

BIM Practices of Commercial MEP Contractors

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Building Information Modeling (BIM) use in the construction industry has grown significantly in recent years, and provides tremendous advantage in MEP (mechanical, electrical, and plumbing) processes. However, how MEP specialty trade contractors actually utilize BIM is not as well understood. This research project was established to explore how MEP specialty trade contractors use BIM in their construction processes, the advantages and disadvantages that they find in doing so, and how implementation of BIM affects MEP applications. An important element of this research was to provide better understanding of the gaps still existing in the collaborative design process. In this research, three different levels of personnel from MEP companies, including executive, middle management, and field personnel, were interviewed to determine the current BIM practices within their respective companies. The majority of companies interviewed were using BIM, and most were using it on a significant portion of their projects. For those using BIM regularly, BIM was having a positive effect on several key performance indicators, including profitability, schedule duration, field efficiency, and rework. The top uses of BIM for MEP contractors included coordination, prefabrication, and producing as-builts. Most MEP contractors have not yet incorporated BIM for scheduling, sequencing, or safety analysis. Additionally, MEP contractors could benefit from incorporating BIM training.

Keywords: Building Information Modeling, BIM, MEP, Coordination, Prefabrication.

Introduction

Building information modeling (BIM) has become a widely researched topic within the construction industry in recent years (Yalcinkaya and Singh, 2015). BIM use within the construction industry initially surged from 28% to 71%, between 2007 and 2012 (McGraw-Hill Construction, 2012), and has continued to grow. A recent report indicated that general contractors especially find a high degree of value in using BIM with regard to specialty trades (Dodge, 2015). However, this same report indicated the most of the modeling is still being performed by the general contractors (Dodge, 2015). Although BIM use in commercial construction is becoming a standard practice, there still seems to be some disconnect between how BIM is utilized by general contractors and their specialty contractors. The purpose of this research was to explore the current BIM practices of U.S. based commercial MEP (mechanical, electrical, and plumbing) specialty contractors. This research was not intended to provide a comprehensive overview of the entire industry, but rather to begin to better understand the issues surrounding BIM use in the MEP trades and ultimately guide future research needs.

Literature Review

The use of BIM in the U.S. construction industry has made tremendous strides in recent years, with most users projecting to gain even more value from BIM in the future (Ku and Taiebat, 2011). BIM includes the capability of modeling architectural, mechanical, electrical, civil, and structural elements within a single cohesive digital representation (McGraw-Hill Construction, 2008). This then, in essence, has become a tool that encourages the integration of the roles of stakeholders participating in a construction project, from design through inception (Azhar, 2011). This integration ultimately brings about greater efficiencies on the project through increased collaboration and communication between project stakeholders (Azhar, 2011). BIM has been demonstrated to be especially useful in commercial construction applications (Farnsworth et al., 2015). However, Oh et al. (2015) cautioned that for effective collaboration to occur during the design phase, the design information has to be effectively shared between the project participants through an integrated design process. This can be problematic for stakeholders using different types of software packages that don't seamlessly integrate with each other. Kelly (2016) further cautioned that the gains in efficiency often associated with using BIM are only available for teams that include personnel that are either experienced with, or trained in its use. This also holds true for needing management staff with some level of experience with the technology. Still, Eastman et al. (2011) indicated that there is a considerable gap between the early adopters of BIM and the majority of the construction industry. For the benefits that can be gained from using BIM, any stakeholders still has to transition through the learning curve of BIM adoption and implementation.

One specific set of stakeholders with significant gains to be made by implementing BIM into their design and construction practices are the specialty trade contractors involved with MEP processes. It has been reported that MEP systems constitute a large portion of both construction cost and asset value, and that BIM serves as a valuable tool in tracking and managing these systems (Bosche et al., 2014; Hanna et al., 2013). Correspondingly, BIM use among MEP contractors has increased in recent years. Dodge (2015) determined that mechanical contractors for HVAC and plumbing/piping were using BIM on about 2/3 of their project, while electrical contractors were only using BIM about 1/3 of the time. Dodge (2015) further determined that the percentage of specialty contractors reporting a high or very high value from using BIM was 93% for HVAC, 91% for plumbing/piping, and 68% for electrical contractors, respectively. Although MEP contractors are not yet utilizing BIM in all applications, this indicates that they are finding value when they do. However, to be useful, BIM use for MEP layout design needs to be incorporated throughout the entire design and construction process (Wang et al., 2016). Important elements of coordination include MEP system coordination, spatial layout coordination, constructability coordination, and verification coordination based on construction deviation. These latter two points are especially true for capturing changes that still may occur between design and construction (Wang et al., 2016). It has further been proposed that capturing coordination information generated in the BIM-based design coordination process is an essential element of using BIM effectively for MEP applications (Wang and Leite, 2015).

