sharing BIM practices and lessons learned.

4.5.9 Question 8 – What Are Your QA/QC Controls on Modeling?

Several participants stated that there were either no controls on modeling or that it was a work in progress. Others stated that the models were just checked against the drawings to ensure that they were accurate. Very few had procedures in place to ensure that it was occurring. Other companies stated that BIM was not treated as a separate entity and was encompassed within the company's general QA/QC procedures. Overall, there appeared to be a lack of structure within approximately half of the companies. This could be further investigated to determine if procedures actually do exist and employees were simply unaware of the procedures. However, if there are not any formal procedures that exist, then this could be an area for future development.

4.5.10 Question 9 – When Do You Charge An Additional Fee for BIM Services?

The general consensus amongst the contractors was there was little room to charge an additional fee for BIM services. BIM was included in the general conditions (GCs) of the contract and unless there were large changes to the design, or unusual requests, there were no additional fees. Some stated that the fees received did not cover the costs of using BIM, and another respondent stated that computer costs within their GCs had raised by $150 a week to cover the costs of the new hardware and software.

4.5.11 Question 10 – In What Ways is Your Company Planning on Expanding Its Use of BIM?

This question provided a variety of directions for company plans on expanding BIM use. However, the most common responses were estimating (which was referenced 6 times), developing apps for the field (mentioned 3 times), and utilizing BIM more within projects and training employees further. Throughout the surveys, it was mentioned several times that BIM can have a big impact on estimating. From this question it was evident that this could be an important use for further development. Apps can be an important aspect in technology, allowing hardware and software to be specifically designed for the purposes required by construction. Several companies stated that they have app programmers as part of their business.

4.5.12 Question 11 – What Percentages of Offices Does Your Company Have Using BIM?

Figure 4-8 shows that all business utilized BIM in all of their offices. It did not specify as to what depth or quality it was being utilized. However, since this research was targeting BIM leaders in the industry, this was expected and now confirmed.

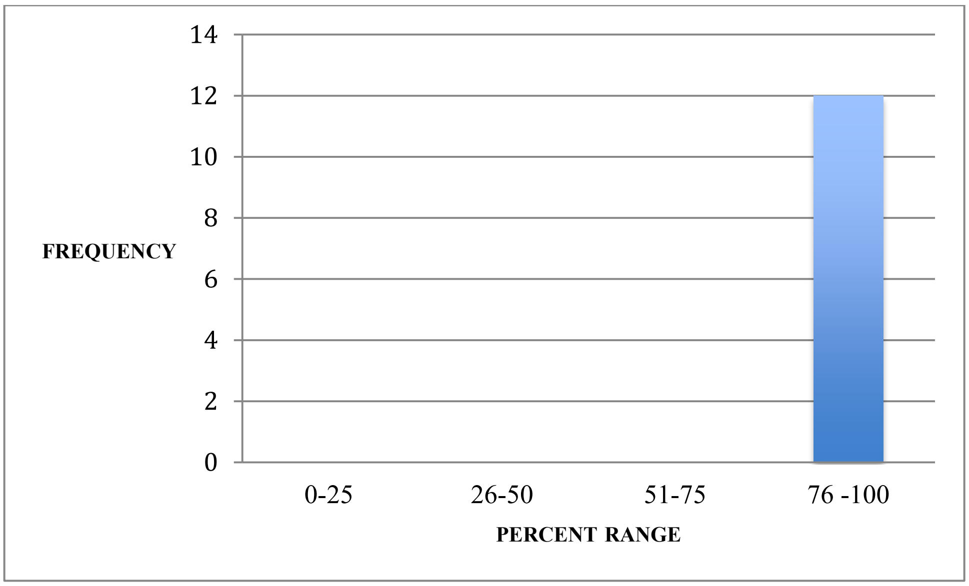


Figure 4-8 Percentage of Offices Using BIM

4.5.13 Question 12 – How Long Has Your Company Been Using BIM?

Figure 4-9 shows that the range of years for BIM experience was between 3 to 11 years. This is relatively short and suggests that if a company was willing to put in the hard work, they could obtain great results. There were others in the industry that had been using BIM for longer than 11 years, but they were not interviewed as part of this research, either due to not meeting the target criteria or being unable to help.

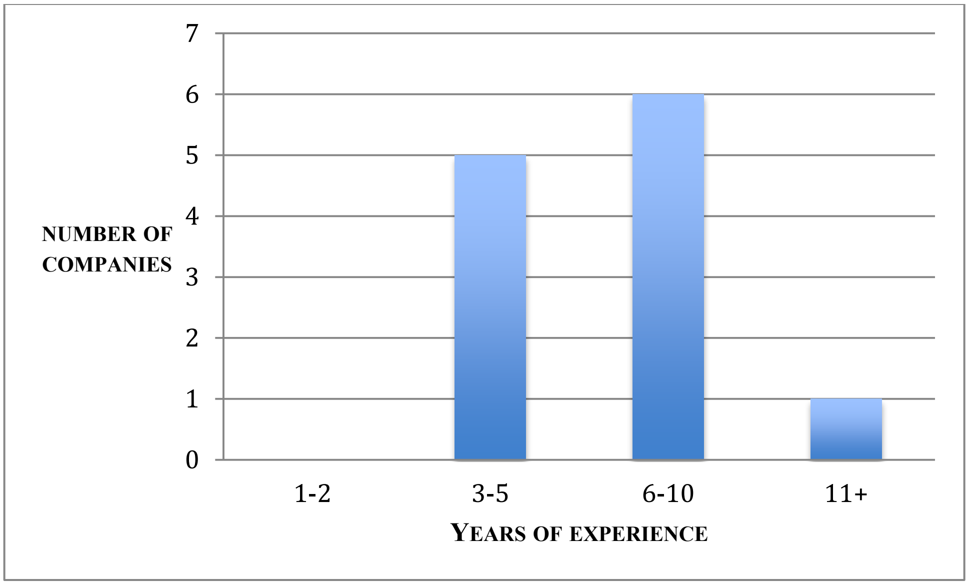


Figure 4-9 How Long the Companies Have Been Using BIM

4.5.14 Question 13 – Any Other Comments?

The mid-management level respondents generally did not provide any additional comments, as most felt that the questions were already sufficient. However, one individual addressed the importance of understanding the change in the industry from drawings to models, and in ensuring that the models were up to date and not just the drawings. In their experience, the models were sometimes not maintained. Since the transition from drawings to models was still occurring, any company not yet implementing BIM could still do so and keep up to date. As one individual stated, "it is still not too late but you can be left behind." They further stated that people forget that you are not required to implement everything to receive the benefits. The final comment was a reminder that BIM is just a tool and to be cautious with it.

4.6 Field Practitioner Level Questions

The field practitioner survey was completed by twelve individuals currently practicing within the industry. A summary of their responses is included within this section.

4.6.1 Question 1 - What Are the Top 3 Advantages of BIM?

The results shown in Figure 4-10 did not produce any advantages of BIM common to most respondents. However, communications and scheduling were mentioned by half of the respondents. Further, costs were identified as an advantage five times, and visualization was mentioned four.

Further comments by several respondents noted that communication in teams also consisted of visualization and that they actually go hand in hand. One stated, "it's a great tool" and it "makes things really crystal clear. Rather than hypothetically talking about a problem, you can physically show a problem". Another emphasized the importance of communication by naming the top three advantages all as communication.

4.6.2 Question 2 - What Are the Disadvantages/ Concerns of BIM?

The results of this question did not produce any faults with BIM as software. It was stated that as software it is fine, but that the processes around BIM can be problematic, such as implementing the software into a company or having people using standard methods. The common concern was the idea of construction expertise in the industry. BIM experts usually had little construction experience and found it difficult to apply BIM in the field. The experienced construction workers had yet to fully grasp the importance of BIM or were unable to adapt to the new technology. There was no clear indication as to why more experienced construction workers were not yet fully grasping the importance of BIM, except for the implication of age. However, some of those interviewed had been in the industry for twenty to thirty years and were able, and willing, to use BIM fully. As a result there was a distinct lack of good BIM construction workers. They generally had one or the other, but not both.

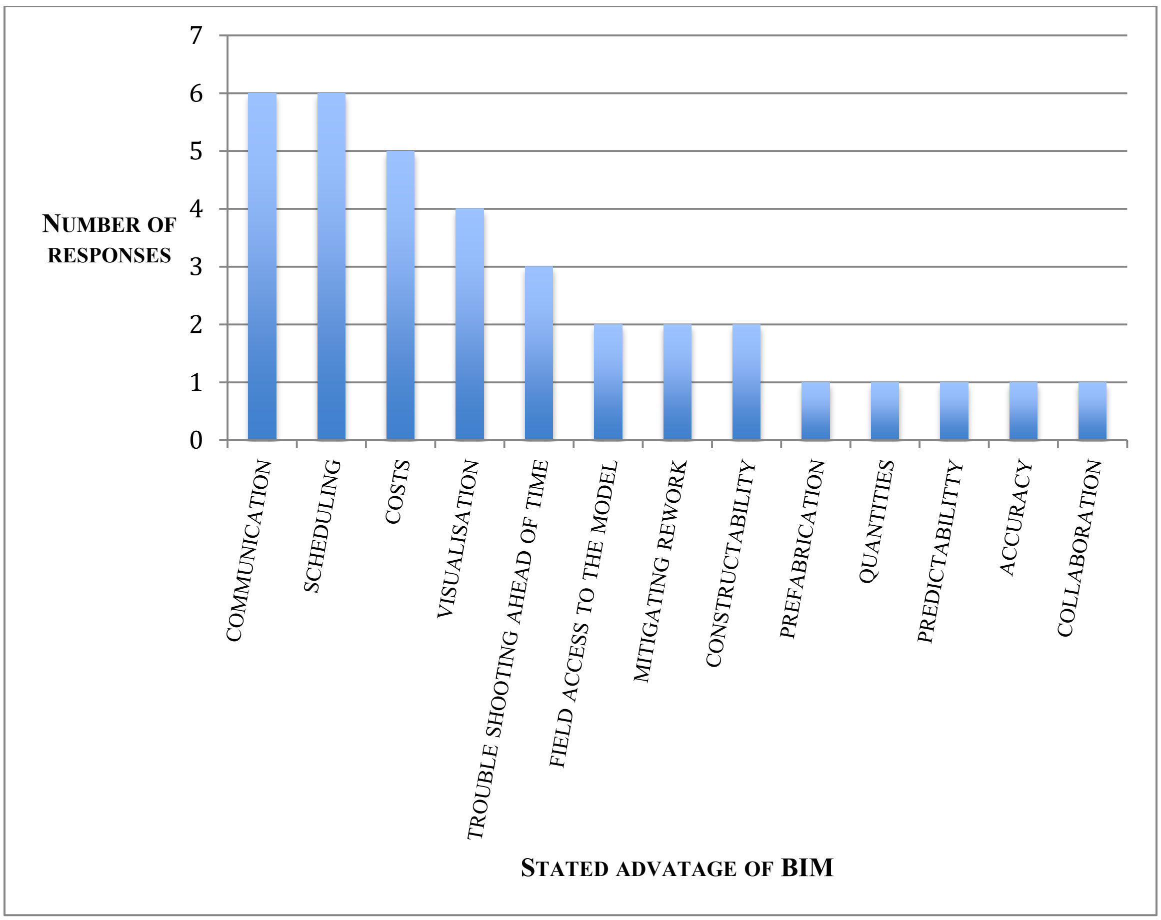


Figure 4-10 Field BIM Practitioners Top 3 Advantages

The other main concerns with BIM were directed in the clients and owners direction and included the owners' expectations and the owners' lack of knowledge. Concerns were expressed that owners did not fully understand BIM and so were expecting too much from the model or teams. They did not understand the learning curve involved with BIM or the time required to construct models and as a result BIM was not being fully implemented. One person stated, "it is very important to be all in or all out, because if you are only going to take a little here or there, that really is where the disadvantages come in." This suggested that any problems associated with BIM could be due to not fully adopting BIM.

