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Current BIM Practices of Commercial MEP Contractors

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ABSTRACT

Current BIM Practices of Commercial Contractors

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Building Information Modeling (BIM) use in the contracting industry has grown significantly in recent years. With this change in the construction industry, consensus has not been reached as to what BIM is, who is using it and what they are using it for. The purpose of this research was to determine current BIM practices of US-based commercial MEP contractors.

Executive, middle management, and field personnel were interviewed to determine the current BIM practices in their companies. The majority of companies interviewed were using BIM and most were using it on a significant portion of their projects. The majority of MEP contractors using BIM were seeing positive results in many of six key performance indicators, profitability, schedule duration, field efficiency, change orders, rework, and safety. The top uses of BIM for MEP contractors were clash detection coordination, prefabrication, design creation, and quantity take-off/cost estimating. Most MEP contractors have not yet incorporated BIM for scheduling, sequencing, or safety analysis. Additionally most MEP contractors did not have a formal BIM training program in their company.

Keywords: building information modeling, BIM, MEP, current practices, clash detection, prefabrication.

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1 INTRODUCTION

1.1 Background to the Problem

Recently Building Information Modeling (BIM) has become one of the most widely written about topics in construction. BIM software has been around, in some form, for over 30 years. Companies such as Graphisoft claim to have "ignited the BIM revolution in 1984 with ArchiCAD, the industry first software for architects" ("About Graphisoft", 2013). However, BIM has not been used by the mainstream construction industry until fairly recently. As recently as 2007 it was estimated that only 20% of designers used BIM (Holness 2008).

1.1.1 BIM – Definition

In any discussion regarding BIM there is difficulty defining BIM. Graphisoft's claim that they ignited the BIM revolution serves as a good example. The software at that time (1984) was little more than a way of drawing 3D lines instead of 2D lines. Eastman et al (2011,19) state that models that contain only 3D data and no (or few) object attributes do not count as BIM models. If you accept this definition, then Graphisoft's Archicad software was not actually a BIM modeling software.

Crotty (2012,3) gives a definition for BIM as a "computerized model of the proposed building in virtual 3D space, using intelligent components, inserted at precise orientations, into precise locations in this space." This definition requires that the model include various features in addition to the 3D capability. Gonchar (2007, 37) describes how BIM is transforming the construction industry and includes a definition that further refines the definition of BIM. This definition described it as "an object oriented digital representation of a building… a compilation of integrated and dynamic data that describes the functional and physical aspects of a building and its components."

This study defined BIM as follows: A building information model is a consistent model of the entire structure with dynamic objects that contain data and features that can be utilized in a consistent manner across the model. Drawing in 3D and having visual representations of objects is not sufficient to be classified as BIM.

1.1.2 Rapid Growth

BIM may not have become mainstream until recently but its rate of implementation has been rapid. Mcgraw-Hill (2013) has reported that as of 2009 nearly 50% of architects, engineers and contractors were using BIM. This was an increase of about 250% in a two year span. Increasing the significance of this rapid growth is the make-up of the construction industry. In his book about how BIM is transforming the construction industry Crotty stated, "Construction, however, is a notoriously fragmented industry with very low levels of market concentration" (2012) What this means is that no two or three organizations adopting BIM would result in this significant of a market penetration. The data was self-reported so it is possible that some contractors may have overstated their actual BIM use. Nevertheless, to realize close to a 250% increase in the usage of BIM a large number of different companies and organizations would have implemented BIM in their company.

1.1.3 BIM and the Construction Industry

The use of BIM is dramatically changing the construction workplace. Gonchar (2007, 37) described it as "a paradigm shift for design and construction. Its adoption forces examination of a host of practice and business issues." One of these business practices is the traditional Design-Bid-Build (DBB) delivery model. Eastman et al (2011, 18) stated "The DBB approach represents the greatest challenge to the use of BIM because the contractor does not participate in the design process and thus must build a new building model after design is completed." Other delivery methods such as the Design-Build or Integrated Project Delivery methods resolve this by including the contractor as a major participant in the design process. However, there are issues with using these contractual delivery methods as well. In an article about building owner's use of BIM, Tuchman quotes Jim Bostic about one of these issues:

> We are requiring architects, engineers, general contractors and sub-contractors to work together where there are no clear lines of demarcation. There is a long-standing lack of respect…and we have individuals with very strong personalities who are having difficulties conforming to the new paradigm that asks them to act as equals and partners with no hierarchy within the project delivery team. (Tuchman 2008, 28)

BIM is causing serious upheaval in the construction industry and is requiring the various members of the construction and design teams to rethink their relationships and strategies for working together.

1.1.4 BIM and the Specialty Trades

In addition to a need to re-examine which project delivery method the construction industry uses and the change in contractual relationships between the various parties, there is also the issue of varying degrees of BIM implementation. Alex Ivanikiw stated, "The steel fabricators are clearly out in front of the other trades. The mechanical and electrical specialty contractors are getting on board…The concrete, curtain-wall, and interiors people are well behind in adopting and implementing BIM." (Sawyer 2008, 36) This can create inconsistency on the construction project where some players are using BIM heavily and others not at all.

There is also a discrepancy in BIM use among different sized contractors of the same trade. Hanna, Boodai, and Asmar (2013) found that a significantly higher percentage of larger companies (over $10M in revenue) use BIM than smaller companies. BIM use varies not only based upon the trade but also upon the size of the company using BIM.

1.2 Purpose of the Research

With all of the variability and change in the construction industry there is very little consensus as to what BIM is, who is using BIM, and what they are using BIM for. The purpose of this research was to determine the current BIM practices used by commercial MEP contractors.

1.2.1 Research Subject – MEP Contractors

The research subject of MEP contractors, (mechanical, electrical, plumbing, and fire protection), was chosen for three reasons. First, Ivanikiw (Sawyer 2008) stated that MEP contractors were in the process of adopting BIM, and Young, Jones, and Bernstein (2008) found that Mechanical, Electrical and Plumbing (MEP) trades were among the highest adopters of BIM. Second, Hanna (2010) found that the MEP trades account for between 40-60% of the total project cost in commercial construction. In addition to this, Hanna (2010) found that rework, a significant cost in building construction, was most visible in the MEP trades. Third, the majority of BIM research has focused on the general contractor but has overlooked the trade contractors.

Due to the advancing level of adoption among these contractors and the critical role they play in the construction process this research was limited to U.S. based mechanical, plumbing, electrical and fire sprinkler trades in the commercial construction industry.

1.2.2 Questions

To accomplish this research the following questions were addressed.

*To what extent do commercial MEP contractors use BIM and how do they determine when to use it?

*Which software is used and for what purposes?

*Who creates and develops the model for the MEP trades?

*What are the advantages and challenges of BIM use?

*How has BIM use affected key performance indicators, (Profitability, schedule duration, field efficiency, change orders, rework, and safety)?

1.3 Delimitations/Limitation/Assumptions

1.3.1 Targeted Survey Group

Hanna, Boudai, and Asmar (2013) also found that BIM use was significantly higher in larger companies than in smaller companies. This research identified the practices used by MEP contractors that have already implemented BIM into their construction processes. Hanna, Boudai, and Asmar (2013) also indicated that larger companies were more likely to incorporate BIM. Therefore, this research focused on larger companies since they were more likely to be using BIM. The basis of identifying larger MEP contractors was the 2013 ENR “Top 600 Specialty Contractors” list (Tulacz 2013).

2 REVIEW OF RELATED LITERATURE

To understand the current practices used by commercial MEP contractors a comprehensive review of the current available literature was undertaken. The literature review consisted of a careful review of scholarly trade journals, peer reviewed journal articles, recent academic research performed on BIM, and recent industry studies.

2.1 BIM use among MEP Contractors

Lee, Dossick, and Foley, quoted a BIM professional as stating, “We are moving to a time when most major subcontractors are creating models for their work.” Hanna, Boodai, and Asmar (2013) surveyed 145 MEP subcontractors. This survey was particularly applicable to this study as it was done recently and applies to a similar demographic of contractor’s as this study. Therefore, it is necessary to summarize their findings.

Of the 145 respondents, Hanna, Boodai, and Asmar (2013) discovered that overall approximately 60% of MEP contractors were currently using BIM, though a higher percentage of electrical contractors use BIM when compared with mechanical contractors, (70% and 51% respectively). It was also found that BIM use was more common in larger companies when compared with smaller companies. (See figure 1).

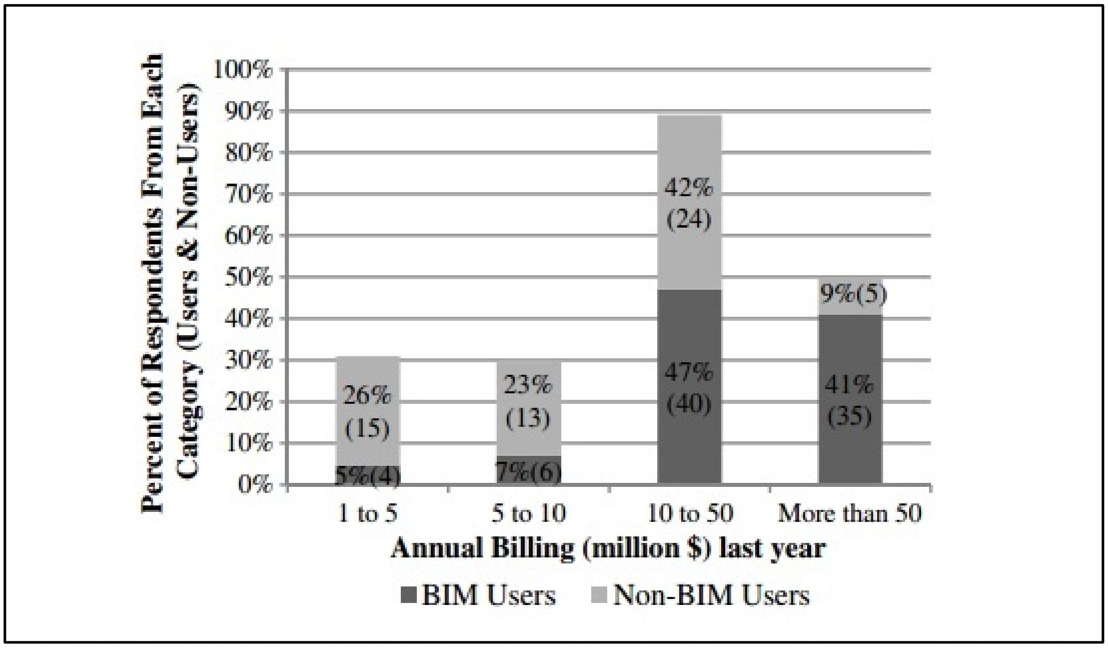

Figure 2-1: Company Size and BIM, Hanna (2013)

The companies that have revenue from $1-10 million have a significantly higher percentage of non-BIM users than BIM users. In the companies with over $10 million in revenue there was a higher percentage of BIM users than non-BIM users. Approximately 88% of BIM users fell into the over $10 million category.

Hanna, Boodai, and Asmar (2013), also surveyed the respondents about their relative expertise in BIM and found that 41% of respondents were considered beginners in BIM and 59% were considered experienced.

2.2 BIM and the Relationship Between the MEP Contractors, Designer, and Contractor

BIM affects the way in which architects, contractors, and subcontractors interact with each other. For the purpose of this research these relationships were examined in terms of: design creation and work collaboration.

2.2.1 Design Creation

Khanzode (2008) and Dossick and Neff (2010), found that the MEP BIM was created by detailers that work for the MEP contractor's instead of being provided by the general contractor, architects, or engineers. However, Dossick and Neff found this to be problematic since the architects and engineers were generally the ones that have the information needed to create these models. The general contractor was usually the entity responsible for facilitating the transfer of this information from the architects and engineers to the MEP subcontractors. However, Gu and London (2010) found that in most cases this information was still transferred by the exchange of 2D drawings. Gonchar (2007) found that even some architects that created a BIM delivered 2D drawings to the other members of the team. Then each MEP contractor often create their own model so there were generally many different models on a project.

2.2.2 Model Collaboration

Various sources portray BIM as a solution to the collaboration and communication issues that have plagued the AEC industry, Tuchman et al (2008), Ashcroft (2008), Eastman et al (2011). Dossick and Neff (2010) found that a BIM alone was not enough to create project collaboration. They stated:

> This counters much of the current rhetoric about the possibilities of BIM as a way to encourage closer collaboration among design and construction professionals. We found that although BIM technology tied MEP coordination team participants together through the coconstruction of consolidated models, there were organizational divisions that kept them from collaborating outside of this group. MEP detailers in both cases did not trust the digital information that they had, did not feel empowered to get the information for themselves, and felt forced to rely upon formal communication channels in which they were isolated from people who had the information they needed. (Dossick and Neff 2010, 463)

Dossick and Neff (2010) then continued on to explain that the leadership provided by the general contractor was still the deciding factor on how well the project collaboration succeeded. Hanna, Boodai, and Asmar (2013) found that most MEP contractors felt the MEP trades should lead in the modeling coordination process, but that the general contractor was usually contractually obligated to lead in the MEP coordination.

