State of Practice of Building Information Modeling in Mechanical and Electrical Construction Industries

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Abstract: The North American construction industry has seen a decline in productivity for decades due to various reasons, including a lack of collaboration and the increase in the complexity of systems. These problems are most visible in labor-intensive trades, such as mechanical and electrical construction. Within the last decade, building information modeling (BIM) has emerged as a potential solution to these problems. This paper attempts to highlight the state of practice of BIM in the mechanical and electrical industries. By analyzing responses from an extensive survey and interview process, this paper reaches three key conclusions, namely, (1) 59% of mechanical and electrical contractors that use BIM have 3 years or less of BIM experience; (2) contractors should use one to three BIM staff members and add 1–2% of total project-cost estimates to account for BIM implementation; and (3) more than 70% of mechanical and electrical contractors that have used BIM agree that BIM reduces field conflicts and improves coordination. These findings can help mechanical and electrical construction firms understand the evolving use of BIM and allocate resources appropriately. **DOI: 10.1061/(ASCE)CO.1943-7862.0000747.** *© 2013 American Society of Civil Engineers.*

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Introduction

There are several estimates of the construction industry's portion of U.S. gross domestic product (GDP), varying from 4% to 12% based not only on the year, but also on the calculation method. For example, Prieto (2011) indicated the construction industry's portion of the GDP to be 9%. Higher construction output creates economic growth. According to the McGraw-Hill SmartMarket report, the decrease in construction productivity within the last 40 years has mainly been caused by the lack of communication and collaboration (Jones et al. 2008). A recent publication by the National Institute of Standards and Technology stated that at least $15.8 billion per year is lost in inadequate interoperability in the U.S. capital facilities industry (Gallaher et al. 2004). Moreover, the Construction Management Association of America released a survey study that found between 40% and 50% of all construction projects were running behind schedule (Thomsen et al. 2010). One major cause of these overruns is rework (Love 2002). The Construction Industry Institute (2005) reports that the direct costs as a result of rework are approximately 5% of the total construction costs. Other studies have also shown that the cost of rework on building projects ranges from 2% to 6% of the contract value (Josephson and Hammarlund 1999).

Rework is typically caused by poor coordination and conflicts of systems, which is why these problems are most visible in labor-intensive trades such as mechanical, electrical, and plumbing (MEP) construction (Hanna 2010). Because of their direct effect on the efficiency of work flow of a construction project, MEP contractors are expected to continue having a strong influence on project success, especially with the increase in complexity of building systems and the growth of green-building construction.

The MEP construction industry plays a vital role in the overall success of the project. Furthermore, the MEP industry is considered to be one of the riskiest construction industries for several reasons. First, a typical MEP portion of project cost represents 40–60% of a total project cost (Hanna 2010). Second, MEP construction is a follow-up trade, which means that their involvement in a project's construction sequence depends on other critical trades, such as the structural or masonry trades. They are also connected among themselves as three different trades. Third, MEP contractors are responsible for building complex systems that are critical to the functioning of constructed facilities.

In the last decade, building information modeling (BIM) was introduced as an information technology–based construction process to improve efficiency and coordination. The BIM can be defined as a more integrated design and construction process that results in better quality buildings at lower cost and reduced project duration. It can also be defined as a model that contains precise geometry and data needed to support the construction, fabrication, and procurement activities through which the building is realized (Eastman et al. 2007). In this paper, BIM is used to denote the process modeling as opposed to the software used in the process.

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A study by the University of Florida (UFL) evaluated the impact of BIM on construction. The UFL study gathered information from across the construction and engineering industry to evaluate the perceptions of BIM on commonly accepted construction key performance indicators. The research found that BIM improves the following key performance indicators: (1) quality, (2) cost, (3) schedule, (4) productivity, and (5) safety (Suermann and Issa 2009). The McGraw-Hill SmartMarket Report surveyed construction industry professionals to gauge their BIM involvement, and concluded that MEP contractors were among the highest adopters of BIM (Jones et al. 2008). However, much of the research involving BIM targets general contractors. There is a lack of emphasis on how specialty trades implement BIM.