4.6.3 Question 3 - For Each of the Following Delivery Methods What Percentage of Projects Do You Receive Models From the Design Team?

Figure 4-11 shows that the type of delivery method of a project affected the frequency of models being received. This did not directly address the quality or LOD of the models being received, but was discussed in later questions. It was interesting to observe that not one delivery method received models for all projects consistently. This could be due to lack of information being produced for a model, insufficient time in the project to produce models or lack of expertise among the design team. Design Build contracts were the delivery method that produced most models being received and hard bid jobs were the least likely to have a model being received.

4.6.4 Question 4 - What Percentage of Projects Do You Generate Models?

Figure 4-12 shows the percentage of the projects where a model was created. For the four different delivery methods shown, contractors stated that creating models was really depended on the impact it would have on the projects. Several respondents were unable to provide percentage breakdowns, resulting in a 'depends' field being created. The two companies who stated 'depends' elaborated with one stating it was dependent on the benefits that could be achieved and the other stating that any project over $20,000,000 required a model to be produced. The respondents who stated zero included a contractor who said that they required design team members to contractually provide models and ensured they received them. As a result, they were never required to produce models.

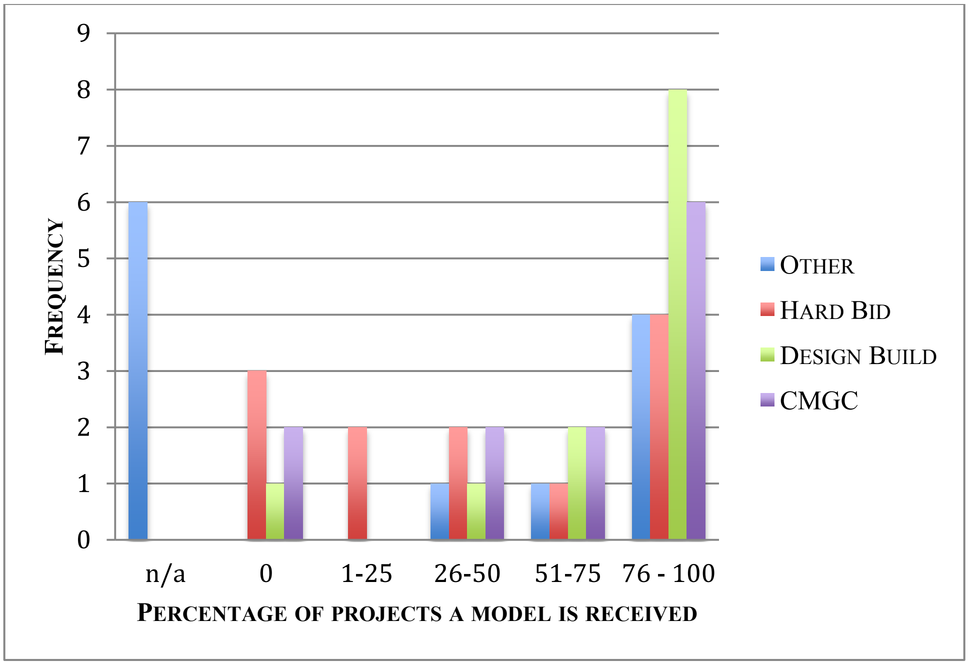


Figure 4-11 Percentage of Models Are Received

The general trend showed that models were being produced for 76 – 100% of the projects, regardless of the delivery method. The results for Design Build were similar to question three, which also utilized BIM model creation more. This suggests that this delivery method was either more conducive to producing or requiring models more or the design and construction teams were able to better work together in the design build delivery method.

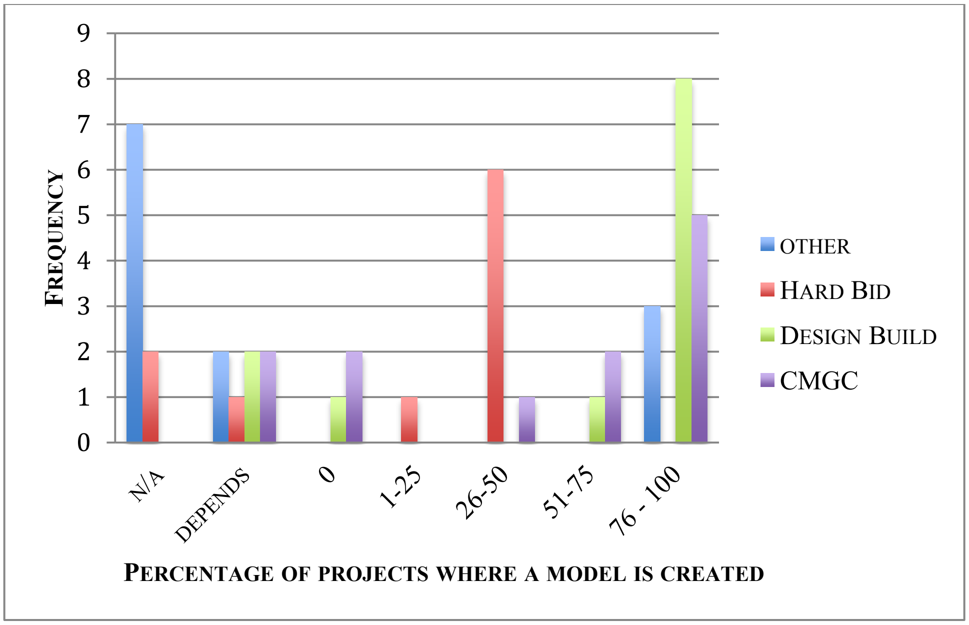


Figure 4-12 Percentage of Projects Where a Model is Received

4.6.5 Question 5 - Of the Models Received, What Percentage of Projects Do You Have to Start From Scratch?

Figure 4-13 shows that there was a tendency to not remodel any models. Most companies tended to keep the model they received and work from it. Very few had real problems with the models they received. However, they did occasionally receive a model that they could not work from. One respondent stated that they would never rework a model since they contractually obligated the design team or subcontractor to provide a model and then held them accountable to provide such. Two respondents said they redid all the models they received for construction purposes but not the architect's models. They did this to ensure accuracy and to learn more about the structure to be built. This is completely opposite to another respondent who stated that it would be a waste of time to redo all the models from scratch. However, the general consensus was that most people worked with what they had received from the architect.

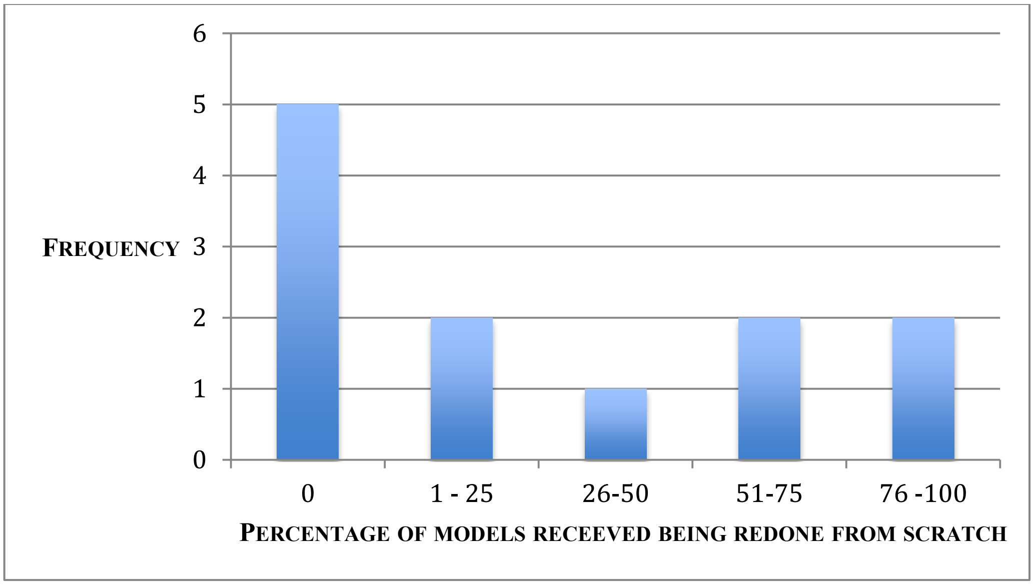


Figure 4-13 Percentage of Models Needing To Be Remodeled

4.6.6 Question 6 - What Percentage of Projects Do You Model Your Self-Performed Work?

Not all of the companies surveyed self-performed any work, as seen in Figure 4-14. Of the eight companies that did self-perform, only one did not model their work. The remainder modeled their self-performed work. Of the eight companies, 50% modeled their own work 76-100% of the time. They stated that it was beneficial as they could track variances and determine if errors were made when quantities did not match the estimates.