Another consideration of model collaboration was how the trades deal with their models and any conflicts between models. Khanzode (2008, 328) stated

> It was our observation that the detailers of other trades (plumbing/electrical/fire sprinklers) would much rather like to know how the HVAC equipment, duct shafts, and main ducts are routed since that has the most impact on how they will run their utilities.

This information allows them to route their systems around these main objects of the HVAC system. Khanzode (2008) suggested that the correct system for collaboration was the “big room,” a system in which the detailers for the various MEP contractors create their models side by side in one location. He argued that this would increase model collaboration and shorten the design schedule.

2.3 BIM Software

Software is the tool by which all of the “so-called magic” of BIM may be achieved. Khanzode (2008) and Lee, Dossick, and Foley (2013) found the following are potential software that could be used in BIM: Autodesk Revit Architecture, Navisworks, Autocad, Quickpen 3d Pipe Designer, CAD Duct, Fab Pro Mechanical Detailing, and SprinkCAD Sprinkler Modeling.

Hanna, Boodai, and Asmar (2013) found that the most used software among commercial MEP contractors were, from least to greatest, Autodesk Navisworks, Autodesk AutoCad MEP, and Autodesk Revit MEP, with 24, 26, and 28% usage respectively.

2.4 Level of Development

In 2013 the BIMForum revised the Level of Detail document and created a new document that changed from Level of Detail to Levels of Development (LOD). Bedrick (2013) detailed the changes as follows:

- LOD 100: The Model Element may be graphically represented in the Model with a symbol or other generic representation, but does not satisfy the requirements for LOD 200. Information related to the Model Element (i.e., cost per square foot, tonnage of HVAC, etc.) can be derived from other Model Elements.

- LOD 200: The Model Element is graphically represented within the Model as a generic system, object, or assembly with approximate quantities, size, shape, location, and orientation. Non-graphic information may also be attached to the Model Element.

- LOD 300: The Model Element is graphically represented within the Model as a specific system, object or assembly in terms of quantity, size, shape, location, and orientation. Non-graphic information may also be attached to the Model Element.

- LOD 350: The Model Element is graphically represented within the Model as a specific system, object, or assembly in terms of quantity, size, shape, orientation, and interfaces with other building systems. Non-graphic information may also be attached to the Model Element.

- LOD 400: The Model Element is graphically represented within the Model as a specific system, object or assembly in terms of size, shape, location, quantity, and orientation with detailing, fabrication, assembly, and installation information. Non-graphic information may also be attached to the Model Element.

- LOD 500: The Model Element is a field verified representation in terms of size, shape, location, quantity, and orientation. Non-graphic information may also be attached to the Model Elements.

Level of Development is an important part of the BIM process. A higher level of development means more time spent detailing the model but also provides potential for additional utility.

2.4.1 3D Modeling/Visualization

As previously stated Crotty (2012) defined BIM as a "computerized model of the proposed building in virtual 3D space." Inherent in this definition is that a BIM be 3D. Therefore, all contractors that use BIM use it in 3D, by definition. However, there was still discussion about 3D modeling as a part of BIM in the literature. Hartmann, Gao, and Fischer (2008, 780) said, "Practitioners can use 3D models of designs with complex geometry during meetings and other discussions to communicate issues that could not be adequately communicated using traditional 2D drawings." Hanna, Boodai, and Asmar (2013) also found that MEP trade contractors rated 3D visualization as the 2nd highest value added activity for BIM. In contrast, Gu and London (2010, 989) reinforced a 2007 AEC Bytes study that found that "3D visualization is not a major concern: most users participating in the survey value the accurate building information model [more] than visualization." In other words he found that the information and inherent capabilities of the model had more draw for contractors than the "pretty pictures."

2.4.2 Scheduling

Hartmann, Gao,and Fischer (2008) describe BIM scheduling as:

> Project managers can use 4D models that link 3D models with construction schedules or sequencing plans. Project managers can then use 4D models to see the parts of the project that have been completed and are under construction at a particular time, simulate the construction for certain time intervals, or virtually step through several construction sequences. (Hartmann, Gao, and Fischer 2008, 780)

Hartman, Gao, and Fischer's study found that "this is the most widely used application of 3D/4D models on the test case projects." (Hartmann, Gao, and Fischer 2008, 781) Lee, Dosick, and Foley (2013, 271) stated that "One of the most important skills of BIM is…linking the BIM files with the Primavera or Microsoft Project files." However, both of these previous studies focused more on general contractor usage.

Hanna, Boodai, and Asmar (2013) found that "more efficient use of time" was rated the fourth highest value generating activity for BIM among MEP contractors. Hanna, Boodai, and Asmar (2013), however, do not specify to what degree they were using BIM for this particular area of emphasis.

2.4.3 Sequencing

For the purposes of this research construction sequencing was similar to scheduling but involves the specific order of installation for various building components. Azhar (2011, 244) stated that BIM "can be effectively used to coordinate material ordering, fabrication, and delivery schedules for all building components. He did not, however, determine whether contractors were actually using BIM for this purpose or not. Post (2011) cites an incident in which the architect and MEP engineer used BIM to fit the building's MEP system into the ceiling plenum, but they did not tell the contractor that the fit depended on a very specific installation sequence. The result of this was an MEP system that did not fit. BIM could be used for MEP sequencing but that it can be problematic if not properly communicated to all parties.

2.4.4 Quantity Take-off and Cost Estimating

Cost estimating was a crucial part of the pre-construction phase of any project and could significantly affect design decisions. Popov et al. (2006) described the process that was commonly used. A building is designed that meets the owner's requirements and then a cost estimate is created. Generally this estimate was higher than expected and this requires the building be redesigned to lower the costs. Due to the amount of time and expense this takes contractor's/owner's were always looking for ways to provide an accurate estimate earlier in the design process.

Ku and Mills (2010) indicates that BIM was used to assist in construction estimating but does not cite specific examples of how, when, or by whom. Sabol (2008, 2), states that "BIM can provide accurate and automated quantification, and assist in significantly reducing variability in cost estimates." Sabol (2008, 14) also states that BIM "offers the capability to develop project cost information with more accuracy throughout the entire building lifecycle." The focus of Sabol (2008), however, were general contractors and the study does not specify how or if the information applies directly to MEP contractors.

Despite the promise that BIM has shown in commercial cost estimating many contractors are not utilizing it. Beveridge (2012), found in a survey of commercial contractors that over half of them used BIM in less than 50% of their cost estimate, though all of them state they use it at least a little.

The quantity take-off (QTO) is a large part of the cost estimating process and can "require as much as 50% to 80% of a cost estimator's time on a project," (Sabol 2008, 2). Monteiro and Martins (2013, 240) stated that "BIM is perhaps the best way to automate QTO." However, the article later stated that the current tools can't get measurements of curved MEP elements. This made a BIM quantity take-off for MEP trade contractors less useful.

2.4.5 Clash Detection

In the review of related research nearly every article that speaks about BIM mentioned clash detection. To understand BIM's utility for clash detection it is important to understand how clash detection was done traditionally. Tabesh and Staub-French (2006) indicates that the previous practice involved a lengthy process of overlaying transparent 2D drawings of each system over a light table in a series of coordination meetings. Tabesh and Staub-French also described the process as time-consuming and error prone. The 2D drawings did not contain elevation information and it was difficult to recognize clashes with only a 2D view of the project.

Hanna, Boodai, and Asmar (2013) performed research specific to MEP trade contractors and found that clash detection was the top activity for which BIM produces value. The study asked MEP contractors rate the various activities for which they use BIM, clash detection was approximately 10% higher than the next highest rated activity.

Hartmann, Gao, and Fischer (2008) found that BIM clash detection reduced requests for information, (RFI), from 60% to 80%, when compared to non-BIM projects. This article also described one case study in which there was not a single field change order due to conflicts among the MEP systems. Khanzode (2008) found similar results in his case study of a large healthcare project. In this project there were also zero field change orders due to conflicts and a significant reduction in RFI's.

2.4.6 Prefabrication

Another potential use for BIM is to assist in the prefabrication of building components. Sacks et al. (2010, 969) stated, "It [BIM] can also be used to support prefabrication and assembly of high tolerance components. In addition to this Leite et al. (2011) not only found that prefabrication was possible with BIM but listed it as one of two preconstruction benefits to BIM. The process to use BIM for prefabrication is as follows:

> On projects with complicated geometrical features the 3D models were even used as direct input for the offsite production of building components. In this way the exact dimension could be transmitted to the factory and the architect could ensure that the offsite fabrication yard produced building parts within the required tolerances. (Hartmann, Gao, and Fischer 2008, 781).

Khanzode (2008), demonstrated the possibilities of BIM prefabrication. The mechanical contractor in his case study was able to reduce labor costs between 5% and 25% on the various parts of his scope of work. The mechanical contractor attributed this savings to the amount of prefabrication that was performed due to the use of BIM, and returned about $500,000 of a $9.4M contract.

2.4.7 Safety

Lee, Dossick, and Foley (2013) states that BIM was used to illustrate safety plans. However, Suermann and Issa (2009) performed a survey of construction and design professionals about various key performance indicators (KPI) and found that only 53.7% of respondents indicated that BIM improved safety as a KPI. Rajendran and Clark (2011, 46) stated that "the construction industry has yet to look at BIM as a tool to improve worker safety." Both of these sources indicated that BIM was not being significantly used to improve safety on the jobsite.

Rajendran and Clark (2011), however, noted two ways in which BIM could help MEP contractors reduce risk. The first was the reduction of re-work. The use of BIM has been shown to reduce rework and construction change orders (Hartmann, Gao and Fischer 2008: Khanzode 2008).. Rajendran and Clarke (2011) noted that less rework was better for safety. This was due to less time spent on field work, and the fact that "rework can cause workers to lose focus, which increases the chances of incidents and injuries." (Rajendran and Clarke 2011, 47) The second method of risk reduction which Rajendran and Clark (2011) noted was in pre-task planning. He cited an example of a project where hot and cold water pipes were installed in the ceiling. The various trades in this example were able to identify several areas of safety concern and plan for them accordingly.

Additional studies, (see Zhang et al 2013 and Qi et al. 2011), suggest that BIM was underutilized in planning for construction safety and preventing workplace injuries. These studies also detail the manners in which BIM could be utilized to create a digital safety design.

2.4.8 As-Built Documents

Goedert and Meadati (2008, 515) stated that, "BIM could eventually become the sole source of information including facilities management and planning," in relation to building documentation. Additionally Goedert and Meadati (2008, 509) explained, "The BIM is an excellent tool for data management capable of information retrieval and display in a format consistent with either the constructor or owner." Azhar (2011, 243) also made the point that the BIM could be used for "renovations, space planning, and maintenance operations." He argued that the design and construction information contained in BIM would be useful for the continuing facilities management. Goedert and Meadati (2008, 509), however, found that "little has been done to implement BIM beyond the use of these models."

2.5 BIM and Key Performance Indicators

Chan and Chan (2004) found that the top three performance indicators for the construction industry were cost, time and quality, adding that other performance indicators such as safety were increasing in importance. For this research six key performance indicators were considered: 1: Profitability, 2: Project Duration, 3: Field Efficiency, 4: Change Orders, 5: Rework, and 6: Jobsite Safety. This was not a comprehensive list of potential performance indicators in the construction industry but these were the KPI examined in this research.

2.5.1 BIM and Profitability (Cost)

Businesses exist to make a profit. Therefore any business tool should be considered in light of its ability to influence company profits. PR Newswire (2013) found that 63% of North American BIM users perceived a positive return on BIM investment. If the findings were narrowed to BIM users who formally measure BIM return on investment (ROI) the number climbed to 82%. Various case studies and surveys found the BIM ROI to be between 16% and 1653%. Focusing on MEP contractors there was significantly less information available. However, Khanzode (2008) performed a case study on a large healthcare project and found that the use of BIM allowed the mechanical contractor to come in $500,000 under his $9.4M bid. From the literature, BIM has the ability to reduce the cost of construction and increase profits.

2.5.2 BIM and Project Duration

The ability of BIM to be used as a scheduling tool has already been explored in this literature review. This section explores if BIM has an effect on MEP project duration. Some of this effect may be caused by use of BIM as a scheduling tool but other features could factor in: reduced re-work due to fewer field conflicts, increased design time to model the various components, prefabrication, etc.

Various studies found BIM to reduce the project duration, (Azhar 2011: Popov et al. 2006: Suermann and Issa 2009). However, each of these studies were focused on contractors in general and not specifically on MEP contractors. Hanna, Boodai, and Asmar (2013) research focused specifically on commercial MEP contractors found that more efficient use of time was the fourth ranked benefit to BIM by the contractors in the study.