In recent years there has been an increased level of research activity pertaining to how BIM is used by MEP specialty trade contractors. Hanna et al. (2013) indicated that most mechanical and electrical contractors using BIM agree that BIM reduces field conflicts and improves coordination, but that the MEP industry has yet to "scratch the surface" of effectively implementing BIM in their routine processes. The most common applications related to MEP use of BIM within the industry are related to MEP coordination (Korman et al., 2008; McFarland, 2007; Guo et al., 2014; Simonian and Korman, 2011). Ashuri et al. (2014) reported that team experience level, preliminary design quality, and project schedule are the principal factors affecting productivity of MEP coordination. Lee and Kim (2014) reported that the manner in which coordination takes place can also affect the speed of coordination, and that a sequential coordination strategy is much more efficient than a parallel coordination approach. It has been demonstrated that experience is an important element in performing effective MEP coordination tasks (Wang and Leite, 2014) and that documented MEP coordination data can make accurate predictions of future conflicts (Wang and Leite, 2013). Finally, Korman and Lu (2011) have reported that BIM is especially useful for coordinating MEP systems in prefabricated construction components. Although coordination seems to have been the focus of recent MEP related research, this project was established to explore some of the other issues still surrounding BIM use by MEP specialty subcontractors, and better understand gaps still existing in the collaborative design process.

Research Methodology

This research was structured around a survey provided to commercial MEP contractors to better understand their BIM related practices. However, it was determined that no single individual working for an MEP contractor would be able to provide a comprehensive view about all current practices of BIM throughout MEP companies. Therefore, the research was structured into three parts for surveying personnel at the executive, middle manager, and field employee levels within each company. Employees that functioned at multiple levels, such as within smaller companies, were asked to answer multiple levels of the survey. A general mixed methods approach was utilized for this research, employing both quantitative data regarding BIM use and qualitative data describing processes and motivation. Executives were asked about ways that BIM was utilized, valued, and affected key performance indicators within the company. Middle managers were asked about the advantages and challenges of using BIM, company organization for using BIM, and processes for integrating BIM into routine construction practices. Field personnel were also asked about the advantages and challenges of using BIM, as well as how often BIM was utilized for 3D modeling, scheduling, coordination, prefabrication, safety, and facilities management.

Since the goal of this research was to determine the current BIM practices of commercial MEP contractors, larger companies were targeted to increase the likelihood of more substantial BIM use. Data gathering took place during 2014. Participants were selected from the Top 600 Specialty Contractors (ENR, 2013), and 30 companies were contacted and participated in the survey. These included 14 electrical contractors, 11 mechanical contractors (HVAC and plumbing), three fire protection contractors, one BIM consultant serving MEP trades, and one exclusively plumbing contractor. Company revenues ranged between \$90M and \$2B, with an average of \$400M, annually. Participants included 21 executive, 23 middle-management, and 21 field-level survey, for a total of 65 total completed surveys. The survey data was collected over the phone, with each call recorded and later manually transcribed. Survey questions included such things as *why does your company value BIM*, *on what percentage of projects does your company use BIM*, and *what are the top three advantages of using BIM*? This qualitative survey data was analyzed using pattern coding techniques identifying common trends in responses.