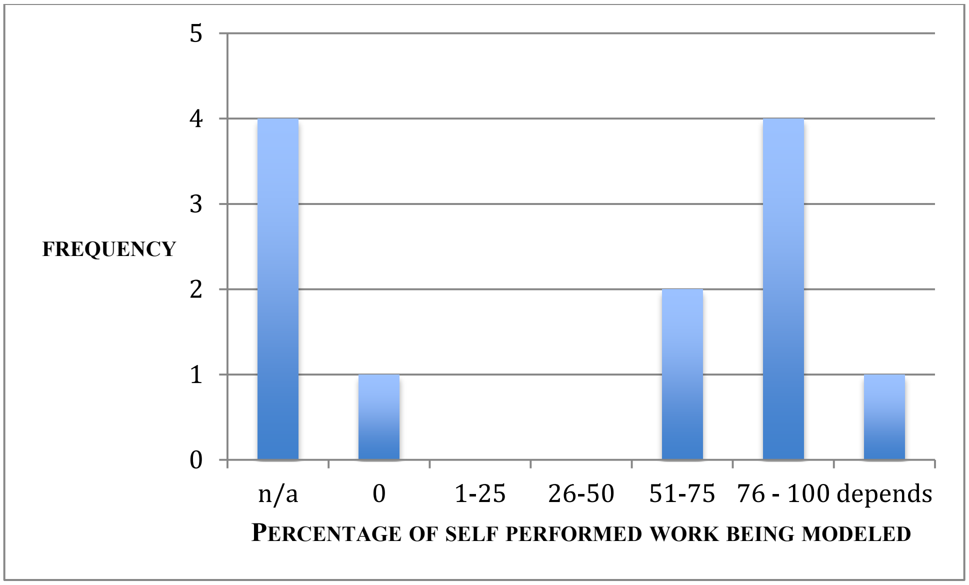


Figure 4-14 Self Performed Work

4.6.7 Question 7 - 3D Modeling

This question provided some interesting insight about the LOD included within the models. Some respondents gave specific LOD's for different aspects being modeled, while others approached it generally and stated a LOD for the whole model. Unfortunately there was not a way to distinguish between the two different approaches. These results should also be used cautiously since there were different interpretations for LOD. Generally, level 400 seemed to be the most common LOD amongst contractors. However, a few broke this down into elements, but stated that the LOD used was dependent on what the model was to be used for, and therefore it was difficult to state a general level. One respondent used the example of a door, arguing that it did not require LOD 500.

One subject that was mentioned numerous times was the LOD requirement for facilities management (FM). Several contractors stated LOD 500 was used for FM when required by the client. However, other contractors stated that LOD 500 contained too much information and irrelevant data and they chose to model only up to level 300 or 400, then only adding additional information as required. Further research could be conducted to determine what level and which information is required for facilities management. The results to this question indicated that there was still a lack of clarity as to what was necessary in the model.

4.6.8 Question 8 - Do You Share Your Model With Your Trade Partners/ Subcontractors?

Figure 4-15 indicates that the clear majority of the contractors shared their model with their trade partners / subcontractors, with 92% stating yes. Several explained that this was the main benefit of BIM, allowing information to be shared easily. Many alluded that anyone not doing this was not using the full benefits of BIM. Other comments suggested that this was what BIM was designed for. However, legalities could be blocking the way. One company overcame this by writing a clause into their contracts that stated the model was not to be considered accurate, but instead to rely upon all construction documents.

4.6.9 Question 9 - Do You Submit a Model With Your Bid?

Figure 4-16 shows the majority of companies stated that they did not include a model with their bid. This was surprising, since the literature reviewed suggested that this was occurring more frequently. A few respondents stated that this could potentially be used in the future as long as the information was received early enough to allow time for the model to be completed. This use of BIM was also reliant upon the delivery method, as

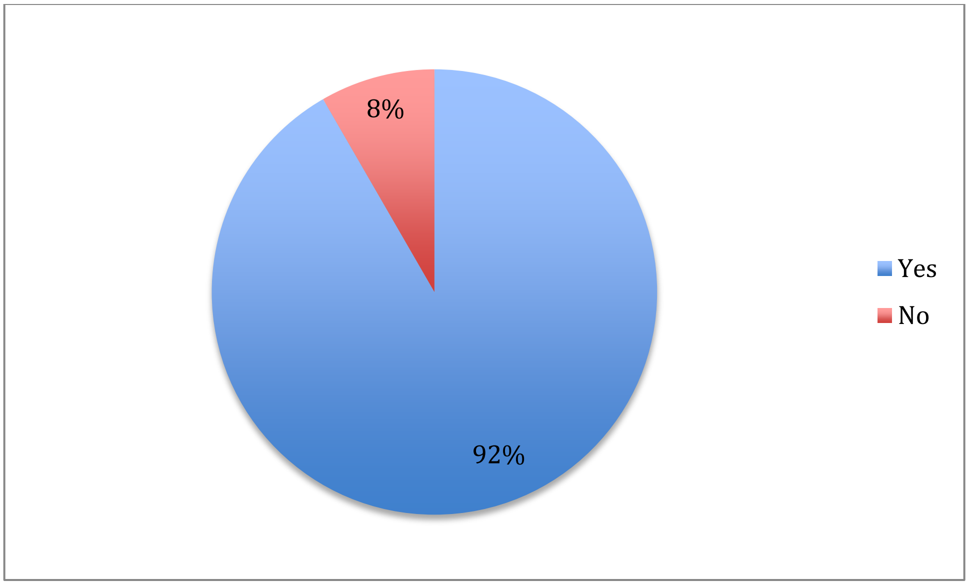


Figure 4-15 Do You Share Your Model

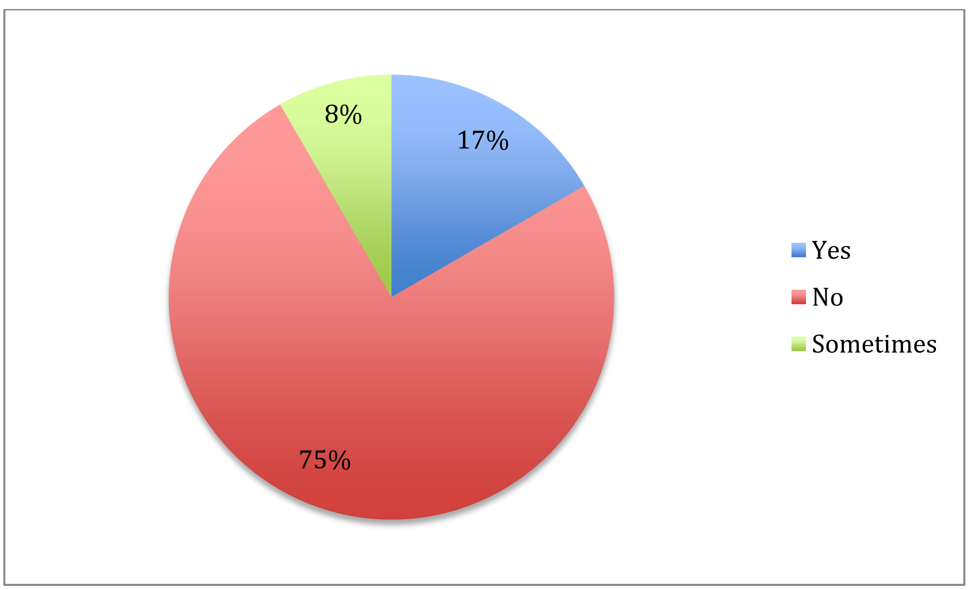


Figure 4-16 Percent of Companies Who Submit a Model With Their Bid

some methods did not allow for models to be created. Depending on the project, detailed information was not received early enough in the project to allow a model to be created.

Companies were however working on receiving information quicker to enable models to be created for all projects.

4.6.10 Question 10 - Do Trade Contractors Ever Take the Lead In Clash Detection Efforts?

The views revealed in this question suggested a divide in whether or not contractors take the lead in clash detection efforts. Figure 4-17 shows that there was a 50-50 split, indicating that there was no consensus, but clear viewpoints and arguments for each. Those who indicated 'yes' spoke about subcontractors having the expertise and the knowledge about the systems and this suggested that they were suitable to take control of the meetings. Those contractors who stated 'no' indicated lack of control over meetings as well as the quality of meetings and clashes ran by the subcontractors as their reason for not allowing trade contractors to take charge. One contractor felt that as the general contractor for the project it was their responsibility to run meetings and ensure it was all performed to a high standard. If the subcontractors were given control, they could lose control over this aspect. Another contractor suggested that trade contractors focused only on their trade, with little interest in other trades, and as a result clashes were not being resolved. This company changed from trade contractor lead meetings to general contractor lead, and reported that since then they have seen a big improvement in their clash detection meetings. Both sides seemed to present logical reasons for their choices and further research could determine if there are better results for one method over the other.

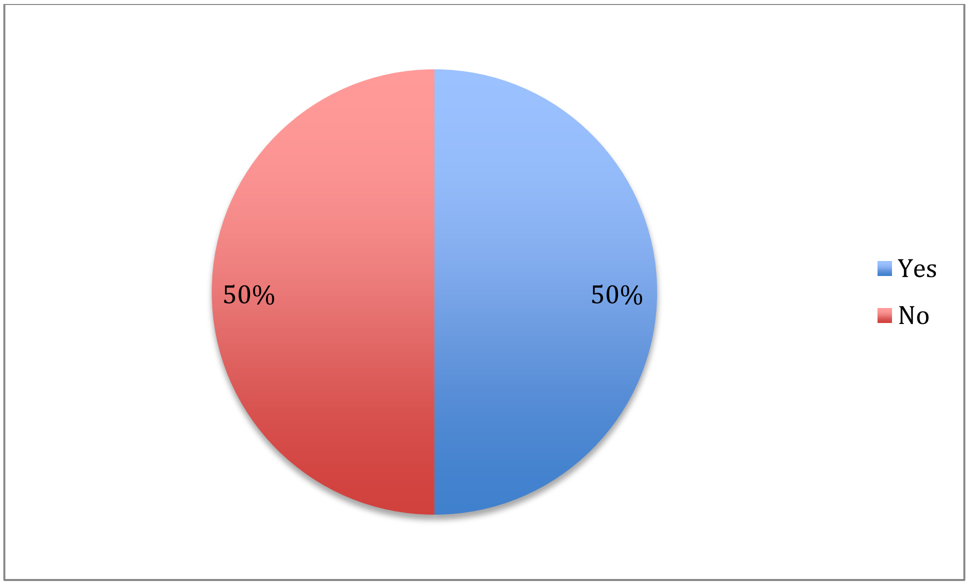


Figure 4-17 Subcontractors Leading Clash Detection Meetings

4.6.11 Question 11- Do You Use BIM to Track Variances During Construction?

Figure 4-18 shows that most contractors did use BIM to track variances during construction. It was stated that this was an effective way to review costs and it was a step towards producing as-built drawings. Another respondent stated that they were not performing this task, since they had not found an effective way to do so. This respondent further stated that they would utilize this option, if an efficient way to do so could be identified.