2.5.3 BIM and Change Orders/Rework

Suermann and Issa (2009) found that 90% of contractors felt that quality control and reduction of rework was the highest rated indicator of performance on a job.

Popov et al. (2006, 98) stated that "In quality aspect using BIM the user has improved coordination between documents, between disciplines, and across the entire team reduces errors and omissions." This leads to lower rework, and change orders. Leite et al. (2011, 602), described this benefit as, "during construction these benefits include less rework, reduction in requests for information, and change orders." Hartmann, Gao, and Fischer (2008) also found this to be the case.

2.5.4 BIM and Safety

Safety has already been fully examined earlier in this section. It is included again here merely to indicate that it is one of the Key Performance Indicators tracked in this research.

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3 METHODOLOGY

3.1 Methodology

From the literature review and consulting with industry experts it was apparent that no single individual in a large commercial MEP contractor would be able to provide a comprehensive view about the current practices of BIM usage throughout a company. Therefore, the survey was structured into three parts that were conducted with personnel at the following levels within a company: an executive, a middle manager, and a field employee.

It was understood that in many smaller construction companies employees may function at multiple levels. If an employee filled more than one role and there was not a better option available, then that employee was asked to answer multiple levels of the survey.

The initial surveys were compiled from the literature review. Questions were formulated based on previous research performed with general contractors and noted gaps in the literature. After the initial questions were developed they were reviewed and edited by a committee of university professors who teach construction management. The survey was then administered to two MEP professionals and the questions were once again refined by the committee based on the MEP professionals' responses. Appendix A contains a copy of the three surveys.

This study was intended to determine current BIM practices of a select group of commercial MEP contractors, consisting of companies from the ENR top 600 specialty contractors. Only descriptive statistical analyses were performed in this study.

3.1.1 Executive Survey

An executive-level survey was conducted with owners and top-level managers within the company. The purpose of this survey was to gain a companywide understanding of several key aspects of BIM.

3.1.2 Middle-Management Survey

This middle-managers', (e.g. BIM managers, senior project managers, etc), survey focused on detailed aspects of BIM that were unlikely to be known by executive or field personnel. It was anticipated that most of the initial contacts with the companies surveyed would occur at the middle-management-level, so question one, "Does your company use BIM?" was included at this level to determine if the company used BIM. However, if the initial company contact happened at a different level of the questionnaire, this question was asked of that individual instead.

3.1.3 Field Survey

The field personnel survey, (BIM detailers, superintendents, assistant project managers) focused on specific uses of BIM likely not known by middle managers or executives. For example, a company executive might know the name of a BIM software program but might not have an understanding of its application.

3.1.4 Phone Survey

After compiling and testing the surveys, it became apparent that there would be value in the ability to clarify the questions in order to obtain more useful data from the survey participants. Therefore, a phone survey was determined to be the best method in which to collect more detailed responses.

3.2 Selection of Survey Participants

Hanna, Boudai, and Asmar (2013) found that BIM use was significantly higher in larger companies than in smaller companies. Therefore, the research focused on larger commercial MEP contractors to maximize likelihood the participant's use of BIM. For this reason the participants were selected from the ENR top 600 Specialty Contractor's list, filtered by MEP contractors. Phone numbers and names of individuals who worked at these companies were collected by beginning at the top of the list and working down to smaller companies until 30 companies responded to the survey.

3.3 Data Collection and Recording

Data was collected by phone interviews. Participants were asked the questions on the survey that applied to their position(s) in the company. Permission was requested from the participants to record the phone calls so that their responses could be transcribed at a later time. After transcription their answers were compiled and analyzed.

4 FINDINGS

To facilitate the production of a publishable journal article this chapter was written in preparation for submission of a peer-reviewed journal article. Therefore chapters 1-3 are restated in an abbreviated format. This chapter also includes the more relevant findings of the research and the conclusions from those findings. The following chapter includes the remainder of the research findings, additional conclusions, and potential for future research.

4.1 Introduction

Recently Building Information Modeling (BIM) has become a widely written topic in construction. However, BIM has not been adopted by the mainstream construction industry until fairly recently. As recently as 2007 it was estimated that only 20% of designers used BIM (Holness 2008).

BIM may not have become mainstream until recently but its rate of implementation has been rapid. Mcgraw-Hill has reported that as of 2009 nearly 50% of architects, engineers and contractors are using BIM (PR Newswire 2013). This was an increase of about 250% a two year span. Increasing the significance of this rapid growth is the make-up of the construction industry. In his book about how BIM is transforming the construction industry, Crotty (2012) states, “Construction, however, is a notoriously fragmented industry with very low levels of market concentration.” What this means is that no two or three organizations adopting BIM would result in this significant of a market penetration. The data in this study was self-reported so it was possible that some contractors may have overstated their actual BIM use. Nevertheless, to realize a 250% increase in the usage of BIM a large number of different companies and organizations would have had to implement BIM in their company.

4.1.1 Purpose of the Research

With all of this variability and change in the construction industry there was very little consensus as to what BIM is, who was using BIM, and what they were using BIM for. The purpose of this research was to determine current BIM practices of US-based commercial MEP contractors.

4.1.1.1 Research Subject – MEP Contractors

The research subject of MEP contractors, (mechanical, electrical, plumbing, and fire protection), was chosen for three reasons. First, Ivanikiw (Sawyer 2008) stated that MEP contractors were in the process of adopting BIM, and Young, Jones, and Bernstein (2008) found that Mechanical, Electrical and Plumbing (MEP) trades were among the highest adopters of BIM. Second, Hanna (2010) found that the MEP trades account for between 40-60% of the total project cost in commercial construction. In addition to this Hanna (2010), found that rework, a significant cost in building construction, was most visible in the MEP trades. Third, the majority of BIM research has focused on the general contractor, but has overlooked the trade contractors.

Due to the increasing level of adoption among these contractors and the critical role they play in the construction process, this research was limited to commercial mechanical, plumbing, electrical, and fire sprinkler contractors.

4.1.2 BIM Use Among MEP Contractors

Lee, Dossick, and Foley (2013, 273), quoted a BIM professional as stating, "We are moving to a time when most major subcontractors are creating models for their work." Hanna, Boodai, and Asmar (2013) reported a survey of MEP subcontractors with 145 respondents. This research was particularly applicable to this study as it was done recently and applies to a similar demographic of contractor's as this study.

Of the 145 respondents approximately 60% are currently using BIM (Hanna, Boodai, and Asmar 2013). Hanna, Boodai, and Asmar (2013, 141), also surveyed the respondents about their relative expertise in BIM and found that "41% of respondents can be considered beginners in BIM expertise and 59% can be considered experienced."

4.1.3 Design/Model Creation

Khanzode (2008) and Dossick and Neff (2010), found that the MEP BIM was created by detailers that work for the MEP contractors instead of being provided by the general contractor, architects, or engineers. However, Dossick & Neff (2010) found this to be problematic since the architects and engineers generally have the information needed to create these models. The general contractor was usually the entity responsible for facilitating the transfer of this information from the architects and engineers to the MEP subcontractors. Gu and London (2010) found that in most cases this information was still transferred by the exchange of 2D drawings. Gonchar (2007) found that even some architects that create a model delivered 2D drawings to the other members of the team. Then each MEP contractor creates its own separate model, so there were generally many different models on a project.

4.1.4 Applications of BIM

Through a literature review, the following applications were identified as likely applications of BIM among MEP contractors: coordination/clash detection, prefabrication, 3D modeling/visualization, quantity take-off and cost estimating, scheduling/sequencing, and safety analysis.

4.1.4.1 Clash Detection

Nearly every article that spoke about BIM mentioned clash detection. Hanna, Boodai, and Asmar (2013), performed research specific to MEP trade contractors and found that clash detection was the top activity for which BIM produces value, and clash detection was rated approximately 10% higher than the next-highest-rated activity.

4.1.4.2 Prefabrication

Another potential use for BIM was to assist in the prefabrication of building components. Sacks et al (2010, 974) stated, "It [BIM] can also be used to support prefabrication and assembly of high tolerance components." Leite et al. (2011) found that prefabrication was not only possible with BIM but it was one of two preconstruction benefits to BIM. The process can be described thus:

> On projects with complicated geometrical features the 3D models were even used as direct input for the offsite production of building components. In this way the exact dimension could be transmitted to the factory and the architect could ensure that the offsite fabrication yard produced building parts within the required tolerances. (pg 781).

Khanzode (2008) was able to demonstrate the possibilities of BIM prefabrication. The mechanical contractor in this case study was able to reduce labor costs between 5% and 25%.

The mechanical contractor attributed the savings to the amount of prefabrication that was performed due to the use of BIM, and returned about $500,000 on a $9.4M contract to the building owner.

4.1.4.3 3D Modeling/Visualization

Crotty (2012) defined BIM as a "computerized model of the proposed building in virtual 3D space." Inherent in this definition was that a BIM be 3D. Therefore, all MEP trade contractors that use BIM are modeling in 3D, by definition. However, there was still discussion about 3D modeling. Hartmann, Gao, and Fischer (2008, 780) said, "Practitioners can use 3D models of designs with complex geometry during meetings and other discussions to communicate issues that could not be adequately communicated using traditional 2D drawings." Hanna, Boodai, and Asmar (2013) found that MEP trade contractors rated 3D visualization as the 2nd highest value-added activity for BIM. However, Gu and London (2010, 989) reinforced a 2007 AEC Bytes study that found that "3D visualization is not a major concern: most users participating in the survey value the accurate building information model (more) than visualization." In other words, Gu and London (2010) found that the information and inherent capabilities of the model had more benefit for contractors than the "pretty pictures."

4.1.4.4 Quantity Take-Off and Cost Estimating

Cost estimating is a crucial part of the pre-construction phase of any project and can significantly affect design decisions. Ku and Mills (2010), state that BIM was used to assist in construction estimating but does not cite specific examples of how, when, or by whom. Sabol (2008, 2), states that "BIM can provide accurate and automated quantification, and assist in significantly reducing variability in cost estimates." Sabol (2008, 14) states that BIM "offers the capability to develop project cost information with more accuracy throughout the entire building lifecycle." (Sabol, 2008, 2) The focus of Sabol (2008) however, was general contractors and does not specify how or if the information applied directly to MEP contractors.

The quantity take-off (QTO) was a large part of the cost estimating process and could "require as much as 50% to 80% of a cost estimator's time on a project." (Sabol 2008, 2) Monteiro and Martins (2013, 240) stated that "BIM is perhaps the best way to automate QTO." However, the same article later stated that the current tools can't get measurements of curved MEP elements. This made BIM quantity take-off for MEP trade contractors less appealing.

4.1.4.5 Scheduling/Sequencing

Hartmann, Gao, and Fischer described BIM scheduling as:

> Project managers can use 4D models that link 3D models with construction schedules or sequencing plans. Project managers can then use 4D models to see the parts of the project that have been completed and are under construction at a particular time, simulate the construction for certain time intervals, or virtually step through several construction sequences. (Hartmann, Gao, and Fischer 2008, 780)

They also found that "this is the most widely used application of 3D/4D models on the test case projects." Lee, Dossick, and Foley (2013, 271) stated that "one of the most important skills of BIM is…linking the BIM files with the Primavera or Microsoft Project files." Both of these studies, however, focused on general contractor usage.

4.1.4.6 Safety

Lee, Dossick, and Foley (2013) state that BIM was used to illustrate safety plans. However, Suermann and Issa (2009) performed a survey of construction and design professionals about various Key Performance Indicators (KPI) and found that only 53.7% of respondents indicated that BIM improved safety as a KPI. Rajendran and Clarke (2011, 46) stated that “the construction industry has yet to look at BIM as a tool to improve worker safety. Both of these sources indicate that BIM was not being significantly used to improve safety on the jobsite. There were also various studies, (Zhang et al. 2013 and Qi et al. 2011), which suggested that BIM was underutilized in planning for construction safety and preventing workplace injuries.

4.1.5 BIM and Key Performance Indicators

Chan and Chan (2004) found that the top three performance indicators for the construction industry were cost, time and quality, adding that other performance indicators such as safety were increasing in importance. For this research six key performance indicators were considered: 1): Profitability, 2): Project Duration, 3): Field Efficiency, 4): Change orders, 5): Rework, and 6): Jobsite Safety. This was not a comprehensive list of potential performance indicators in the construction industry, but these were the KPI examined in this research.

4.2 Methodology

From the literature review and consulting with industry experts it was apparent that no single individual in a large commercial MEP contractor would be able to provide a comprehensive view about the current practices of BIM throughout the company. Therefore, the survey was structured into three parts that were conducted with personnel at the following levels within a company: an executive, a middle manager, and a field employee.