Findings

Advantages, Disadvantages, and Key Performance Indicators

One of the first objectives of this research was to evaluate how often MEP companies were utilizing BIM on their projects and what they were using BIM for. Over half of the participants indicated that BIM was used in some capacity on over 75% of their jobs. On the other hand about 20% of the participants indicated that they used BIM on less than 5% of their jobs. However, the majority of the respondents, including those with minimal use, indicated that they anticipated using it even more in the near future. This means that although about half of the MEP companies surveyed in this research were routinely using BIM, unfortunately there were also a number of MEP companies that had minimal integration of BIM use within the practices of their companies. Despite the number of benefits of using BIM that have been shown, there are still companies lagging behind. This might indicate that there is still some disconnect between industry training and adoption of BIM practices. Regarding BIM use, respondents were asked to identify the top ways that BIM was used in their companies. The top uses for MEP contractors included coordination/clash detection, prefabrication, and producing as-builts. It is not surprising that clash detection was the most frequent use of BIM for specialty trade contractors, since MEP systems rely so heavily on coordinated placement. All of the participating companies indicated using BIM for clash detection, and nearly all for producing as-builts. This means that even those companies that were using BIM on a limited basis were occasionally performing clash detection and perhaps producing as-builts. Other ways that BIM was used on MEP related projects included creating designs, jobsite layout, constructability analysis, performing quantity take offs, preventing delays, scheduling, and meeting miscellaneous client needs. Just over half of the responding companies indicated using BIM for performing prefabrication or quantity take off / estimating purposes. None of the participating MEP contractors in this research were using BIM for scheduling or safety analysis.

Participants were also asked to identify the advantages of BIM on MEP related projects and why their companies valued using BIM. Interestingly, the responses for advantages very nearly mirrored the ways that companies were using BIM. This could be interpreted in one of two ways. Either companies are using BIM on MEP projects more for the tasks that provide the most benefit to them, or the companies are simply finding the most benefit in those tasks that they do more often. Enhanced MEP coordination was identified as the principal benefit. Other notable benefits included resolving issues prior to building, better enabling prefabrication, increased field efficiency, reduced rework and change orders, increased accuracy of drawings, and enhanced ability to perform quantity takeoffs and estimating. Although not generating as much response, additional benefits of using BIM included reduced schedules, better communication, better teamwork, understanding complex installations, double checking the engineering, and ultimately leading to a better product. One middle manager responded that there were no benefits to using BIM for MEP work. Although this response is not in sync with the others, this response correlated with a company not using BIM on a frequent basis. This supports the notion that continuing to provide factual data and educate the industry regarding the benefits of using BIM within the specialty trades is still warranted. Executive employees were also asked to explain why their company valued using BIM on MEP related projects. Saving time and money, increasing field efficiency, and providing better MEP coordination were most frequently identified. However, the idea that BIM does not provide any value was once again expressed by multiple participants. As before, this notion was typical for companies with minimal use, seemingly correlating with the idea that value is not achieved until a company gets beyond the initial learning curve of using BIM and regularly incorporates BIM into their processes. This research did not specifically investigate the ratio of the actual investment costs of using BIM within company processes relative to the added value for MEP projects.

Middle managers and field personnel were asked to identify the specific challenges that they experienced with using BIM in MEP construction processes. The principal difficulty expressed by both sets of participants was working with other subcontractors. The most common issues expressed included other subcontractors not sufficiently competent in their BIM use, not pulling their weight, or not putting enough priority on MEP coordination. Other notable responses by many of the participants included increased cost and time associated with modeling, software and hardware related issues, not being provided enough time to model, dealing with poor design or bad models, challenges with using BIM in the field, and finding qualified personnel to utilize BIM features. It is interesting to note that there were two different challenges associated with time. The first challenge was the amount of time it took to model their respective MEP systems, and the corresponding high cost of modeling in either dollars or man hours. The other response referred to the general contractor not allowing sufficient time for the subcontractor to finish their model before starting construction. Other challenges expressed by only one or two participants included getting the information needed for modeling, being required to model to a high level of detail, the model didn't always match reality, an increased level of pre-planning, and having an increased level of quality control and quality assurance mid-design. Many of these challenges can be overcome with more effective communication between the general contractors and specialty trade subcontractors. On the other hand, some of these challenges can be alleviated through education, further research, and a general increased mutual understanding of the needs associated with MEP contractors using BIM.