4.6.12 Question 12 - Do You Use the Model to Produce As-Builts?

Figure 4-19 shows that all of the respondents suggested that at least some of their projects, if not all, were using BIM to produce as-built drawings.

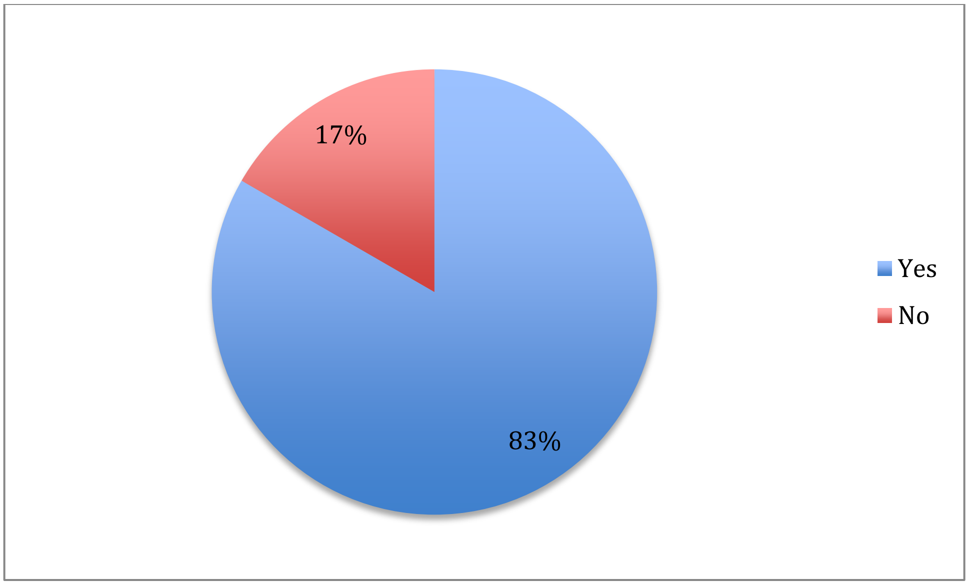


Figure 4-18 BIM Being Used to Track Variances

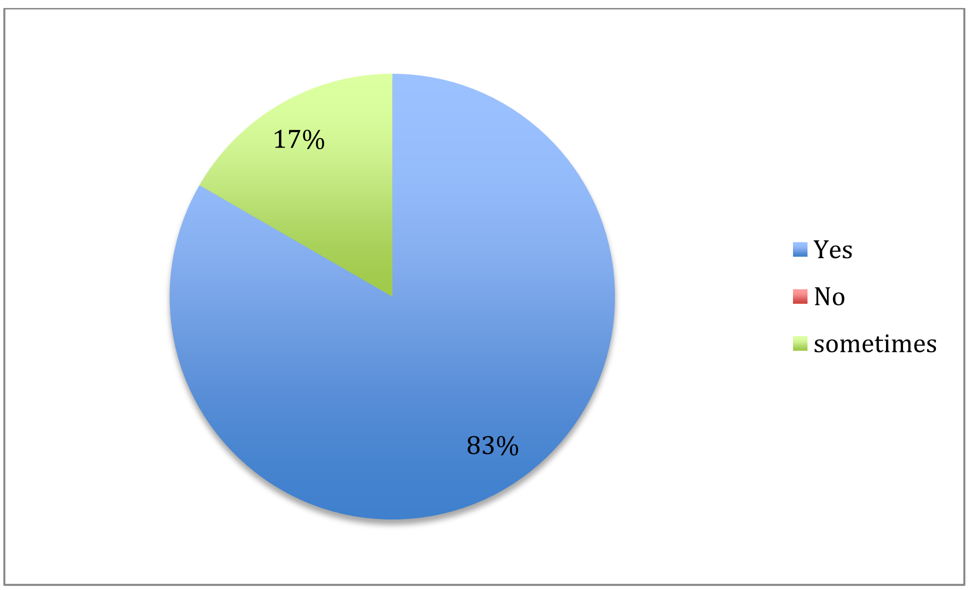


Figure 4-19 BIM Being Used to Produce As-Builts

4.6.13 Question 13 – Any Other Comments?

The addition of this question to the BIM practitioner level survey provided some useful insights into BIM, but not all were directly relevant to this research. The common theme was ensuring that the right people were given the right tools and training. It was stated that BIM was a powerful tool and given to the right person there was potential for a powerful solution. As BIM continues to evolve, there needs to be an emphasis within a company of continually exploring new ways to use BIM. Those in the field were hesitant to get involved with BIM, but when they saw the actual results, they generally appreciated the technology.

4.7 Combined Top 3 Advantages

Figure 4-20 shows the overall top three advantages from all three survey levels. Since the survey question only asked for the top three advantages, a ranking order could not be created. However, from Figure 4-20 it was observed that the top two collective advantages were communication and scheduling, with thirteen different respondents identifying each. The third advantage was also a tie between coordination and visualization, each being identified eleven times.

Figure 4-21 shows the side-by-side comparison of each of the three survey levels. It was interesting to observe that the field BIM practitioner had a smaller spread compared with the other two levels. This suggests that more uses were commonly mentioned and that there were a more distinct group of uses that were beneficial to the field practitioner level. The largest spread of BIM advantages was observed in the mid management level. This was perhaps due to the opportunities of BIM being used on different projects or in the case of most participants, as BIM managers they work more directly with BIM and its implementation within the company. The different responses could also simply be an indication of the different needs that each individual company had.

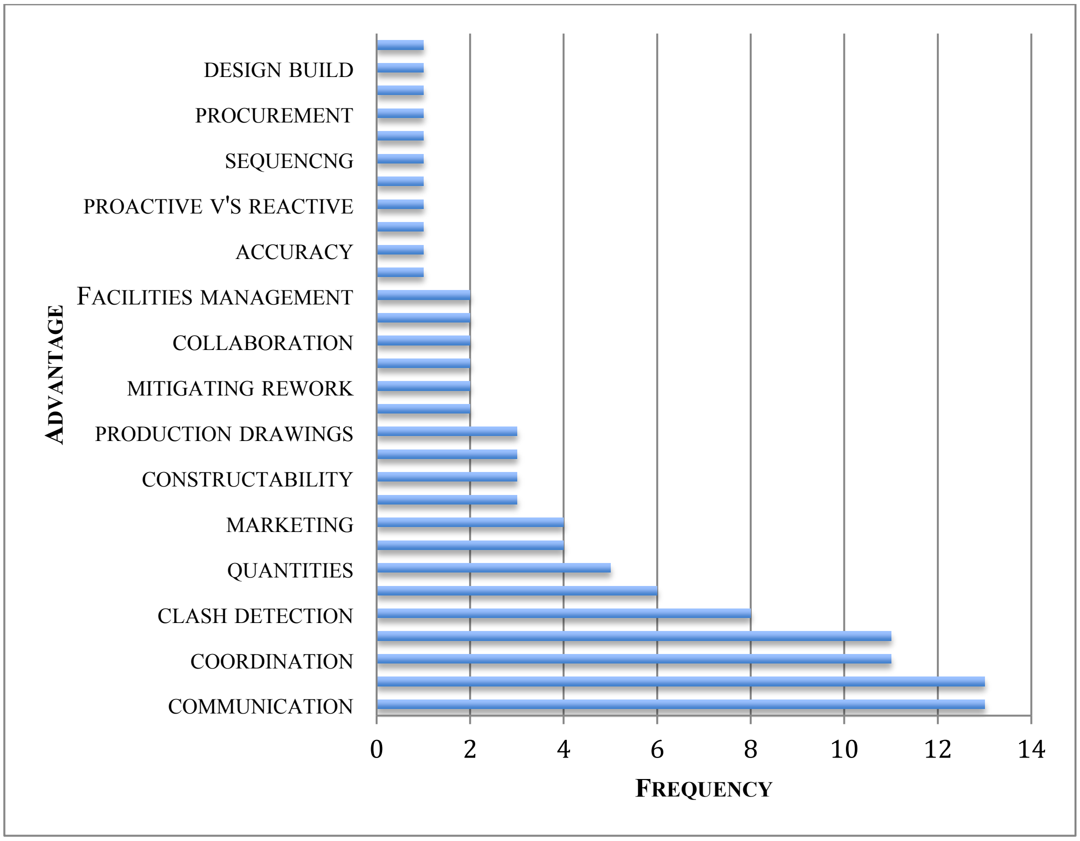


Figure 4-20 Combined Top 3 Advantages of BIM

4.8 Comparison of The Eight Complete Sets

The purpose of this research was to determine how companies were structured and to determine how the information was flowing and who was directing the use of BIM within the company. Most companies had at least a BIM manager who was responsible for the BIM implementation within the company. All executives interviewed were competent