It was understood that in many smaller construction companies employees may function at multiple levels. If an employee filled more than one role and there was not a better option available, then that employee was asked to answer multiple levels of the survey.

The initial survey was compiled from the literature review. Questions were formed from similar research performed with general contractors and noted gaps in the literature. After the initial questions were developed they were reviewed and edited by a committee of construction educators. The survey was then given to two MEP professionals and the questions were once again refined by the committee based on their answers. Appendix A contains a copy of the three surveys.

This study was not intended to project to a population, but rather to determine current BIM practices of a select group of commercial MEP contractors. Therefore, no inferential statistical analysis was conducted.

4.2.1 Survey Participants

This research was limited to commercial MEP contractors with an emphasis on larger contractors, in order to maximize likelihood of BIM use. For this reason the majority of participants were selected from the ENR Top 600 Specialty Contractor’s List. Phone numbers and names of individuals who worked at each company were collected through various means. These individuals were contacted and asked to participate in the survey. It was difficult to contact the right individuals in the companies by cold calling companies from the Top 600 list. Therefore, when the correct individuals were able to be contacted, they were asked to refer other individuals at MEP companies that used BIM. This expanded the survey pool and facilitated surveying other MEP contractors using BIM.

4.2.2 Data Collection and Recording

Data was collected by a phone interview. Participants were asked the questions on the survey that applied to their position in the company. Permission was requested from the participants to record the phone calls so that their responses could be transcribed at a later time.

4.3 Findings

The purpose of this research was to determine the current practices of commercial MEP contractors with respect to BIM. Thirty companies were contacted and participated in the survey. Thirteen of the respondents were electrical contractors, eleven were mechanical contractors, three were fire protection contractors, one was a BIM consultant that served the MEP trades, and one was exclusively a plumbing contractor. (Most mechanical contractors included the plumbing in their scope of work). Finally, an employee of a general contractor, who was recently employed by an electrical firm, also participated in the survey. Of the 30 respondent companies financial data was available for 18 companies. The mean annual revenue was $405.16 million. The range of revenue was between $90.5 million and $2+ billion.

From these 30 companies 21 individuals answered the executive survey, 23 answered the middle-management survey, and 21 answered the field-level survey. Their responses are summarized in the following sections.

4.3.1 Company BIM Use

During the course of the research, there were several instances where the company's middle manager and the field person were the same individual. Also, the middle managers and the field personnel responses were very similar. Therefore, in some instances their responses were combined.

Twenty-one of the respondents to the middle management survey and an additional four from field level survey, where a middle manager response was not available, gave detail as to what percentages of their jobs were using BIM see Figure 4-1.

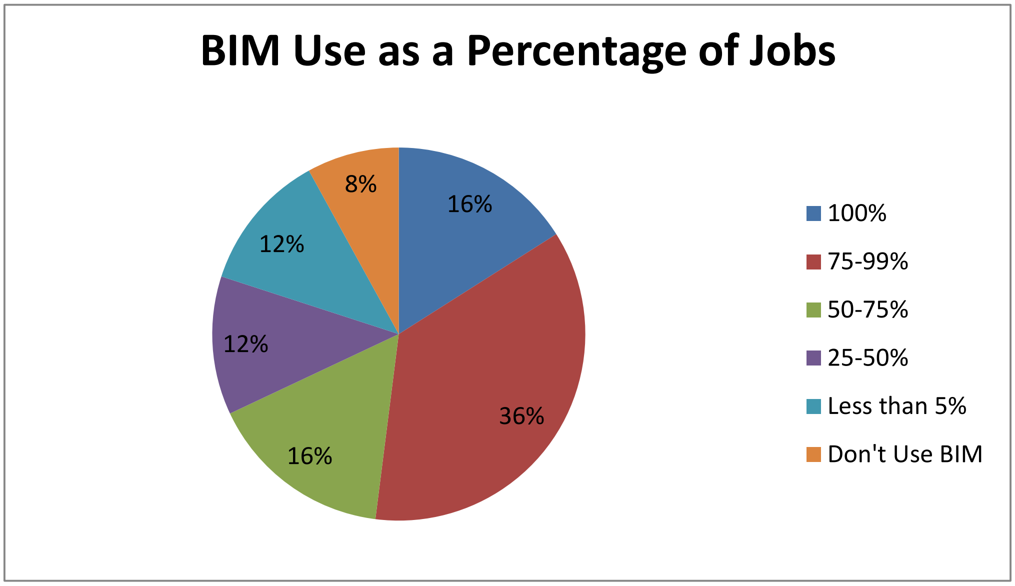

Figure 4-1: BIM Use as a Percentage of Total Jobs

Over half of participants used BIM on 75% or more of their jobs and 20% of respondents either didn't use BIM or used it on less than 5% of jobs. Most of the respondents who were using BIM on less than 75% of their projects mentioned that they were expecting their BIM use to increase in the near future or they were just beginning to use BIM in their company.

4.3.2 Common Uses of BIM

One of the primary purposes of this research was to determine how MEP contractors were using BIM. The executive respondents listed the top three ways (in priority order) that BIM was used in their company. Their answers were compiled and weighted by assigning three points to their first answer, two points to their second answer, and one point to their third answer see Figure 4-2.

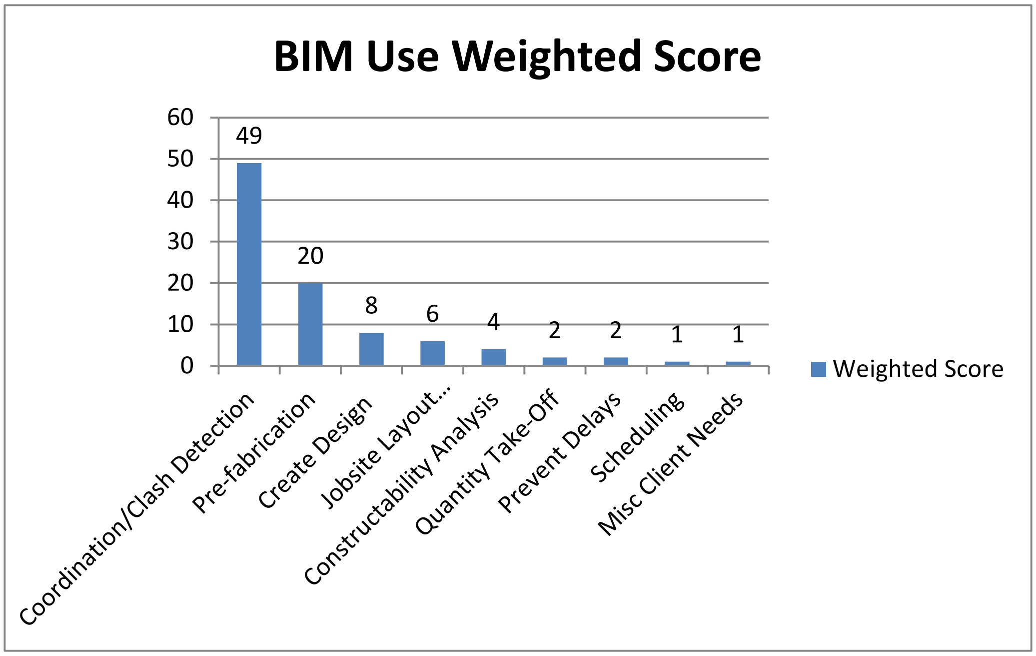

Figure 4-2: Executive: BIM Use Among MEP Contractors.

Middle managers were asked about the use of BIM for prefabrication and QTO/estimating in their companies. Field personnel were asked about the use of BIM for clash detection, production of as-built documents, prefabrication, scheduling, and safety analysis see Figure 4-3.

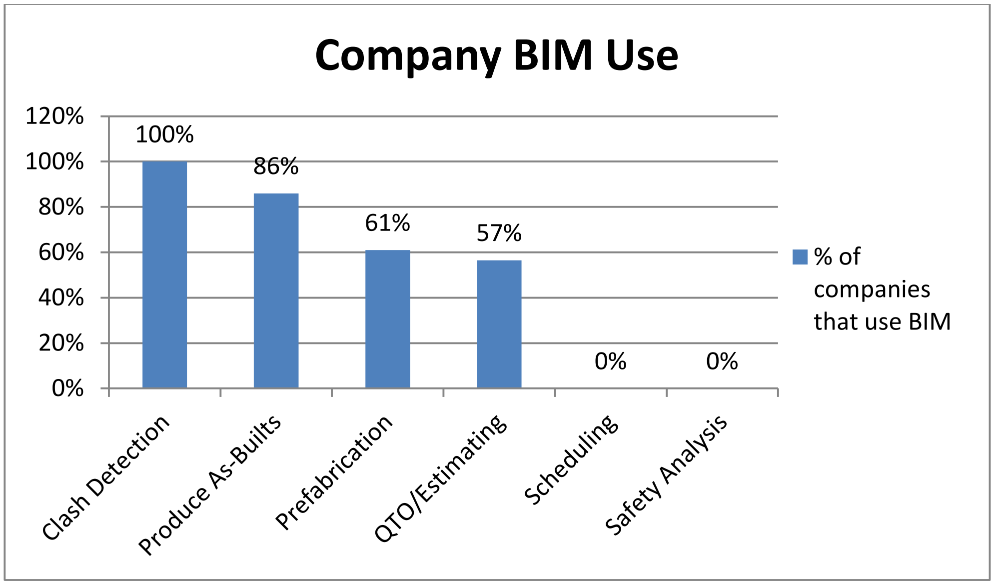

Figure 4-3: Middle-Management/Field: Specific Uses of BIM

Coordination/clash detection was the number one use of BIM in the MEP construction industry among all survey respondents. Many of the contractors who responded to the survey used the phrases BIM and coordination interchangeably as if BIM were the same things as trade coordination. Four of the respondents only used BIM for coordination and nothing else. From all participant groups of this survey, coordination and clash detection were the most mentioned and most understood uses of BIM.

Prefabrication was second most mentioned response and in several cases it was mentioned ahead of coordination as the most used aspect of BIM by executives. Middle-management and field personnel indicated that prefabrication was used third most use of BIM.

There was a disconnect between the answers of middle-management and executives when it came to QTO/cost estimating. Executives only gave it a weighted score of two regarding it as one of their uses of BIM. Middle managers, however, indicated that BIM was used for

QTO/cost estimating by over half of the companies. This makes QTO the same level of usage as prefabrication which was one of the more common uses of BIM.

Although the remaining items fall far behind coordination, prefabrication and QTO/cost estimating, the respondents supplied some notable information concerning the other uses of BIM. "*Create design*" was only mentioned in the design-build setting where MEP contractors were both designing and installing their own systems.   "*Jobsite layout*" was referring to the use of a Total Robotic Station with a downloaded BIM model being used to lay out hangers, supports, sleeves, etc, for installation. Jobsite layout received more votes than creating design (5 to 3) and only falls behind it because create design received higher place votes.

4.3.3 Software

Field personnel were asked to identify what software they use to create their models see Figure 4-4.

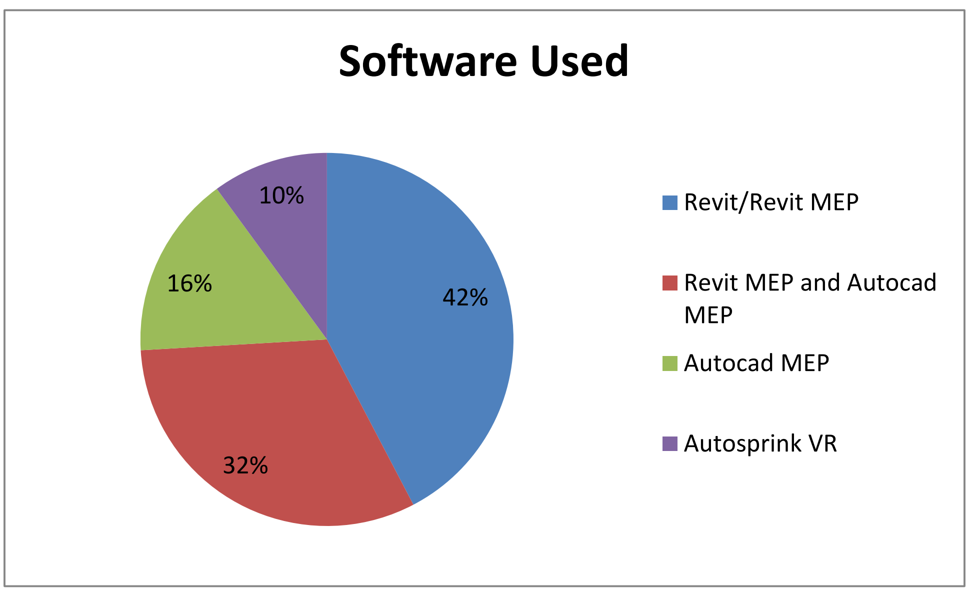

Figure 4-4: Field: Software Used to Model.