One unique feature of this research was exploring the effect of BIM on key performance indicators of MEP specialty trade contractors. Executive level participants were asked to describe the effect of BIM on six different key performance indicators including profitability, schedule duration, field efficiency, change orders, rework, and safety. Although not specifically comprehensive of all potential key indicators, these six were selected because of their significance to subcontractors. Respondents were nearly unanimous in indicating that BIM improved profitability, schedule duration, field efficiency, and construction rework (see Figure 1). Respondents especially claimed that the

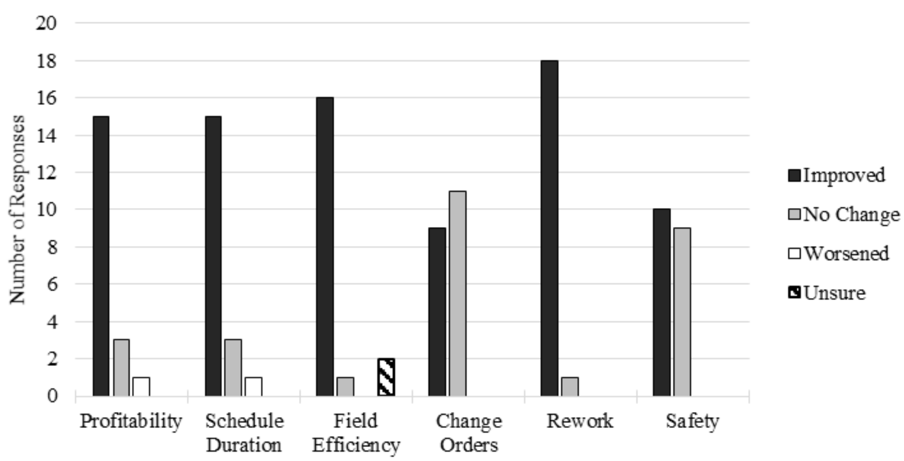

Figure 1: Effect of BIM on key performance indicators.

reduction in rework provided by using BIM in MEP applications was drastic, and that rework was nearly completely eliminated. Companies reporting improved profitability and schedule durations, attributed the improvement to increased field efficiency, prefabrication, and reduced conflicts/rework due to MEP coordination. One company tracking the effect of BIM on field efficiency had identified improved efficiency of 50% by combining BIM with prefabrication. Several other companies estimated field efficiency improvements of 15-25%. Although the number of change orders was not specifically decreased, participants noted that the negative impacts typically associated with change orders was greatly reduced. With regard to change orders and safety, responses were nearly evenly split between BIM either providing an improvement or having no effect on these key indicators. One respondent provided an example of safety where BIM was used to assist in the prefabrication of a large duct bank prior to lowering into a trench, as opposed to having workers assembling in the trench. Still, respondents indicated that BIM had much untapped potential for the analysis and improvement of job-site safety. It should be noted that only one of the companies that described BIM as not having an effect or a negative effect on these key indicators actually used BIM on over five percent of their jobs. This suggests that the learning curve for using BIM effectively on MEP related tasks has an initial negative effect on profitability and schedule. Once companies get beyond the learning curve, MEP companies begin to more readily associate BIM use with overall benefit.

BIM Implementation for MEP Applications

Field personnel provided some of the most important findings in this research, specifically regarding how often companies used certain applications and the effects to these processes. Each respondent indicated performing coordination and clash detection on all jobs using BIM, and noted that it was unproductive and inefficient to model without performing coordination and clash detection for MEP applications. The principal effects of using BIM for MEP included automatically detecting where systems intersect, visually allowing problems to be identified and potential solutions discovered, and the ability to generate completely clash free models. Prefabrication was another important BIM application for MEP processes, with 27% of respondents indicating using prefabrication with BIM on all projects. On the other hand, 37% of respondents indicated only prefabricating from BIM on less than a quarter of their jobs, and another 26% of respondents not using BIM for prefabrication. The principal effects of BIM to the prefabrication process were identified as increased accuracy in dimensions, savings associated with time of labor, and enabling more of a project to utilize prefabrication. Respondents also indicated that prefabrication was made easier by incorporating models with automated equipment.