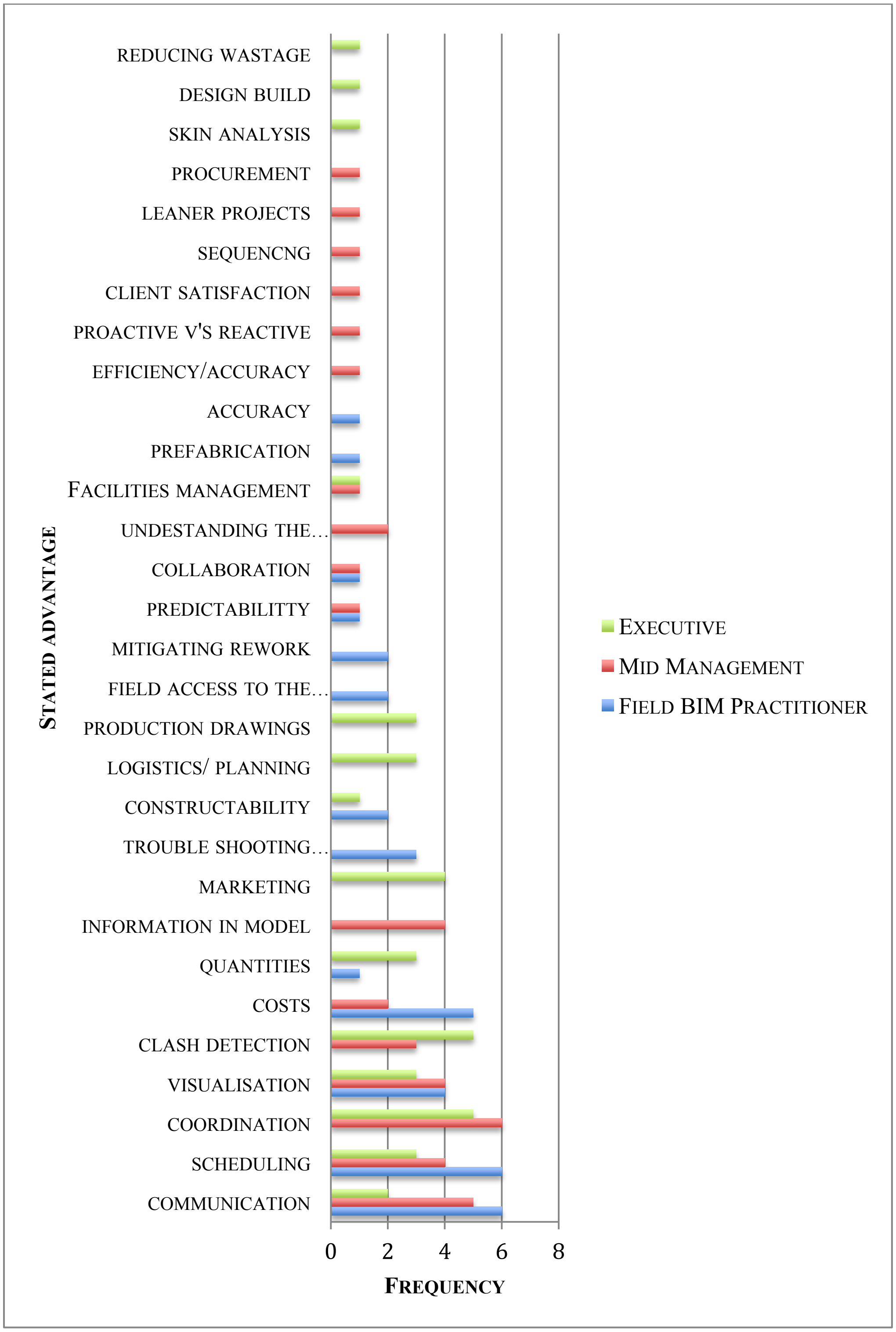


Figure 4-21 Comparison of Top 3 Advantages

with knowing how BIM was being used within their company. They were aware of the benefits and often were the people in charge of BIM in the company.

Some mid-management participants had little awareness of how BIM was actually being used or the frequency of BIM uses. Several had to seek assistance or clarify what uses were being adopted and their frequency. In general, the survey participant's role within the company directly influenced their knowledge of BIM. BIM managers were fully aware of uses. However, superintendents were not as aware of BIM uses. One superintendent was able to find the required information, which suggests there is a mechanism in place that allowed them to get information on BIM. Other mid-management participants knew exactly what was being done and even had documents providing that information. There was an apparent divide between the experience at the mid-management level with several people having limited construction experience but had personally been using BIM longer than the company. Others had the construction experience but lacked in depth of BIM experience. However, they were still very capable with implementing and leading BIM efforts.

Several of the field BIM practitioners knew very little about how BIM was being used within the company and only knew what they were working on. Generally they had the experience and knowledge to answer all questions, although some did not understand LOD or terminology that was not essential but aids with BIM training. Overall, the field BIM practitioners had similar knowledge.

Generally there were no clear indications that executives were not aware of BIM or that they were not directing the BIM efforts. There were several staff who praised the executive level for their enthusiasim and efforts in developing BIM throughout the company and these companies in general appeared to be performing well.

5 CONCLUSIONS

5.1 Conclusions

This chapter concludes why commercial contractors are using BIM, the uses of BIM they have adopted. the frequency that these uses are being implemented, and the best practices of these uses. The conclusions are then followed by suggestions for further research.

5.2 Reasons for BIM Adoption

Through the various questionnaires it was evident that BIM was being used for a number of reasons, with the most common reasons being to increase efficiency, to win projects and be more competitive, and to deliver accurate schedules and costs. Most companies stated it was a company decision to use BIM and not an external driver such as client demand that led to their use of BIM.

5.2.1 Increase in Efficiency

The survey participates repeatedly stated that BIM was a tool in the industry to improve procedures throughout the company. It was used to improve communications both visually and verbally through improved coordination efforts. As the project teams shared information they were able to work together to resolve problems early in the process before the problems affected costs and schedules. Resources were able to be appropriately allocated to allow for efficient schedules.

5.2.2 Increase Competitiveness

Several companies stated that they were able to win more projects by implementing BIM, since clients were able to visually see that the company could provide a solution to their needs and meet the desired schedule. Other companies stated that they were able to compete for larger valued projects than they previously could without the use of BIM. Their companies were more efficient with resources, and therefore, able to work on larger projects. One company stated that they were able to be competitive with other companies in attracting the best employees, as the use of BIM made them an appealing employer.

5.2.3 Improved Schedules and Cost Estimates

BIM allowed general contractors to obtain tight schedules and even reduced the duration of the schedules, in some instances by several months for lengthy projects. BIM increased confidence in the information that was required and with the reduction of changes due to errors, these schedules were achieved. These improvements to the schedule reduced costs, since there was correspondingly less time on site. Resources were efficiently deployed and allowed for further savings in cost. When accuracy in the model information was obtained, costs and estimates were also reportedly more accurate.

5.2.4 Top Advantages as Found in the Results

Communication, scheduling, coordination and visualization were stated as the top advantages by those who participated in the survey. These uses allowed the interviewed companies to be efficient, effective and competitive in the current market. Communication allowed problems to be resolved at an earlier stage avoiding rework in the field. Coordination closely followed this, as resources and trades were better coordinated to ensure trades could work concurrently. This allowed for efficiency in the scheduling enabling the trades to work beside each other or in different areas of the structure, as necessary. Visualization allowed clients to see what the companies were capable of, and led to an increase in jobs being won. It also helped the design teams and field teams know what the project entailed, and problems could be reviewed graphically in a model to provide assistance in understanding the project requirements.

There were some negatives reported to using BIM. For example, the cost of investing in BIM is expensive. However, the rewards obtained from using BIM greatly outweighed the costs of investing. In general, the positives by far exceed the negatives, with most of the negatives only being a temporary setback.

5.3 Frequency of BIM Uses

There were many uses of BIM identified as part of this research. Some of the more non-standard uses of BIM included estimating, facilities management, laser scanning and green buildings. The results of the questionnaires showed that these uses were not used often on projects. There is a need for further experience within the industry to allow these uses to be applied both practically and often. Several companies stated they had not found an effective way to implement the uses of BIM within their company, yet others have adopted it on most of their projects.

5.3.1 Top Uses of BIM as Stated by Contractors

The results shown in Table 4-1 provided the current usage of BIM and the percentage that each usage type was being used. It was evident from this table that different aspects of BIM were used more commonly than others, with the most frequent uses being clash detection, 3D modeling, team collaboration and sales. The other uses of BIM were used less frequently with some uses rarely being used at all. Several participants were unaware of the ability of using BIM with tools such as GPS, GIS and tracking time. This was perhaps due to companies not having enough BIM experience, necessary resources, or sufficient training.

Most participants stated that they expected an increase of usage with field technology, using the models for FM, and an overall increase of usage to all projects that can utilize BIM. Other applications such as cost estimation and facilities management were becoming more common and their use expected to increase. There were a few companies able to state that the majority of the uses have in fact already become common practice within their businesses. These companies were seeking the next advantages, including better evaluating which uses are practical and should therefore be utilized more often.

Not all projects allowed for the use of BIM and was reflected in the results. Uses such as sonar scanning would have not been required on many projects, and therefore would not have been ranked highly. In order to determine if BIM was applicable, contractors examined the potential ROI, size and complexity of projects, to determine if BIM use would be beneficial to the project.

5.3.2 Estimating

During the literature review, there were many claims identified that BIM was being used for estimating as is shown in Appendix D. During the surveys several participants acknowledged their need to increase their use of BIM with estimating, since they were not currently receiving the full advantages. Table 4-1 shows that over half of the companies interviewed were not using BIM to estimate over 50% of their projects. In fact, nine companies were only in the 1-50% range.

5.3.3 Clash Detection

As expected, clash detection and 3D modeling were the most common uses of BIM being practiced by general commercial contractors. During the literature review there were many articles that stated clash detection was the "low hanging fruit" and this phrase was used many times within the responses. The participants felt that this was the case and there were many more exciting things that could be done with BIM. However from Table 4-1 it was clear that not all of the companies surveyed utilized clash detection on all projects. One company stated that their use of clash detection was as low as 50% of projects. It seems that with this being such a basic and valuable use, clash detection should be used on all projects. If a company was not using BIM for that purpose, they were not taking advantage of the information contained within the model.

5.4 Best Practices

The primary purpose of this research was to identify the best practices of BIM use by commercial contractors. This section identifies and explains these best practices as determined in this research.

5.4.1 Company Organization

There were two main aspects to a company that were best practices. All companies that participated in the surveys had BIM projects in every office and had begun to ensure training and resources were available to each team and office. It was important that a company use and fully integrate BIM throughout the entire company. The other main aspect was the importance of BIM setup within the company. The most common and successful setup was the use of BIM experts in a project team as well as having a dedicated BIM team. Keeping the BIM expert on a project after the initial stages allowed BIM to be used throughout the whole project. Furthermore, it was necessary to have better trained BIM engineers with field experience, thus improving future models. Experience was important to companies, but although several companies had been using BIM for only three years, they were already leading other companies in BIM use. Even with the lack of BIM experts having extensive construction experience, it was essential that a company be willing to fully invest in resources, training and competent staff that could use BIM. The successful companies had managed to achieve this combination.

5.4.2 BIM is Used on All Projects

Companies that were using BIM on all or most projects had a corresponding increase of profitability and reduced schedules. With the increased use of BIM, the lessons learned from projects could then be reapplied to other projects to further increase efficiency. Experience on projects allowed employees to become increasingly competent in BIM and allowed for additional employees to utilize BIM even more effectively. By using BIM to its full capacity as much as possible, and on all projects, a company could further develop their BIM use and increase their knowledge of BIM. In order to increase efficiency of employees, BIM should be utilized on all possible projects.