4.3.4 Advantages to BIM Use/Value of BIM

The executive survey asked, "Why does your company value BIM?" In the other two surveys middle management and field personnel were asked to list the top three advantages to BIM in priority order. The answers received were very similar and a comparison of the three shows interesting trends. Figure 4-5 shows the results of the executive level answers. The numbers in this chart represent the number of times an executive mentioned that item as a reason to value BIM.

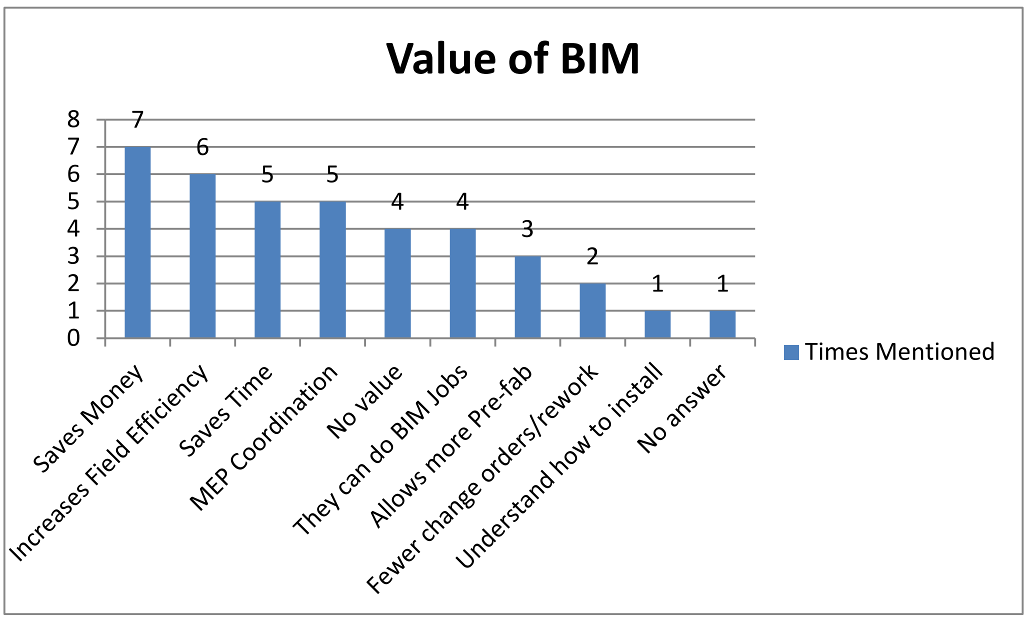

Figure 4-5: Executive: "Why Does Your Company Value BIM?"

Figure 4-6 shows the middle-management and field-level responses to the top three advantages to BIM use. Their answers were compiled and weighted by assigning three points to their first answer, two points to their second answer, and one point to their third answer.

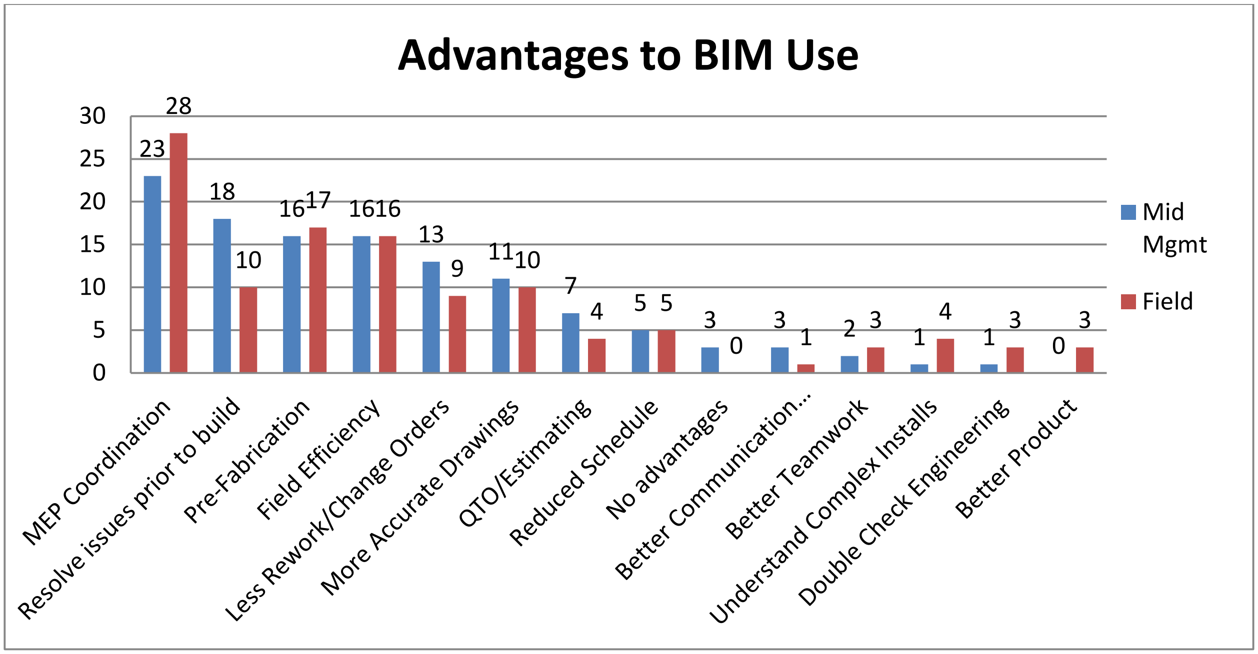

Figure 4-6: Middle Management/Field: Top 3 Advantages to BIM.

In Figure 4-6 the middle management responses and field level responses were very similar. The top 6 responses are the same for both groups. The order was slightly different, and the weighted scores were slightly different, but they generally agree on the advantages to BIM use. It should be noted that there was one middle management respondent who stated that there were no advantages to BIM; while no field level employees stated that BIM had no advantages.

Comparing Figure 4-5 to Figure 4-6; the executive responses were notably different compared to the middle management and field personnel. These differences may be due to the different focus of the executives. The executives focused on the financial and time aspects of BIM use rather than on the actual functionality of BIM. The different wording of the question may also have contributed to these differences. Executives were more likely to say that BIM did not add value to the company than either middle managers or field employees.

Coordination/clash detection and prefabrication were stated, by all respondent groups, to be the main advantages and value adding components in the BIM process. Several of the other responses, such as field efficiency, resolved issues, saved money, and saved time could be directly attributed to these two factors. Many of the respondents linked coordination and pre-fabrication directly with these advantages of BIM.

4.3.5 Executive Key Performance Indicators

To determine the effect of BIM on construction key performance indicators (KPIs) executives were asked to describe the effect of BIM on six KPIs. Their responses were categorized into four possible options: improved, no change, worsened, and not sure. (See Figure 4-7).

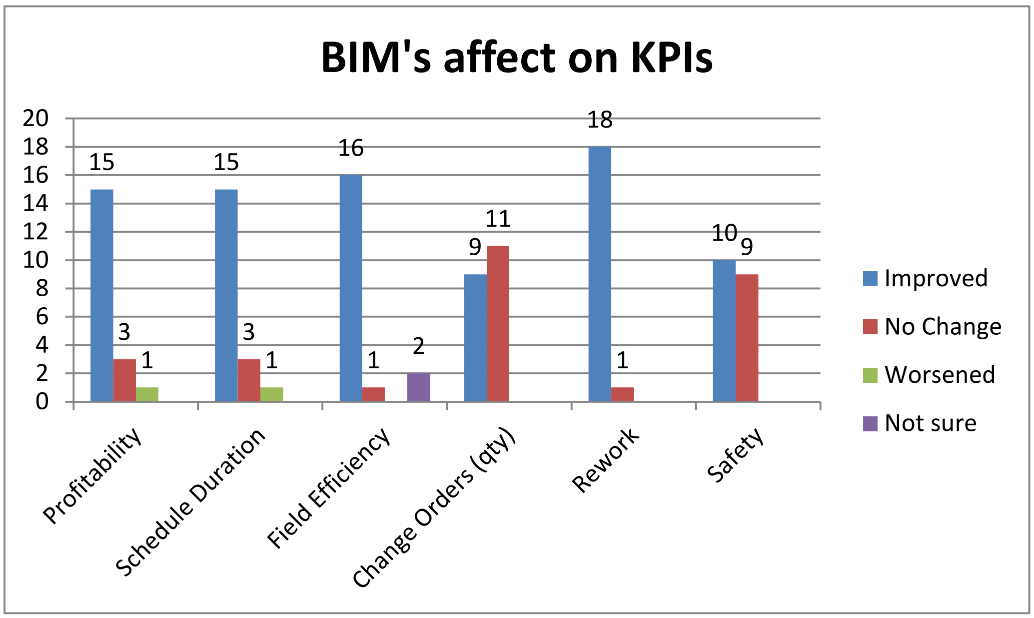

Figure 4-7: Executive: Key Performance Indicators.

Executive respondents also provided details as to why BIM was or was not having the stated effect on KPIs. Only one of the companies that described BIM as having no effect or a negative effect on profitability and schedule duration used BIM on over 5% of its jobs. This suggests that there was a learning curve to BIM that initially hurt profitability and schedule. Once a company was past the learning curve, BIM became profitable and more efficient. The remaining companies credited their improved profitability and schedule durations to the following: listed in order, increased field efficiency, prefabrication, and reduced conflicts/rework due to MEP coordination.

The only company that did not state an increase in field efficiency was the same company that stated that BIM did not have any effect on their profitability or schedule durations, even though they used it on a significant number of jobs. The remaining companies all stated improvements in field efficiency. Their stated reasons for the increased field efficiency were the following listed in order: field laborers don't have to stop and figure out where something should go, prefabrication, and reduced conflicts/rework due to MEP coordination. The one company that actually tracked BIM's effect on its field efficiency found that by combining BIM with prefabrication it had improved its field efficiency by 50%. Several other companies estimated their improvement to be between 15-25%.

From the literature review it was expected that BIM would greatly reduce change orders. However, over half of the companies surveyed stated that it did not reduce the number of change orders they encountered. When asked why it had no effect on change orders, seven of the eleven executives that mentioned change orders stated that the overall number of change orders remained the same but that they occurred earlier in the project, during the coordination phase. Several executives mentioned this as a significant savings in cost and schedule due to the relative ease of changing the model versus changing installed components. One executive, however, expressed a concern that contractors and owners were beginning to try and "push everything off as a coordination issue rather than a change order." Although BIM may not always reduce the number of change orders on a job, it significantly reduces their impact on the project.

The company that stated BIM had no effect on the amount of re-work needed on a job was the same company that stated BIM had no effect on any of the other key performance indicators. (It should be noted that the field-level employee of this company disagreed with the executive and noted both a reduction in rework, money savings, and time savings). The remaining companies stated improvement due to the improved coordination/clash detection efforts of the various trades. Fourteen of these executives claimed the reduction in rework was "drastic," or that rework was "virtually/almost eliminated."

It should be noted that not a single executive stated that BIM had a direct effect on safety. Those that indicated BIM's positive effect on safety attributed it to less time in the field and more work performed in a controlled environment (prefabrication shop). One executive gave the example of a time they were constructing a large duct bank. BIM allowed them to pre-fabricate the duct bank and then lower it into the trench already complete so that they didn't have to have workers in the trench. Another executive felt that BIM had a lot of potential for the analysis and improvement of job-site safety but that it was underutilized.

4.3.6 MEP Coordination/Clash Detection

Field personnel were asked the following: the percentage of jobs that they used BIM to perform coordination and clash detection, the value that BIM added to clash detection, and the software that they used. All respondents indicated that they performed coordination and clash detection on 100% of the jobs that used BIM. Most respondents thought that it was unproductive/inefficient to model without performing clash-detection coordination. When asked what value BIM added to the process the responses were varied, but most of the answers could be grouped into three categories. The first was the ability of the software to automatically detect where systems intersected. The second was the visual properties of BIM that allowed problems to be identified and potential solutions discovered. The final category was the ability of the software to identify 100% of all clashes so that a "100% clash-free model" could be achieved.

Navisworks Manage was the most used software for clash detection coordination with approximately 80% of respondents using it. The following programs were also mentioned as being used by between 1-3 respondents, BIM 360 Glue, Tekla BIMsight, Autosprink VR, Bluebeam, Autocad MEP (internal clashes only). One company also mentioned that it sent its model to the architect to perform clash detection and the architect sent them a list of needed changes.

4.3.7 Prefabrication

Field personnel were asked to describe the percentage of jobs they prefabricated from the model, what value prefabrication added to the project, and what software they used for their prefabrication. Figure 4-8 shows the percentage of projects they used the model for prefabrication.