An important element of BIM implementation is the creation of the model. Middle-management personnel were asked how often they received a model from the design team or general contractor, specifically for jobs that they anticipated using BIM. Interestingly, all respondents indicated receiving a model more than 60% of the time, with more than half receiving the model on all jobs. Unfortunately, 79% of respondents further indicated that they still rebuilt the model from scratch more than half of the time, and 42% indicated rebuilding models from scratch all the time. Even for the few respondents that indicated never modeling from scratch, they still noted that a significant amount of work was necessary to make the model usable. About half of the respondents indicated that they typically planned to rebuild the model from scratch, with the other half indicating that models created completely from scratch did not provide any worth or were not worth the effort. It is interesting to note how contrary these two different approaches are, yet how both seem to imply the lack of effectiveness in the models received. Factors that could be affecting this include lack of communication, liability, differences in modeling needs, software packages utilized, accuracy awareness, and necessary level of development. Although some of these factors are not necessarily easily overcome, this is certainly an area in which efficiencies of BIM use for MEP subcontractors can be improved.

Another associated topic is deciding what level of development (LOD) should be used in the model. 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 prefabricate, and 4% said they determined LOD based on the project size. The remaining respondents indicated that they did not have a process for determining LOD and that each detailer in the company would model to whatever level they thought necessary. The value added to MEP processes through model visualization included the ability to facilitate coordination, understand installation or alternation installation methods, spot errors or problems, enhance communication with the owner, and more effectively convey design intent. Certainly subcontractors focused on developing their own models to ensure achievement of the desired level of development and value from the process.

Another area where BIM aids in MEP processes is the ability to perform quantity take offs (QTO) and cost estimating. The majority of the responding companies (69%) used BIM for performing QTO, another 8% used it for cost estimating, and 23% used it for both applications. However, only half of the respondents were using BIM for QTO or cost estimating on over half of their jobs. When asked to describe the value BIM added to the QTO and cost estimating process, nearly half of the respondents described the ability to export exact quantities of materials from BIM and ultimately create more accurate estimates. Other points of value included reducing the amount of time for performing quantity take offs and cost estimating, the ability to generate a cost estimate during the model development process and eliminating the need to redo this after getting a bid, and facilitating pre-ordering materials to reduce the lead times often associated with specialty items. Although these latter points of value were identified by several companies, the practice of these tasks is not being widely used.

It is interesting to note that although BIM has been broadly associated with enhanced scheduling, sequencing, and safety features, not a single respondent worked for a company where these were utilized for MEP processes. With respect to scheduling and sequencing, the general consensus was that it was the responsibility of the general contractor to set the schedule and that they simply adhered to that schedule. This was somewhat surprising since scheduling and sequencing have been demonstrated to be an effective use of BIM. Also, many participants seemed somewhat surprised by the questions regarding using BIM to analyze job-site safety. However, most indicated that although their company did not currently use BIM for that purpose, they could envision the benefit of doing so. The lone exception was an individual that indicated using a model to prevent workers from crawling above a half-demolished ceiling to work. In this case, after noting the serious safety concern they were able to work with the general contractor to find a safer alternative solution. Several individuals mentioned potential ancillary benefits of BIM improving safety by allowing more prefabrication, less site work, and less rework. However, none of these companies were actively using BIM as a way to analyze jobsite safety.

Middle managers were also asked if their companies had an in-house BIM training program. Only one company indicated that they did have an in-house program for providing BIM training. This particular company indicated that they provided regular training for their BIM detailers and periodic training for other individuals within the company. All other companies indicated that they either did not have a BIM training program or that they used so-called on-the-job training. This latter case was generally described as a more experienced detailer looking over the shoulder of a newly hired employee and helping the newly hired employee figure out how to make things work. This is an area where MEP specialty contractors can certainly benefit from increased attention.