5.4.3 Subcontractors and Collaboration Meetings.

Subcontractors were reported to be increasingly competent with BIM. This was partly through general contractor led training. Even though there was an even divide in who ran clash detection efforts, the best practice was to allow subcontractors to run their own clash detection on models, resolve any clashes that they could and only bring forward the larger clashes that needed to be addressed by the collective project team. All companies surveyed suggested that the subcontractors were all treated equally since they have specific knowledge about their individual trades. It appeared that most general contractors still took the lead in the clash detection meetings. This was because they were still the general contractor and felt it was there role, or they simply had a lack of trust in the subcontractor's abilities to remain unbiased. The current best trend was therefore allowing subcontractors to take control of their own clash detection efforts, while the commercial contractor takes responsibility of the overall trade coordination efforts.

5.4.4 Models

The quality of models commercial contractors received was improving and they were being received in more projects, as stated by several survey participants. The model quality usually allowed for a base for creating construction models. Very rarely were contractors starting from scratch out of necessity. One company ensured any model received was of high standard or it was returned to the creator to improve and meet the requirements. Models were being created for most jobs, but was dependent on project type and perceived advantage. Models were generally being created to LOD 300 or 400. However this was again dependent on the use of the model. If it was only being used for visualization it could be constructed at a lower LOD.

Most companies shared their models, either through cloud technology such as FTP, or by allowing others within the design teams to view the models. This allowed for an increase in communication and collaboration. Contractors stated that sharing the model and the benefits received was far more important and outweighed any concerns they may have had in sharing the model. However, a few companies were submitting a model with their bids as they were not receiving the information in time or simply did not feel it was appropriate. These companies were creating models only to visually show the clients what their ideas were, but these models were not being submitted as part of the bid.

5.4.5 Invest in the Future

Most contractors agreed that using BIM was no longer optional, but rather a standard practice within the industry, and therefore the debates about the benefits were no longer valid. There might have been little evidence in terms of numbers to confirm this, but it was clear that BIM use is an important part of the industry. The general consensus was that BIM is no longer about ROI or costs, but rather is about being the best tool available. The real issue was how to most effectively implement BIM on more projects and where the technology was going with regards to future uses. Several individuals discussed the potential of augmented reality, increase in field tablets and apps, facilities management and cost estimating. Several companies have invested in research to determine which uses will bring the most value to the company and which uses will become standard.

5.4.6 Marketing

Using BIM to allow clients and potential clients to visualize the project and to demonstrate capabilities was a best practice, since it allowed the companies interviewed to win more projects. It was important that BIM was used to ensure the company was sellable to clients and future employees. Without this skill, companies would struggle to attract clients and the employees necessary to complete BIM projects.

5.4.7 Field Technology

Many of the survey participants were excited by the prospects of fully implementing BIM in the field, since it had dramatically changed and improved construction methods. The advantages of BIM were easily recognizable when BIM had been executed on site correctly. Site layout was more accurate when GPS and BIM were combined. Construction crews were able to review the model onsite, reducing the need for ROIs as most issues were resolved before the construction actually began on site. It was assumed that the reduction of ROIs was from the contractor side and not the client side. This saved both time and money and was therefore increasing the efficiency of projects. Many stated that this was where the true power of BIM resided. They were currently trying to develop apps to allow the technology to be in the hands of the field team and to create processes and standard methods within their own company to enable them to address the efficiency and effectiveness of this technology in the field. They were also seeking to develop their methods and uses through further research and development. Several contractors stated that they have begun to research augmented reality and expect that it will become an important tool within the industry. Any company who was using BIM, and not investing into further research or development, should have considered if their approach would enable them to compete in the future and continue to reap the benefits of BIM. With various participants reporting significant time and costs savings, it was clear that BIM was an important tool to implement. Since BIM continues to evolve, current BIM users that are not engaging in further progress, will be in danger of being left behind.

5.4.8 Facilities Management

Facilities management (FM) was discussed several times throughout the interviews, since it was an emerging use that was gaining momentum. The current trend was an increasing amount of projects to using the model in facilities management purposes, after the completion of the structure. It was seen by most people as a tool for the client to increase efficiency of time and investment of the structure. It was suggested that more clients were seeking to use the models for facilities management and that this was expected to continue to increase. This would result in further developments, thus enabling this feature to be used as a more common practice. It was unclear from this research as to which LOD was required to ensure a practical, usable model. There seemed to be a divide developing amongst those who talk about BIM being used for FM; some stated that the clients are receiving information that was not needed while others stated that every individual component should be modeled. Those desiring to use BIM to deliver FM to the clients should determine what information their clients need or want and ensure that they have the protocols in place to deliver them.

5.5 Recommendations for Further Research

There were several topics highlighted throughout this thesis that could be researched in further detail. This included exploring the level of detail (LOD) required for BIM to be used for facilities management, to enable future adopters this opportunity. There was an apparent divide in which LOD was required and what information should be included within the model for FM purposes.

Future developments in technology and software, such as augmented reality and robotics, could be investigated to determine the best methods of utilizing the technology in construction management and the impact that it will have on the industry. There were several contractors who spoke about using the technology once it is perfected. However, in the meantime, it is imperative the impacts on the industry be determined.

One of the biggest areas identified for further research, was the use of field BIM and utilizing tablets, GPS, GIS and other such resources. One direction of BIM is an increase in field implementation, since contractors felt that there was great power in these tools. It would be important to determine how to best progress and determine which uses are practical and which areas need further development before being fully implemented.

Further research could also be taken to determine if subcontractors are biased in their coordination efforts in performing clash detection, and whether they should take the lead in clash detection meetings. Many of the issues raised by the participants in this research could be addressed by enabling the subcontractors to run the clash detection meetings, but this should be further researched. The final recommendation for further study, is quantifying the presumed shift in change orders throughout the entire industry, resulting from BIM use, and determining who should be liable to pay for any resulting changes.

REFERENCES

AIA Document E202 PDF." fm.virginia.edu. http://www.fm.virginia.edu/fpc/ContractAdmin/ProfSvcs/BIMAIASample.pdf (accessed November 15, 2012).

All Things BIM: AIA BIM Protocol (E202)." All Things BIM. http://www.allthingsbim.com/2008/12/aia-bim-protocol-e202.html (accessed February 11, 2012).

Aouad, G. Constructing the Future nD Modelling. London: Taylor & Francis, 2007.

ArchiCADmonkey. http://www.archicadmonkey.com/files/bentley_shows_off_BIM_for_iPad.html (accessed December 4, 2012).

Barton Malow Company. http://www.bartonmalow.com/bim (accessed January 30, 2012).

Benham, J. "Construction Today Blog - The Must-Have Technology Tools, Part 2 – In The Cloud." Construction Today Blog - The blog for people who build America!. http://blog.construction-today.com/?p=229 (accessed November 29, 2012).

BIM Task Group A UK Government Initiative. http://www.bimtaskgroup.org/ (accessed January 30, 2012).

Briggs, M. "Architectural Models." The Burlington Magazine, April 1929, 175-183. buildingSMART alliance | The National Institute of Building Sciences. http://www.buildingsmartalliance.org/index.php/nbims/about/ (accessed January 30, 2012).

Bridgers & Paxton. http://www.bpce.com/bim-levels-of-development (accessed December 4, 2012).

Building Design + Construction (bdcnetwork). http://www.bdcnetwork.com/sites/default/files/BIM_contractors_v4.pdf (accessed September 27, 2011).

Building Information Modeling Management Analysis. http://www.3dbim.com/ (accessed November 29, 2012).
BusinessDictionary.com - Online Business Dictionary. http://www.businessdictionary.com/definition/best-practice.html (accessed November 15, 2012).

CADAZZ. http://www.cadazz.com/cad-software-history.htm (accessed January 30, 2012).

Constructech magazine. http://www.constructech.com/news/articles/article.aspx?article_id=8801 (accessed November 16, 2012).

Corrigan, K. "The new era of BIM." ensight. (http://www.encon.ca/English/resources/Publications/Newsletters/Pages/Article.aspx?newsletter=Ensight_June_2010&article=TheNewEraofBIM.aspx (accessed November 26, 2012).

DPR Construction. http://www.dpr.com/construction/expertise/collaborative-virtual-building (accessed January 30, 2012).

Eastman, C. BIM handbook: a guide to building information modeling for owners, managers, designers, engineers, and contractors. 2011 ed. Hoboken, N.J.: Wiley, 2008.

Elevations BIM. http://www.elevations-bim.com/Services/bim---3d--4d-5d-6d-7d-modelling-services-30.htm (accessed November 26, 2012).

Grady, J. "Epic BIM: What is up with all the damn D's?." Epic BIM. http://www.epicbim.com/2012/08/what-is-up-with-all-damn-ds.html (accessed November 29, 2012).

GRAPHISOFT. http://www.graphisoft.com/company/about_graphisoft/ (accessed September 10, 2012).

GreenBiz.com. http://www.greenbiz.com/news/2010/10/27/building-information- modeling-core-sustainable-design (accessed January 30, 2012).

Gunn, S . Risk and financial management in construction. Farnham, England: Gower, 2009.

Hoffman Construction. http://www.hoffmancorp.com/hoffmanvalue/building_info_modeling.aspx (accessed January 30, 2012).

Holder – Building Information Modeling http://www.holderconstruction.com/services/Pages/Building-Information-Modeling.aspx (accessed January 30, 2012).

Hunt. www.huntconstructiongroup.com/about/bimvdc.html (accessed January 30, 2012).

JE Dunn Construction Company. http://www.jedunn.com/content/services/bim (accessed January 30, 2012).

Jernigan,F.. "Ch 1-2." In Big BIM, little bim: The Practical Approach to Building Information Modeling : Integrated Practice Done the Right Way!, 22-55. 2nd ed. Salisbury, MD: 4Site Press, 2008.

Jones Lang LaSalle. "What Is Building Information Modelling." Perspectives on Building Information Modelling. http://www.us.am.joneslanglasalle.com/ResearchLevel1/Perspectives%20on%20Building%20Information%20Modeling.pdf (accessed January 30, 2012).

Khanzode, A. Reed, D. and Lamb, E. "Transcending the BIM Hype: AECbytes Viewpoint #48." AECbytes: Analysis, Research, and Reviews of AEC Technology . http://www.aecbytes.com/viewpoint/2009/issue_48.html (accessed February 10, 2012).

Khemlani, L. "Graphisoft's New White Paper on BIM: AECbytes Newsletter #55." AECbytes: Analysis, Research, and Reviews of AEC Technology . http://www.aecbytes.com/newsletter/2012/issue_55.html (accessed November 16, 2012).