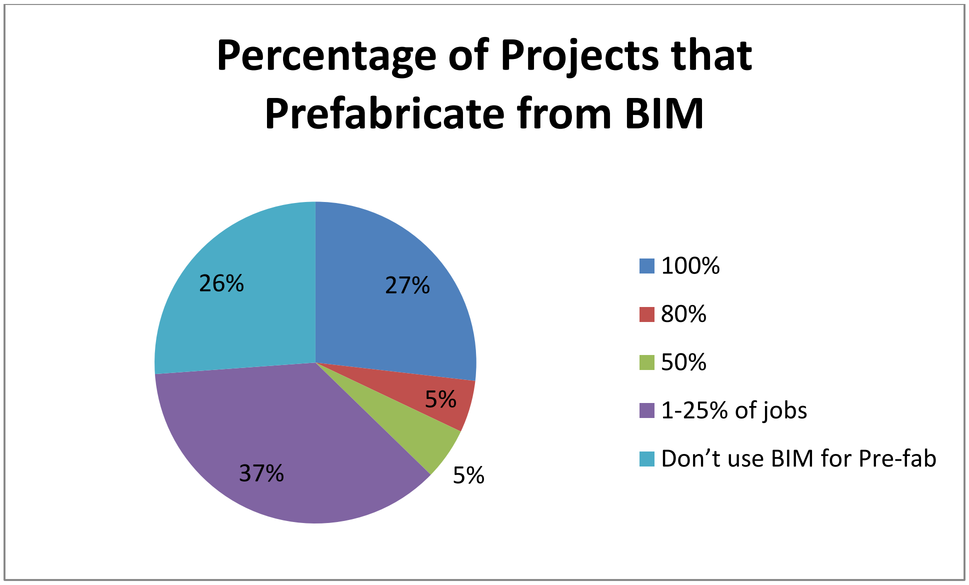

Figure 4-8: Field: Prefabrication as a Percentage of Jobs?

Several of the respondents who used BIM to prefabricate less than 100% of their projects mentioned that they planned to increase their quantity of prefabrication in the near future. All of the respondents but one indicated that they used the same software to fabricate as they used to model, (see section 4.3.3). Field personnel were asked what value BIM added to prefabrication. (See Figure 4-9).

Value BIM adds to Pre-fabrication	
Exact lengths/dimensions - Accuracy	38%
Labor/time savings	18%
You can fabricate more of a project	13%
No Difference (from 2d drawings)	13%
Easier to understand drawings	6%
Easier to Identify Areas to Pre-fab	6%
Hated it/ Negative value	6%

Figure 4-9: Value BIM Adds to Prefabrication.

Several respondents also mentioned that the model could be downloaded into equipment that was used to automate processes that were part of the prefabrication process, such as equipment that cuts ducting to size.

4.3.8 Model Creation

Middle-management personnel were asked on what percentage of jobs they received a model from the design team/GC. This question was specifically narrowed down to jobs on which they planned to use BIM. (See Figure 4-10).

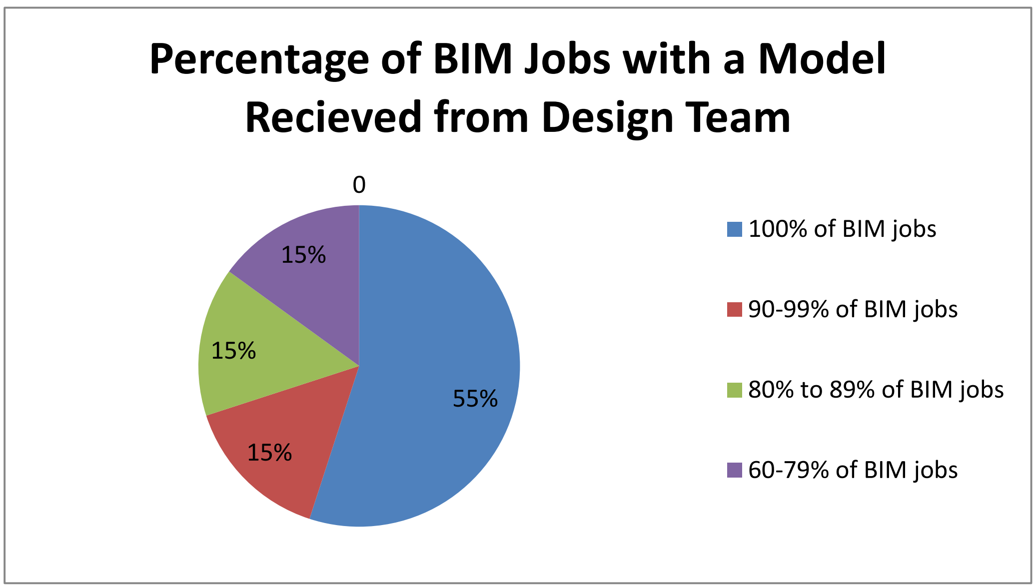

Figure 4-10: Middle Management: Models Received From Design Team.

The next question asked them to quantify what percentage of those models received from the design team needed to be modeled again from scratch. For the purpose of this question *from scratch* only included their trade's portion of the model. (See Figure 4-11).

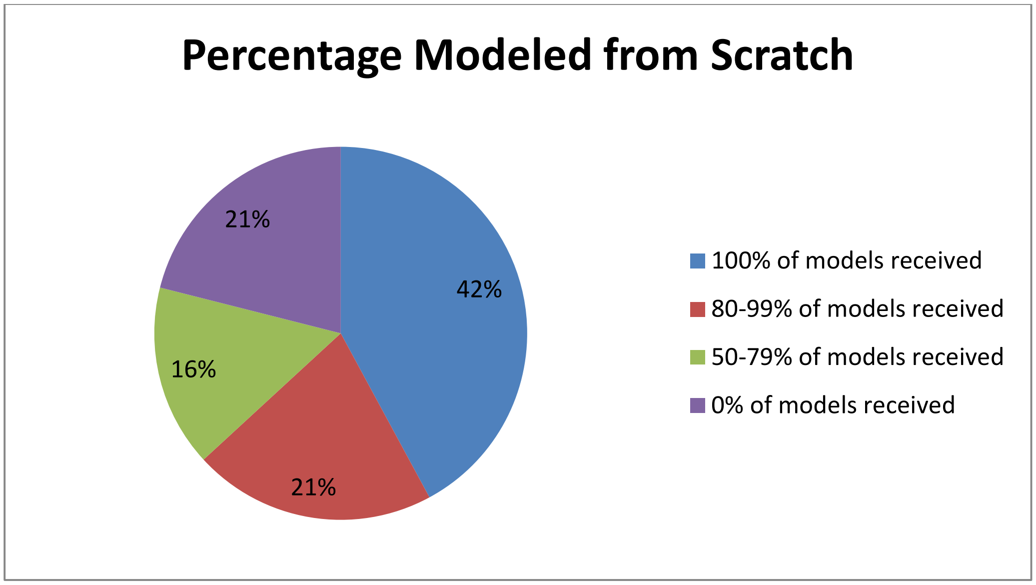

Figure 4-11: Middle Management: Percentage Modeled from Scratch.

Even those individuals who stated they never modeled again from scratch indicated they always did a significant amount of work to make the model buildable. One manager stated, "There is always something that we can use," indicating that the majority of the model was unusable. Several respondents mentioned that all they received from the engineer was a schematic or conceptual design. Many of them added that it would have been better to have them involved with the engineer as the initial engineered design was made, or to have had an in-house engineer create a design that was buildable. Other individuals also mentioned that the designs they were receiving from the engineers were not always as complete as they used to be. One respondent specifically mentioned that he believed that the engineers were now relying on the coordination process to catch any errors left in the design.

Middle managers were asked if they would create a model for their own in-house use even on a job where they did not receive a model from the design team. Fifty-six percent of middle managers stated that they would create their own model to one degree or another. The remaining 44% responded that they would have no use for a model in that circumstance or that it would not be worth the effort.

4.3.9 Model Visualization

Field personnel were asked to describe how they decided what level of development (LOD) they would use in their modeling. Seventy four percent of respondents stated that they either used the minimum LOD required in the contract or modeled to the same LOD every time. An additional 11% of respondents said they modeled to the level necessary to pre-fabricate, and 4% said they determined LOD based on the project size. The remaining 11% said that they didn't have a process for determining LOD and that each detailer in the company would model to whatever level they thought necessary.

These same individuals were then asked what value model visualization added to the project see Figure 4-12.

MEP coordination fell into the same category described by Gu and London (2010), which stated that contractors were more interested in the information contained in the model rather than the visualization aspects. However, the remaining responses were focused specifically on "the pretty pictures." This shows that MEP contractors valued BIM not only for the information it contained but also for the added value created by 3D visualization. 3D images are an effective way of communicating difficult concepts visually as could be seen by the high percentage of respondents who mentioned the ability to understand installation and communication. In addition to the above answers one respondent stated, with tongue in cheek, that "it keeps you from falling asleep in meetings."

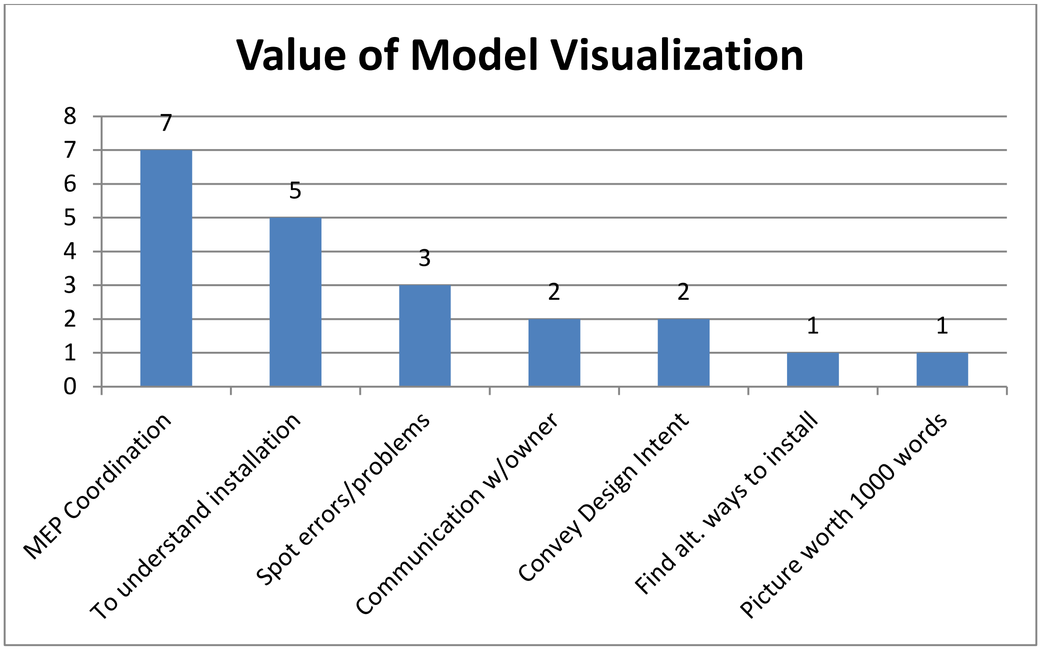

Figure 4-12: Field: Value of Model Visualization

4.3.10 Quantity Take-Off/Cost Estimating

Middle managers were asked to describe their company's use of BIM for quantity take-off (QTO) and cost estimating. Of the respondents, 65% used BIM for either QTO or cost estimating. Of those who used BIM for QTO or cost estimating, 69% used it for QTO, 8% used it cost estimating, and 23% used it for both. Only half of respondents were using BIM for QTO or cost estimating on over half of their jobs. It should be noted that the executive responses did not list QTO/cost estimating as a common use of BIM, but the middle management responses placed it as the third most common use of BIM, with almost the same percentage of use as prefabrication.

When asked to describe the value BIM added to the QTO/cost estimating process 44% of respondents commented on the ability to export exact quantities of materials from BIM and to create more accurate estimates. BIM was said to reduce the amount of time that the QTO/cost estimating process required by 39% of respondents while 11% mentioned the ability to create a cost estimate and a BIM at the same time, thus eliminating the need to redo your work after getting a bid. Further 6% of respondents found that BIM allowed them to pre-order materials thus reducing lead times on specialty items.

4.3.11 In-House BIM Training

Middle-managers were asked if their companies had an in-house BIM training program. Only one company had a BIM training program. That company provided regular training for their BIM detailers and periodic training for other individuals in the company. The remaining companies either said they did not have a BIM training program or that they used so-called on-the-job training. This was generally described as a more experienced detailer looking over the shoulder of a newly hired employee and helping the newly hired employee to figure out how to make things work.

4.3.12 Scheduling, Sequencing, Safety

Field personnel were asked to describe their company's use of BIM for scheduling, sequencing, and safety. Not a single respondent worked in a company where BIM was used consistently for scheduling, sequencing or safety.

With respect to scheduling and sequencing most respondents explained that they felt it was the general contractor's responsibility/prerogative to set the schedule and they would simply adhere to the schedule the GC created.