The final question regarding implementation of BIM within MEP processes was to identify the various BIM software packages employed for MEP applications. Forty-two percent indicated using a combination of Revit / Revit MEP, 32% Revit MEP / AutoCAD MEP, 16% AutoCAD MEP, and 10% Autosprink VR. Based on the software packages being used, it is likely that MEP specialty contractors were attempting to assimilate their efforts with those of the general contractors. Unfortunately, there were also a variety of software/hardware issues identified by the respondents. First, current BIM software was not yet fully functional for their trade, was difficult to use, and did not allow them to fully model their systems. Second, hardware (e.g. computers or servers) was not sufficient to handle the heavy memory loads associated with using BIM. Finally, participants expressed concern that software incompatibility between trades negatively affected the coordination process. All three of these issues will certainly decrease over time as the software vendors respond to industry needs. However, for early adopters this has apparently been a frustratingly slow process.

Conclusions and Recommendations

MEP processes account for a significant portion of large commercial construction projects. The use of building information modeling within MEP processes continues to increase. This research was established to explore some of the issues still surrounding BIM use by MEP specialty subcontractors, and better understand gaps still existing in the collaborative design process. This research was unique in that it focused on BIM perceptions from multiple levels of management among MEP contractors. The majority of the commercial MEP contractors that participated in this survey were using BIM on over half of their jobs. The remaining contractors were beginning to use BIM or were planning to increase BIM use in the near future. Of those companies using BIM, the overwhelming majority were finding a positive return on their key performance indicators. Profitability increased, schedule durations decreased, and field efficiency/productivity increased due to a drastic reduction in the amount of rework on the jobsite. This means that an MEP company currently using BIM should be more competitive than a company not fully using BIM.

The top uses of BIM by MEP specialty contractors included coordination, prefabrication, and producing as-builts. However, MEP contractors were also using BIM for creating designs, jobsite layout, constructability analysis, performing quantity take offs, preventing delays, scheduling, and meeting miscellaneous client needs. This list indicates that there are significantly more ways that BIM is being used in MEP applications of commercial construction. However, beyond coordination these uses appear to still be fairly limited, thus indicating that there is still sufficient room for the MEP industry to expand the current implementation of BIM into MEP design and construction processes. MEP contractors indicated that the principal benefits of doing so included enhanced coordination and ability to perform quantity takeoffs and estimating, as well as an increased ability to resolve issues prior to constructing and improve accuracy of drawings. The principal challenges associated with using BIM in commercial MEP applications included working with other subcontractors. This was further defined by research participants as subcontractors not sufficiently competent with regard to effectively using BIM, not pulling their weight, or not appropriately prioritizing MEP coordination. Other notable challenges included increased cost and time associated with modeling, a need to resolve software and hardware related issues, not being provided sufficient time to model, dealing with poor design or bad models, field implementation challenges, and finding qualified personnel. These challenges indicate gaps in current BIM implementation for MEP applications and should be the focal point for further research.

This research also provided an overview of how companies more effectively implement BIM into their current MEP applications. Respondents indicated that BIM provided enhanced coordination and prefabrication processes. However, the creation of models for use on MEP projects is an area in which efficiencies in BIM use for MEP specialty contractors can still be improved. Most respondents indicated a reluctance to utilize models created by anyone other than themselves, and even those who accepted models from others spent significant time reworking the models. This doesn't seem to be just a trend amongst only MEP contractors throughout the industry, but continues to be an area in which significant efficiencies in communication and coordination could be gained among all stakeholders. Future research should focus on improving these modeling exchange processes. Additional observations regarding BIM implementation of MEP applications included most respondents not having an established process for determining the level of development needed, the need to increase performance of quantity take offs and cost estimating using BIM, analyzing job-site safety, and establishing better in-house training regarding the use of BIM. These latter observations indicate further research needs for more effectively utilizing BIM by MEP specialty trade contractors across the entire commercial construction industry. As this paper focused primarily on the use of BIM by specialty contractors during the construction phase, another area with tremendous potential for future research is how BIM can be effectively used by MEP specialty contractors during the operations phase and correspondingly how the operations phase can be used to validate the efforts of using BIM during the construction phase. Despite these further research needs, this paper has demonstrated that BIM use by MEP contractors has a proven track record and is becoming more mainstream within the commercial construction industry. As more companies continue to utilize BIM, as academics continue to prepare the next generation of BIM users for the industry, and as these further research needs are met, the effectiveness and breadth of BIM use within MEP applications will certainly strengthen.

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