Krygiel, E, and Nies B. Green BIM: Successful Sustainable Design with Building Information Modeling. Indianapolis, Ind.: Wiley Pub., 2008.

Kymmell, W Building Information Modeling Planning and Managing Construction Projects with 4D CAD and Simulations. New York: McGraw-Hill, 2008.

Levy, S.. Project Management in Construction. 2012 ed. New York: McGraw-Hill, 1987.

LinkedIn 1. http://www.linkedin.com/groups/Is-state-art-far-enough-98421.S.133719309 (accessed November 26, 2012).

LinkedIn 2. http://www.linkedin.com/groups/Levels-Detail-LOD-as-defined-3919425.S.59035026 (accessed November 30, 2012).

McCarthy Building Companies: Commercial Construction Companies. http://www.mccarthy.com/about/leading-technology/bim-technology/ (accessed January 30, 2012).

Messer Construction Co. - BIM: The Future of Construction.. http://bim.messer.com/ (accessed January 16, 2012).

Micea.net AEC info mgmt. www.micea.net/modeling_v5.html (accessed November 26, 2012).

Mortenson Construction. http://www.mortenson.com/VDCProjectImpact.aspx (accessed January 30, 2012).

National Institute of Building Sciences. http://www.nibs.org/?page=about (accessed February 10, 2012).

Naoum, S. G.. Dissertation Research and Writing for Construction Students. Jordan Hill, Oxford, England: Butterworth-Heinemann, 1998.

Naumovich, D. "IDP and BIM go Hand in Hand." The Zweig Letter. http://www.gilbaneco.com/uploadedFiles/Home/Gilbane/News_and_Events/Publications/Archive/2011/ZW_Letter_BIM-IPD.pdf (accessed February 10, 2012).

Oldbury, J. " Seeking Clarity – Editing 6D, 7D and 8D BIM from our Vocabulary." Assemble The Big Bad BIM Blog. http://blog.assemblesystems.com/bid/168905/Seeking-Clarity-Editing-6D-7D-and-8D-BIM-from-our-Vocabulary (accessed November 26, 2012).

PR Newswire. http://www.prnewswire.com/news-releases/new-mcgraw-hill-construction-study-compares-building-information-modeling-in-western-europe-and-north-america-104278283.html (accessed November 30, 2012).

Revit Forum - Revit, BIM, Architecture & Engineering. . http://www.revitforum.org/out-there/2437-bim-world-problems.html (accessed November 29, 2012).

Rosenbloom, S. "How Does BIM Change Your Project Processes and Where Does Revit Fit In? | BIMuzer." BIMuzer. http://bimuzer.com/2011/04/06/how-does-bim-change-your-project-processes-and-where-does-revit-fit-in-2/ (accessed November 26, 2012).

Ryan Companies US, Inc.. http://www.ryancompanies.com/ryan/lean-and-green/ (accessed January 30, 2012).

Scarborough, W. "Chapter 7 Project Delivery." In *The CSI Project Delivery Practice Guide*, 112 - 114. Hoboken: John Wiley & Sons, 2011.

Skanska. http://www.usa.skanska.com/News--Press/Coast-to-Coast/Coast-to-Coast---no2_2011/ (accessed January 30, 2012).

Structure Tone. http://structuretone.com/ST/Index.nsf/vPages/BIM?OpenDocument (accessed January 30, 2012).

Sutherland, I. Sketchpad: a man-machine graphical communication system. New York: Garland Pub., 1980.

Swinerton Commercial Building Construction Services & General Contracting. http://www.swinerton.com/web/do/content/services/bim_vdc (accessed January 30, 2012).

Vico Software 1. http://www.vicosoftware.com/BIM-Level-of-Detail/tabid/89638/Default.aspx (accessed November 29, 2012).

Vico Software 2. http://www.vicosoftware.com/6d-bim-models/tabid/297171/Default.aspx (accessed November 26, 2012).

Vico Software 3. http://www.vicosoftware.com/model-based-estimating/tabid/88210/Default.aspx (accessed November 29, 2012).

Vico Software 4. http://www.vicosoftware.com/what-is-4D-BIM/tabid/88206/Default.aspx (accessed December 4, 2012).

Vico Software 5. http://www.vicosoftware.com/what-is-grayscale-bim/tabid/88203/Default.aspx (accessed December 4, 2012).

W.M. Jordan Company. http://www.wmjordan.com/services/virtual_construction.html (accessed November 16, 2012).

Walsh Construction & Archer Western Contractors. http://www.walshgroup.com/capabilities/bim.html (accessed January 30, 2012).

WBDG – The Whole Building Design Guide. http://wbdg.org/bim/nibs_bim.php (accessed February 10, 2012).

Webcor Builders. http://www.webcor.com/the-webcor-way/virtual-building-ipd/ (accessed January 30, 2012).

Weitz Company. http://www.weitz.com/services/virtual-design-and-construction/ (accessed January 30, 2012).

WSP Group. http://www.wspgroup.com/en/wsp-group-bim/BIM-home-wsp/ (accessed November 26, 2012).

Young, N. Smart Market Report: The Business Value of BIM. New York: McGraw Hill, 2009.

Zyskowski, P. "Why BIM? . . . Again?." Applied Software Blog. http://appliedsoftwareblog.blogspot.com/2012/01/why-bim-again.html (accessed November 29, 2012).

APPENDICES

APPENDIX A – GIANTS 300 TOP BIM CONTRACTORS

GIANTS 300 BIM CONTRACTORS

Rank	Company	2010 Revenue ($)
1	Turner Corporation, The	4,602,000,000
2	Jacobs	4,071,610,000
3	Fluor Corp.	2,657,929,000
4	Hensel Phelps Construction	2,457,747,200
5	Mortenson Construction	2,336,525,000
6	McCarthy Holdings	2,079,550,000
7	Tutor Perini Corp.	1,910,053,781
8	Walsh Group, The	1,661,675,412
9	Balfour Beatty US	1,614,274,619
10	Skanska USA	1,539,500,000
11	Suffolk Construction	1,269,200,000
12	Holder Construction Co.	1,192,140,000
13	DPR Construction	1,002,180,900
14	Barton Malow	1,001,377,404
15	JE Dunn Construction Group	961,875,000
16	Swinerton Builders	745,901,240
17	Lend Lease	608,663,134
18	Hunt Construction Group	577,500,000
19	Hoffman Corporation	549,375,000
20	Whiting-Turner Contracting Co., The	528,202,276
21	Weitz Company, The	501,121,076
22	Webcor Builders	483,602,400
23	Manhattan Construction Group	462,135,219
24	Pepper Construction Group	419,681,600
25	Gilbane Building Co.	413,845,380
26	C.W. Driver	384,523,200
27	Consigli Construction Co.	354,868,000
28	Bernards	350,250,000
29	Structure Tone	336,087,000
30	M+W U.S.	328,926,713
31	Haskell	314,039,539
32	Robins & Morton	297,160,000
33	Austin Commercial	285,280,752
34	Ryan Companies US	282,822,500
35	Beck Group, The	280,723,300
36	Yates Companies, The	273,264,000
37	Kitchell	244,073,160
38	Layton Construction	240,240,000
39	Messer Construction	189,921,000
40	Gray Construction	187,227,893
41	McGough Construction Co.	186,750,000
42	W. M. Jordan Co.	183,730,169
43	Brasfield & Gorrie	156,393,862
44	STV	141,750,000
45	URS Corp.	138,400,000
46	O'Neil Industries/W.E. O'Neil	138,286,500
47	Flintco	136,400,000
48	Absher Construction Co.	121,390,000
49	SSOE Group	117,936,000
50	Coakley & Williams Construction	117,141,559
51	KBE Building Corp.	74,700,000
52	Heery International	70,087,710
53	Hardin Construction	69,139,800
54	Rodgers Builders	67,052,000
55	Alberici Corp.	62,436,183
56	Kraus-Anderson Construction	60,600,000
57	New South Construction	60,080,000
58	IPS Integrated Project Services	60,011,200
59	Hardin Construction	58,768,830
60	Cogdell Spencer ERDMAN	56,587,217
61	S. M. Wilson & Co.	50,768,577
62	KBE Building Corp.	49,800,000
63	Hoar Construction	38,260,500
64	Wight & Company	32,734,787
65	Michael Baker Jr., Inc.	30,880,000
66	Linbeck Group	30,800,000
67	Harley Ellis Devereaux	29,930,000
68	EMJ Corporation	25,188,477
69	Choate Construction Co.	21,488,141
70	Harkins Builders	21,000,000
71	BETTE Companies, The	19,800,000
72	McShane Construction	18,511,045
73	Hill International	17,500,000
74	Atkins North America	12,840,000
75	Jones Lang LaSalle	12,200,000
76	Hunt Co.'s	11,131,597
77	CORE Construction Group	10,069,440
78	Doster Construction	5,781,000
79	Stalco Construction	3,205,250
80	E.W. Howell Co.	2,533,710
81	Zak Companies	333,078

APPENDIX B – FIELD BIM PRACTITIONER, MID-MANGEMENT AND EXECUVTIVE QUESTIONNAIRES

Field BIM Practitioner Questions

1- What are the top 3 advantages of BIM?
   a.
   b.
   c.
2- What are the disadvantages/ concerns of BIM?
3- For each of the following delivery methods what percentage of projects do you receive models from the design team?

   Design Bid Build (Hard Bid)
   Design Build
   Construction Manager at Risk (CMGC)
   Other
4- What percentage of projects do you generate models?

   Design Bid Build (Hard Bid)
   Design Build
   Construction Manager at Risk (CMGC)
   Other
5- Of the models received, what percentage of projects do you have to start from scratch?
6- What percentage of projects do you model your self-performed work?
7- 3D modeling – Please see table "Question 7".
8- Do you share your model with your trade partners/ sub-contractors?
9- Do you submit a model with your bid?
10- Do trade contractors ever take the lead in clash detection efforts?
11- Do you use BIM to track variances during construction?
12- Do you use the model to produce as builts?
13- Any other comments

Definition
Level 100 – Basic Geometric shapes
Level 200 – Equivalent to schematic drawings
Level 300 – Construction Drawings equivalent
Level 400 – Suitable for fabrication and assembly
Level 500 – Every individual component is modeled

Question 7		To what level of detail are you modelling for the following delivery methods? Please list which systems you are modelling at each level.
Design Bid Build	Level 100	
	Level 200	
	Level 300	
	Level 400	
	Level 500	
Design Build	Level 100	
	Level 200	
	Level 300	
	Level 400	
	Level 500	
CMGC	Level 100	
	Level 200	
	Level 300	
	Level 400	
	Level 500	
Self performed work	Level 100	
	Level 200	
	Level 300	
	Level 400	
	Level 500	
Other	Level 100	
	Level 200	
	Level 300	
	Level 400	
	Level 500	

MId Management Questionnaire - Part 1

The purpose of this questionnaire is to determine the current best practices of BIM. The questions below will be asked through the Webex interview that will be arranged. Please take a few minutes to read over these questions before the interview so that you can be prepared with any information you require. For part 1, we will be asking the frequency of use along with the software used if applicable.