Many of them seemed surprised by the questions regarding using BIM to analyze job-site safety and found it a novel concept. After thinking about it for a short time the individual would almost invariably respond that their company didn't use BIM for that purpose but that he or she could see BIM being used for it. The only exception to this was one individual who indicated that one time his company was doing a remodel project on a barrel roll ceiling. Half of the ceiling had been demolished. After looking at the model he realized that they would be doing work on the half of the ceiling that had not been demolished as well. This would require his workers to crawl above the half demolished ceiling to work. He deemed this a serious safety concern and informed the GC that another solution needed to be found. In addition to this experience, several individuals mentioned the ancillary benefits to BIM of more prefabrication, less site work, and less rework as ways that BIM would improve safety. However, none of these companies were actively using BIM as a way to analyze jobsite safety.

4.3.13 Challenges to BIM Use

In addition to describing the advantages to BIM use, both field and middle management personnel were asked to describe the top three challenges to BIM use in priority order. (See Figure 4-13).

"*Working with other subs*" was the number one response for both levels of employees. Under this heading the most common complaints were other subcontractors not being sufficiently capable in their BIM use, not pulling their weight, and not putting the proper priority on MEP coordination.

Two of the responses dealt with time. The first challenge with time was the amount of time it took to detail their respective systems. By this they meant the cost of modeling either in dollars or man hours. The second response concerning time referred to the GC not allowing the subcontractor sufficient time to finish their model before starting construction.

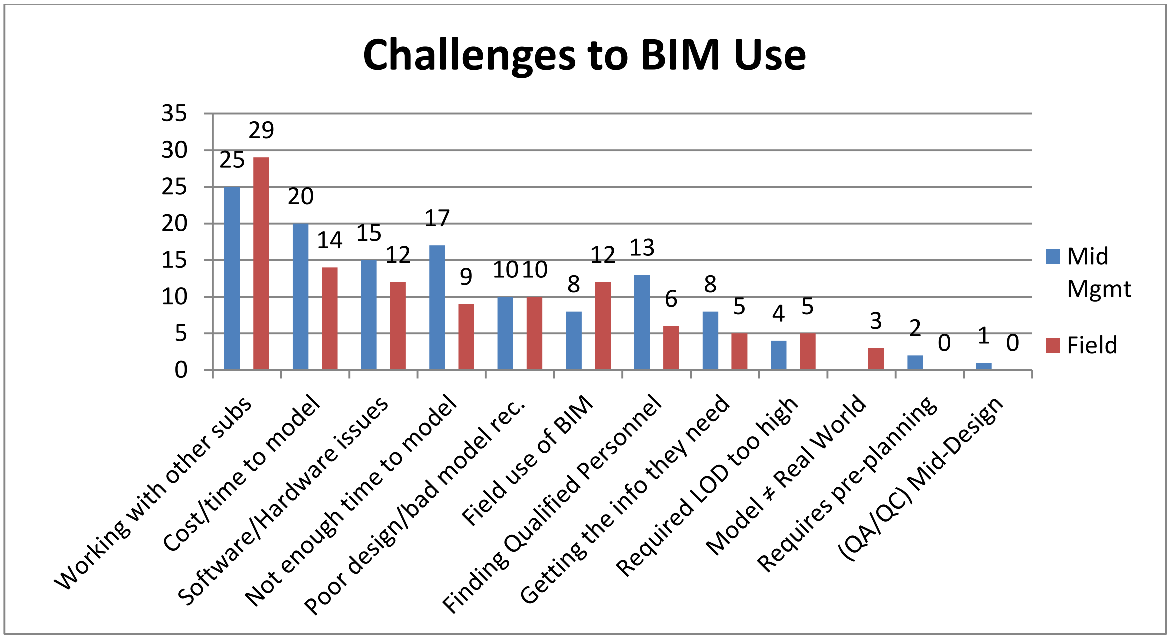

Figure 4-13: Middle Management/Field: Challenges of BIM.

There were a variety of software/hardware issues mentioned by the respondents. The majority fell under three main headings. The first was that the current BIM software was not fully functional for their trade and was difficult to use and did not allow them to fully model their systems. The second was that their hardware (e.g. computers or servers), was not sufficient to handle the heavy memory loads caused by use of BIM. The final problem was software compatibility between trades. Different software programs do not always communicate well with each other, and this caused problems during the coordination process.

Both middle-management and field personnel agreed equally that receiving a poor design or model from the design team was a major challenge to BIM use and led to hours of lost productivity for their modeling department. They generally defined poor design as either a design that didn't fit in the structure and wasn't buildable or described it as a design that was not detailed and required significant modeling/coordination time to make buildable. While this is often discussed in the industry, it should be noted that this challenge was 5th on the list.

The response, "*Field use of BIM*," dealt more specifically dealing with the ability of the BIM department to transfer the information contained in BIM to the installers in the field and to get them to install it according to the coordinated BIM design.

4.3.14 How to Improve the BIM Process

Middle-management and field personnel were asked how the BIM process could be improved. The answers they gave were varied but informative. The following list details the responses given along with the number of respondents who gave them.

- The various models need to be completed and coordinated by the trades before beginning construction. (4 times)
- The software needs to be upgraded to make it more user-friendly and to allow for a more complete model. (4 times)
- The trades need to be involved earlier in the process so that they can affect design decisions. (3 times)
- All of the trades need to be involved in the coordination process. Sometimes one or more trades do not participate and that caused problems. (3 times)
- There needs to be a better method of collaborating the various models. One respondent mentioned that they once used an ftp site where all the trades kept their current version of the model, thus allowing all participating trades to see real time data. (3 times)
- The various software programs used by the design team and the trades need to be compatible so that they can be more easily shared and updated. (3 times)

- Subcontractors need to be given better access to the individuals who are actually making design decisions. (3 times)
- The field installers need to be trained on and buy into the BIM process. (2 times)
- Vendors need to have models created for the various parts they supply so that individual companies don't have to model them themselves. (2 times)
- BIM detailers and coordinators need to have more experience in the construction field so that they understand what drives design decisions. (2 times)
- There needs to be a national BIM standard set up so that everyone is on the same page. (1 time)
- Design engineers (MEP) need to be involved earlier in the design process so that the building's architectural and structural components are not finalized prior to MEP input. (1 time)

4.3.15 Additional Comments

At the end of each section of the survey respondents were asked if they had any additional comments about the use of BIM in their company. Many respondents answered about the use of BIM in their company, but others responded about the use of BIM in general. The top answers are detailed in the list below along with the number of respondents who gave that response to the question.

- The respondents were optimistic about the future of BIM in the company or in the industry, stating that the use of BIM was going to increase and improve. (9 times)
- The software was not up to speed for their particular trade. It needs to be upgraded to make it more effective. (3 times)

- BIM, if used effectively, could be the difference that wins you a job over one of your competitors (2 times).
- BIM generally tends to be under-resourced from the beginning of the project which delays the detailer's ability to fully model and coordinate before beginning construction. (2 times)
- BIM was not being utilized to its fullest potential. (2 times)
- A good BIM coordinator (from the GC) makes all the difference between a successful and a difficult project. (1 time)
- Many owners and general contractors know they want to use BIM but are not sure what they want to do with it. (1 time)

Of all responses to this question, optimism for BIM was the most prevalent, revealing a feeling in the industry that they were just beginning to scratch the surface of what BIM could do. As BIM becomes more prevalent in the industry, and the industry becomes more proficient at using it, the industry will experience improvements both in capabilities and results. There were also several responses stated that were similar to those given in the how to improve BIM question. That was likely partially due to the fact that the additional comments followed directly after the question about how to improve BIM, but it also indicates that these are the topics that matter to BIM professionals.

4.4 Conclusions and Recommendations

Over two-thirds of the commercial MEP contractors that participated in this survey were using BIM on over half of their jobs. All but one of the remaining contractors stated that they were either just beginning their BIM use or were planning on increasing their use of BIM in the near future. Of those companies using BIM the overwhelming majority were finding a positive return on their key performance indicators. Profitability had increased, schedule durations had decreased, and field efficiency/productivity increased drastically, by as much as 50% in one case. Some of these results were due to the fact that the subcontractors were seeing drastic reduction in the amount of rework that needed to be done. Although change orders and safety were not improving as much they were also seeing improvement in these areas.

Based on these findings a company that is currently using BIM will be more competitive in the industry than a company that is not using BIM. A company that is not currently using BIM should begin now so as to remain competitive. Companies just starting BIM should keep in mind that there is an upfront cost and a learning curve to BIM that may affect short-term performance. However, failure to implement BIM is likely to have long-term negative effects on profitability and efficiency.

The most common application of BIM was MEP coordination. All companies using BIM were using it for MEP coordination, on almost 100% of projects. This was the top response from all three surveys and all respondents agreed that MEP coordination was a one of the greatest benefits to BIM. For new companies implementing BIM this is the area to focus your initial efforts.

Prefabrication was the second most common application of BIM.   However, a majority of companies used BIM on less than half of their jobs, so there is significant room to increase the use of BIM for prefabrication. Those who prefabricate the most, were the most enthusiastic about the potential BIM has to save money and increase efficiency. This was the application of BIM that generated the most enthusiasm from MEP executives, when they talked about why their company values BIM. A company that was currently using BIM for MEP coordination, could increase their efficiency and profitability by prefabricating.

QTO/cost estimating was the third most common application of BIM. Roughly the same numbers of companies were using BIM for QTO/cost estimating as were using it for MEP coordination, however, they were not using it to the same degree, and executives almost didn't mention that it is being used. Although the respondents were not as enthusiastic in their support of using BIM for QTO/cost estimating those who did, have found it to add value to the process and save time and money. This appears to be a use of BIM that is beginning to mature and is currently underutilized. Several respondents who were not currently using BIM for QTO/cost estimating stated that they would be beginning in the next six months. The researcher expects the use of BIM for QTO/cost estimating to increase significantly in the near future. A company could create additional efficiencies by using BIM for QTO/cost estimating.

The responses indicate that although the design team was creating the original model, in the majority of circumstances the model was not buildable or usable for prefabrication as created. In the overwhelming majority of cases the MEP contractor had to go through the model and almost completely rebuild the model to make it work. If the engineer spent significant time creating the design model then it appears there is a significant amount of duplicated work between the design engineers and the MEP contractors.

A better handoff process between design engineers and MEP contractors would eliminate duplication of work. The researcher was able to discover an inefficiency in the process but was unable to discover the correct solution to improve the handoff. MEP contractors should work with general contractors and design engineers to eliminate inefficiencies and duplications in the creating MEP models. One possible method to improve the handoff is to have the design engineers focus on creating a schematic design and allow the MEP contractors to create the model.

The research also showed that training among MEP contractors was almost non-existent. Another challenge to BIM was the need for highly upgraded computer hardware to run the software. If more money was put into training it is possible that less money would be needed for upgraded hardware, as better trained employees could find ways to take large data sets and break down the data into more manageable data sets.

Additionally, training would create a pool of talented employees who could discover additional ways to use the BIM to improve efficiency and productivity on the job-site. Several potential uses for BIM that are almost completely ignored by the companies surveyed were, scheduling, sequencing, or safety analysis. Finding an efficient way to use BIM for these purposes could create a competitive advantage.

Another challenge to BIM use was that it takes a significant amount of time to create a model and coordinate it with other trades. This creates an expense for MEP contractors as well as making it difficult to create a coordinated model before construction begins. Additional training could make BIM detailers more efficient thus reducing the cost and time needed to create a model. Additional training on collaboration tools could also make the process more efficient.

Other challenges mentioned about BIM were; the ability to get all of the various trades to work together effectively, lack of BIM experience among contractors, or a BIM coordinator that cannot lead a team effectively. These could all be related to a general lack of BIM training as well. However, it is possible that these challenges are due in part to the adversarial nature of contracts and conflicting personalities.

The results found by those MEP companies using BIM clearly indicate that BIM is becoming a standard practice among the participants of this research. BIM is increasing profitability, job-site productivity, and other key performance indicators.

5 CONCLUSIONS

5.1 Additional Findings

As explained previously chapter four was written in preparation for submission of a peer reviewed journal article. To meet the length limitations of a journal article, various findings of this research were not included in chapter four. They are included in chapter five as follows:

5.1.1 Determining Projects on Which to Use BIM

Executive personnel were asked to describe how their company decided on which projects they would use BIM see Figure 5-1.