	What percentage of projects do you use BIM for the following?					
Tasks/uses	90 -100	75 - 90	50-75	25 - 50	1 - 25	0
3D Modelling						
Scheduling						
Sequencing						
Cost exercises / Estimating						
Clash detection						
Team collaboration						
Site co-ordination with eqiupment and trades						
Constructability issues of designs						
Design change implications						
Quantity takeoffs						
Facilities management, EOM						
Walkthroughs						
Digital plans workstation off-site						
Digital plans workstation on-site						
Laser scanning						
Field BIM - ipads, tablets etc						
Site safety						
Prefabrication						
Waste reduction						
LEED/Green buildings						
Building life cycle						
X-Ray scanning						
Sonar scanning						
Cloud technology						
Virtual reality mock ups						
Global position software (GPS)						
Geographic Information System (GIS)						
Lift drawings						
As built drawings						
Sales						
Tracking materials off and on site						
Tracking time spent / punch cards						

Any other uses not mentioned above:

Mid management Questions Part 2

1- What are the top 3 advantages of BIM?
    a.
    b.
    c.
2- How do you involve trade contractors in your clash detection meetings?
3- Do you use it as a marketing tool and if so, how?
4- How do you collaborate with others using BIM?
5- How is BIM used on-site?
6- How are you organized to use BIM, select all those that apply
    a. Dedicated BIM team
    b. Each unit has a BIM expert
    c. Utilize BIM consultants
    d. Other, explain
7- How is the BIM process reviewed to create lessons learned?
8- What are your QA/QC controls on modeling?
9- When do you charge an additional fee for BIM services?
10- In what ways is your company planning on expanding its use of BIM? What are your next steps with BIM in your company?
11- What percentage of offices does your company currently have using BIM?
12- How long has your company been using BIM?

Questionnaire – Executive Level

1- What are the top 3 ways BIM is used in your company?
   i.
   ii.
   iii.
2- How has each of the above affected your company?
3- What percentage of your company's projects incorporate BIM services?
4- How do you decide on which projects to use BIM?
5- Do you require your sub-contractors to use BIM?
   Always
   Often
   Sometimes
   Never
6- How has BIM affected profitability?
7- How has BIM affected the construction time?
8- How has BIM affected change orders and litigation?
9- Why does your company value BIM?
10- Is there anything else you would like to add about BIM that will benefit our research into best practices?

APPENDIX C – LIST OF TOP 40 BIM CONTRACTORS

Position	Company Name	Position	Company Name
1	Turner	21	Weitz Company
2	Jacobs	22	Webcor Builders
3	Fluor Corporation	23	Manhattan Construction Group
4	Hensel Phelps Construction	24	Pepper Construction Group
5	Mortenson Construction	25	Gilbane Building
6	McCarthy Construction	26	C W Driver
7	Tutor Perini Corporation	27	Consigli Construction
8	Walsh Group	28	Bernards
9	Balfour Beatty US	29	Structure Tone
10	Skanska US	30	M+W US
11	Suffolk Construction	31	Haskell
12	Holder Construction	32	Robins and Morton
13	DPR Construction	33	Austin Commercial
14	Barton Marlow	34	Ryan Companies US
15	JE Dunn Construction Group	35	Beck Group
16	Swinerton	36	Yates Companies
17	Lend Lease	37	Kitchell
18	Hunt Construction	38	Layton Construction
19	Hoffman Corporation	39	Messer Construction
20	Whiting Turner Contracting	40	Gray Construction

APPENDIX D – USES OF BIM STATED BY CONTRACTORS' WEBSITES

BIM Use	Turner Corporation	Jacobs	Fluor Corp	Hensel Phelps Construction	Mortenson Construction	McCarthy Construction	Tutor Perini Corp	Walsh Group	Balfor Beatty US	Skanska USA	Suffolk Construction	Holder Construction	DPR Construction	Barton Malow	JE Dunn Construction Group	Swinerton Builders
No Information		•	•	•			•									
Design Change	•				•	•		•	•			•				
3D Modeling	•				•	•		•	•	•		•	•	•	•	•
Scheduling	•				•	•		•	•	•	•	•	•	•	•	•
Cost exercises / Estimating	•				•	•			•			•	•	•	•	•
Clash Detection	•				•	•		•	•	•		•	•	•	•	•
Facilities	•				•						•	•			•	•
Digital Plans					•					•			•			
Equipment	•				•	•			•			•			•	•
Laser Scanning					•	•				•			•			
Team Collaboration	•				•				•	•	•		•		•	•
Quantity Takeoffs	•				•				•	•		•	•			•
Site Co-ordination	•				•	•			•	•		•	•		•	•
On site Technology - Tablets					•	•				•				•		
Site Safety	•				•			•	•							
Prefabrication	•				•			•	•	•						
Waste Reduction	•				•			•								
Constructability	•				•				•		•	•	•	•		•
Walkthroughs												•				
LEED/Green buildings	•										•			•		•
Building Life Cycle	•															•
X-Ray																
Sonar																
GIS					•											
As Built Drawings	•				•											
Tracking Materials										•						
Tracking Time										•						

BIM Use	Lend Lease	Hunt Construction Group	Hoffman Corporation	Whiting Turner Contracting Co	Weitz Company	Webcor Builders	Manhatan Construction Group	Pepper Construction Group	Gilbane Building	C W Driver	Consigli Construction	Bernards	Structure Tone	M+W US	Haskell	Robins and Morton
No Information	•													•	•	
Design Change				•		•	•						•			
3D Modeling		•	•	•	•	•	•	•	•	•	•	•	•			•
Scheduling		•		•	•	•	•	•	•	•	•	•	•			•
Cost exercises / Estimating		•		•	•	•	•	•	•	•	•		•			
Clash Detection		•	•	•	•	•	•		•	•	•		•			•
Facilities		•					•	•			•					•
Digital Plans																•
Equipment		•														
Laser Scanning			•													•
Team Collaboration		•			•				•	•						
Quantity Takeoffs		•			•					•						
Site Co-ordination				•	•		•				•					•
On site Technology - Tablets																•
Site Safety				•												•
Prefabrication					•											
Waste Reduction					•											
Constructability					•	•			•	•						
Walkthroughs									•		•					
LEED/Green buildings					•											
Building Life Cycle																
X-Ray																
Sonar																
GIS																
As Built Drawings		•	•													
Tracking Materials																•
Tracking Time																•

BIM Use	Austin Commercial	Ryan Companies US	Beck Group	Yates Companies	Kitchell	Layton Construction	Messer Construction	Gray Construction	McGough Construction	W M Jordan	Brasfield & Gorrie	STV	URS Corp	O'Neil Industries/ W E O'Neil	Flintco	Absher Construction
No Information	•			•	•	•		•	•			•	•	•		•
Design Change		•	•							•						
3D Modeling		•	•				•			•	•				•	
Scheduling		•	•				•				•				•	
Cost exercises / Estimating		•	•				•				•				•	
Clash Detection			•				•			•						
Facilities			•				•								•	
Digital Plans																
Equipment							•			•						
Laser Scanning			•				•									
Team Collaboration		•								•					•	
Quantity Takeoffs							•				•					
Site Co-ordination							•									
On site Technology - Tablets																
Site Safety																
Prefabrication										•						
Waste Reduction																
Constructability							•									
Walkthroughs							•									
LEED/Green buildings											•					
Building Life Cycle															•	
X-Ray		•														
Sonar		•														
GIS							•									
As Built Drawings							•									
Tracking Materials																
Tracking Time																

BIM Use	SSOE Group	Coakley & Williams Construction	KBE Building Corp	Heery International	Hardin Construction	Rodgers Builders	Alberici Corp	Kraus-Anderson Construction	New South Construction	IPS Integrated Project Services	Cogdell Spenser Erdman	S M Wilson & Co	Hoar Construction	Wight & Company	Michael Baker Jr Inc	Linbeck Group
No Information			•	•	•		•		•		•	•		•	•	
Design Change						•							•			•
3D Modeling	•	•				•		•		•			•			•
Scheduling	•	•				•		•		•			•			•
Cost exercises / Estimating	•	•				•		•		•			•			•
Clash Detection	•	•				•		•		•			•			•
Facilities										•						•
Digital Plans																•
Equipment										•						•
Laser Scanning																
Team Collaboration		•						•		•			•			•
Quantity Takeoffs						•				•			•			•
Site Co-ordination		•				•		•					•			•
On site Technology - Tablets																
Site Safety																
Prefabrication													•			
Waste Reduction																•
Constructability								•		•			•			•
Walkthroughs	•					•		•								•
LEED/Green buildings	•									•						
Building Life Cycle										•						
X-Ray																
Sonar																
GIS																
As Built Drawings						•										
Tracking Materials																•
Tracking Time																

BIM Use	Harley Ellis Devereaux	EMU Corporation	Choate Construction Co	Harkin Builders	Bette Companies	McShane Construction	Hill International	Atkins North America	Jones Lang LaSalle	Core Construction Group	Doster Construction	Stalco Construction	E W Howell Co	Zak Companies	**TOTALS**
No Information	•	•		•	•	•	•	•			•	•	•	•	**37**
Design Change			•							•					**18**
3D Modeling			•						•	•					**40**
Scheduling			•						•						**38**
Cost exercises / Estimating			•						•						**33**
Clash Detection			•						•						**34**
Facilities									•						**17**
Digital Plans															**5**
Equipment															**12**
Laser Scanning															**8**
Team Collaboration			•							•					**21**
Quantity Takeoffs			•												**17**
Site Co-ordination			•												**21**
On site Technology - Tablets															**5**
Site Safety															**6**
Prefabrication															**8**
Waste Reduction															**5**
Constructability			•							•					**19**
Walkthroughs			•						•						**10**
LEED/Green buildings															**8**
Building Life Cycle															**4**
X-Ray															**1**
Sonar															**1**
GIS															**2**
As Built Drawings															**6**
Tracking Materials															**3**
Tracking Time															**2**