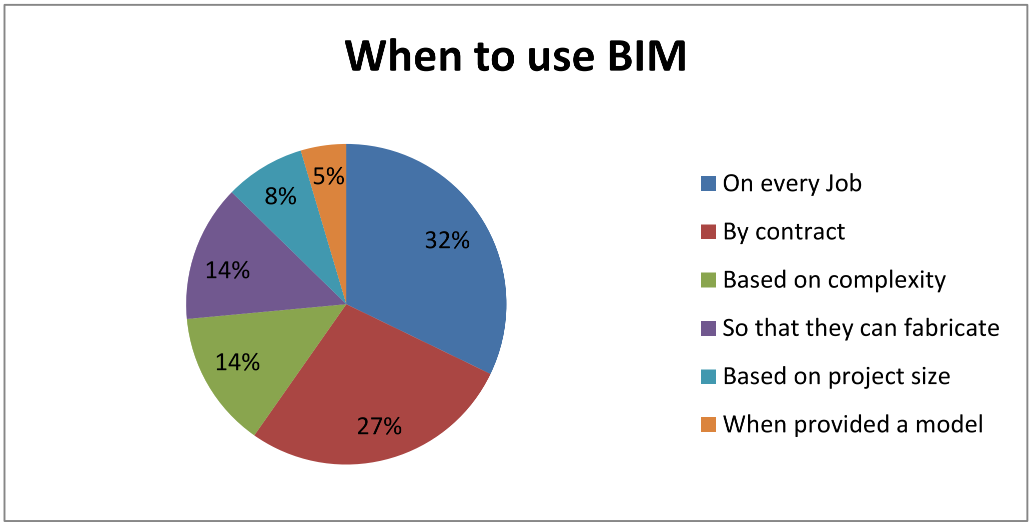

Figure 5-1: Executives: Determining when to use BIM.

Thirty-two percent of executive respondents stated that their company's used BIM on every project. Twenty-seven percent used BIM when required contractually. Fourteen percent used BIM on jobs they planned to prefabricate. Five percent of respondents use BIM when provided with a model. Twenty-two percent decided to use BIM based on the project complexity/size. However, for these twenty-two percent there were no formal methods for determining what project size or complexity required BIM.

5.1.2 BIM as a Contract Document

Middle managers were asked how BIM was being incorporated into the contract documents. Only one individual surveyed had ever seen the BIM used as an actual contract document. The remaining 18 respondents found that the BIM was referenced in the contract documents, usually by some form of a "BIM execution plan." The BIM execution plan would set out the details for BIM use, level of development, coordination, and other details. Two respondents mentioned that after completed coordination the BIM would then become a contract document, but they did not know of any contract verbiage that actually accompanied this change.

5.1.3 Who Leads in Clash Detection Coordination

All but one middle manager found that the general contractor usually takes the lead in clash detection coordination. However, 35% of respondents mentioned there were exceptions to this rule. The most common exception was a general contractor that was not experienced in the use of BIM. In that case respondents said that the mechanical subcontractor would usually lead clash detection coordination.

5.1.4 Big Room Modeling

Middle managers were asked if their company ever models in a "Big Room" environment. (A big room environment is when all of the trades were modeling side by side in one large room). Seventy-four percent of respondents had never participated in a big room. The remaining 26% of respondents had only participated in a big room modeling environment once or twice. Those who had participated in a big room found that it was not helpful to the productivity of the modeling process. One common concern mentioned was that it was rare to have a detailer that was only working on one project. If a detailer was working on more than one project, other projects would be neglected. Several respondents mentioned online collaboration tools and cloud hosting services as a better solution.

5.1.5 Communication Between GC/Design Team and the Trades

Seventy-six percent of middle managers said that they felt BIM had improved the communication channels between the GC/design team, and the trades. The majority of them attributed the improved communication to two factors. The first was clash detection coordination. The process of clash detection generally required a representative from the GC to be involved, automatically increasing communication. The second contributing factor was the increased information contained in the model itself. One respondent summed it up by saying, "you know what they say, a picture is worth a thousand words." However, several respondents still mentioned that they have difficulty getting the information/decisions they need from the GC/design team to complete the model.

5.1.6 Company BIM Organization

Middle managers were asked to describe the organization of their company's BIM department. Their responses fell into two categories. The majority, 81%, of respondents had a dedicated BIM/detailing department with BIM experts being assigned to specific jobs as necessary. While they were assigned to specific jobs, they were generally assigned to multiple jobs simultaneously, unless the project size warranted dedicated BIM personnel. The remaining 19% of respondents only had one individual in the company who used BIM. That individual was responsible for all of the detailing, coordination, etc for the entire company.

5.1.7 On-site BIM

Field employees were asked how their company manages their on-site BIM. Of the responses, 52% stated they exclusively used BIM in their field production on-site. The remaining respondents either used 2D plans or a combination of 2D plans and supplemental BIM information on-site. In the cases where a combination was used the BIM expert assigned to the project was generally required to assist field personnel in understanding the BIM. Also, 19% of respondents mentioned that they used the BIM model in conjunction with a total robotic station to lay-out the sleeves, anchors and other embedded hardware.

5.1.8 BIM to Track Equipment Information

Field employees were asked if they used BIM to track information about equipment being installed, e.g. model numbers, maintenance requirements, etc. The information collected from this question was of limited use since many respondents did not understand the question and answered it erroneously or not at all. Initially respondents understood the question to be asking if they tracked changes in the model during construction. After realizing this was the response being given the question was clarified to future respondents. From those individuals who understood the question and responded five were using BIM to track information about the equipment installed on the majority of their jobs.

5.1.9 As-Built Models

Field employees were asked on what percentage of jobs they used the model to produce as-built documents for the owner. Eighty-six percent of respondents stated that they used the model to produce as-builts, while 14% did not use the model for this purpose. Of the respondents that used BIM to produce as-built documents 83% of them used it on all of their jobs, while the remaining 17% used it on between 40 and 90% of jobs.

5.2 Conclusions/Recommendations

BIM was being referenced by the contract documents, usually in the form of a BIM execution plan. This plan detailed contractual requirements as to how BIM should be used on each project. MEP contractors should verify how BIM is incorporated into contracts for projects they are bidding and include the necessary resources to successfully implement BIM.

The GC was leading out in MEP clash detection coordination. The main exception to this was when the GC did not have the experience to lead the process. In these cases the trade with the largest scope generally led the BIM coordination effort. This was often the mechanical subcontractor.

"*Big Room*" modeling was not prevalent in the survey respondents and was not found to be useful to those respondents who had participated in a "Big Room" project. It was recommended that online collaboration be used instead, such as online meeting tools and cloud hosting services.

Communication between the design team, general contractor and the trades has improved due to the inherent nature of the BIM process. Respondents stated that they felt having the GC lead the coordination process improved the communication flow. Additionally, the researcher felt from conducting the surveys that the improved communication could also have been contributed to MEP subs coordinating more fully and sooner in the process than they did previously. Also some of the improvement to communication could be due to the 3d nature of BIM. If a picture is worth a 1,000 words then a 3D picture is worth 10,000 words. The 3D nature of BIM provides relational information unavailable in previous methods.

Most MEP contractors either have a single BIM expert or a dedicated BIM/detailing team that handles modeling, coordination, and other BIM functions. Most MEP detailers are also responsible for multiple projects simultaneously, rather than being dedicated to a single project.

Field implementation of BIM was not as complete as BIM implementation in preconstruction. In preconstruction; design, coordination, and planning occurred in 3D, however, 2D plans were often delivered to field personnel for installation. Sometimes the 2D plans would be supplemented with 3D information if field personnel requested it. There appeared to be room for improvement in the delivery of the model as a field installation tool.

BIM was being used to produce as-built models for the end user and in some cases to track additional information about the equipment being installed. Further communication between the end-user and the trades was recommended by one survey respondent to ensure the as-built model served the end-user's needs.

5.3 Recommendations for Future Research

This research was designed to determine the current practices of U.S. based commercial MEP contractors. Many of the details of how those practices were implemented and what means and methods were used in BIM processes to create the best results were outside the scope of this research. The following are suggestions for additional research topics.

First, this research was limited to MEP contractors. Additional research is recommended to determine whether other trades are adopting BIM use to the same degree or in the same manner.

Second, prefabrication and QTO/cost estimating were identified as uses of BIM that show positive results but were not being fully utilized. Additional research should be performed to determine the means and methods currently being employed by MEP contractors who use BIM for these purposes and potential ways to improve/increase the use of BIM for prefabrication and QTO/cost estimating.

Third, scheduling, sequencing, and safety analysis were identified as potential uses of BIM that were almost completely overlooked by MEP contractors. Additional research is recommended to determine what benefits BIM could have in these applications for MEP contractors.

Fourth, BIM was being referenced in contract documents through BIM execution plans. There is still some question as to the precedence between 2D documents and the BIM, with a BIM execution plan in place. Additional research is recommended into how BIM is being incorporated into the contract documents.

Fifth, this research showed that BIM was used on-site to assist in product installation but many contractors were still using 2D drawings, either in part or in full, to communicate with their field personnel. Additional research is recommended into how BIM could be used by on-site personnel and ways to improve the delivery of the BIM model from the office to field personnel.

Sixth, several respondents mentioned that the BIM model could be downloaded into equipment and used to automate processes, e.g using a total robotic station to layout embedded hardware, or downloading the model into an automated cutter for a mechanical sub. Additional research is recommended into ways that BIM could automate labor intensive processes.

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APPENDIX A - EXECUTIVE, MIDDLE MANAGEMENT AND FIELD SURVEYS

Executive Survey

1. In order, from most used to least used, what are the top three ways BIM is used in your company?
    a.
    b.
    c.
2. Why does your company value BIM?
3. How does your company decide on which projects to use BIM?
4. Key Performance Indicators
    a. How has BIM affected profitability?
    b. How has BIM affected project duration?
    c. How has BIM affected field efficiency?
    d. How has BIM affected change orders and rework?
    e. How has BIM affected job-site safety?
5. Is there anything else you would like to add about BIM's current practices in your company?

Middle Management Survey

1. Does your company use BIM?
2. On what percentage of projects does your company use BIM?
3. In order, (from greatest to least) what are the top three advantages of BIM?
    a.
    b.
    c.
4. In order, (from greatest to least) what are the top 3 challenges to using BIM?
    a.
    b.
    c.
5. Does your company have an in-house BIM training program?
    a. Briefly describe the training program (who takes it, how long)
6. How is BIM being incorporated into the contract documents?
7. Who usually takes the lead in clash detection coordination (GC, Trade Contractor, Architect, Engineer, or other)?
8. On what percentage of projects does your company receive a model from the design team/architect/GC?
    a. How does this change by delivery method? (Design-build, CMGC, DBB. etc)
9. Of these models received (from architect/engineer/GC), what percentage does your company model again from scratch?
10. On projects where your company doesn't receive a model from the design team/GC how often do you create your own model? (By percentage)
11. Does your company ever model in a "Big Room" Environment? If so, please describe benefits/challenges.
12. Do you feel that BIM has improved the communication channels between the design team/GC and the trades? Please explain how or why not.
13. Does your company pre-fabricate from the model?
    a. What value does BIM add to material fabrication?
14. Does your company use BIM for quantity take-off or cost estimating?
    a. On what percentage of projects does your company use BIM for Quantity take-off (QTO)/cost estimating?
    b. How does BIM add value to the estimating/QTO process?
    c. Do you use BIM to track the revision process during construction?
    d. What software does your company use for QTO or cost estimating?
15. How is your company organized to use BIM?
    a. Dedicated BIM department
    b. Each project has a BIM expert
    c. Utilize outside BIM consultants
    d. Other, please explain

16. What could be done to improve the BIM process?
17. Is there anything else you would like to add about BIM's current practices in your company?

Field Survey

1. In order from greatest to least what are the top 3 advantages of using BIM?
    a.
    b.
    c.
2. In order from greatest to least what are the 3 greatest challenges you face in BIM use?
    a.
    b.
    c.
3. How does your company manage on-site BIM usage? (Tablets, job-site computer, etc)
4. 3d modeling
    a. How do you decide what level of development to use for a particular project?
    b. How does model visualization add value to the project?
    c. What software does your company use for 3d modeling and visualization?
5. Scheduling/sequencing
    a. On what percentage of projects does your company use BIM for sequencing?
    b. How does BIM add value to the sequencing process?
    c. What software does your company use for sequencing?
6. Coordination/clash detection
    a. On what percentage of projects does your company use BIM for coordination/clash detection?
    b. How does BIM add value to the clash detection process?
    c. What software does your company use for coordination/clash detection?
7. Prefabrication
    a. On what percentage of projects does your company use BIM for prefabrication?
    b. How does BIM add value to the prefabrication process?
    c. What software does your company use for prefabrication?
8. Safety
    a. On what percentage of projects does your company use BIM to improve safety?
    b. How does BIM add value to jobsite safety?
    c. What software does your company use to improve safety?
9. Facilities Management/Lifecycle
    a. On what percentage of projects does your company use the model to produce an as-built model for the property owner?
    b. On what percentage of projects does your company use BIM to track information about equipment being installed?
    c. What software do you use to produce as-builts, and/or track equipment installed?
10. What could be done to improve the BIM process?
11. Is there anything else you would like to add about current BIM practices in your company?