Objectives and Methodology

Quantifying the impact of BIM on MEP trades is crucial to the understanding of the state of the industry and the creation of adequate construction standards. To address the aforementioned gap in the literature, this paper investigates the current state of BIM practice in the mechanical and electrical construction industries in North America through two main objectives: (1) gaining insight on current and future implementations of BIM, and (2) identifying the effect of BIM use on project performance.

To achieve these objectives, a survey was developed and distributed to a total of 1,896 mechanical and electrical construction firms in North America. The development of the survey was based on a previous survey created by McGraw-Hill (McGraw-Hill Construction 2009). Then, with the help of a professional panel consisting of professors, contractors, and survey specialists from the University of Wisconsin Survey Center, the survey for this study was finalized. The survey consisted of 24 questions divided into three sections: (1) company background, (2) current BIM use, and (3) future BIM use. A total of 145 completed survey responses were received (response rate of 8%). The responses were evenly distributed between mechanical contractors (75 surveys) and electrical contractors (70 surveys). The majority of respondents were from U.S. Midwestern states (41%), followed by Western states (28%) and Eastern states (12%). The remaining were Canadian contractors (19%). The types of projects executed by respondents are commercial, industrial, and institutional. The company sizes of respondents, measured in annual billings, ranged from $1 million to more than $50 million, with the majority of respondents (73%) having annual billings of more than $10 million.

Survey Results

The survey results will be discussed under the following four focus headings: (1) overall BIM use at the company level, (2) current state of practice of BIM, (3) future implementation of BIM, and (4) value generated from BIM implementation.

Overall BIM Use at the Company Level

In this focus area of the study, five different sections investigated the overall BIM use at the company level. The five sections are the contractors' level of involvement, the relationship between company size and BIM use, the level of experience and level of expertise with BIM, a comparison of the levels of experience and BIM expertise, and the value that BIM has provided in the past.

The first section under overall BIM use is the contractors' level of involvement with BIM. Of the 145 respondents, 40% are currently not implementing BIM, as shown in Fig. 1. The remaining 60% of respondents using BIM can be categorized as follows: 13% are creating BIM tools in-house; 17% are using existing tools but not necessarily creating their own in-house BIM tools; and 30% are both using existing tools and creating their own in-house BIM tools. In-house BIM tools include, but are not limited to, cost databases, internal BIM procedures, or modeling objects to use within BIM programs.

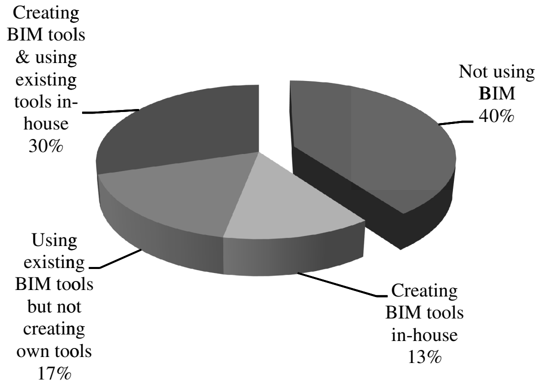

Fig. 1. Contractors' level of involvement

One interesting finding with respect to overall BIM use is the difference between mechanical and electrical construction firms. Approximately 70% of electrical contractors are using BIM, compared with a value of 51% for mechanical contractors. This result highlights the fact that BIM use is more widespread in electrical construction than it is in mechanical construction.

The second section is evaluating the relationship between company size and BIM use. Company size is measured in billings (i.e., the amount a contractor bills clients) in millions of dollars within the last 12 months. Eighty-eight percent of contractors using BIM have annual billings of over $10 million. However, non-BIM users are almost evenly divided between two ranges of annual billings, namely, $1 million to $10 million, and $10 million to $50 million. Fig. 2 shows the relationship between company size and whether or not the respondents are implementing BIM. In the figure, the darker portions all add up to 100% of current BIM users, while all the light-colored portions add up to 100% of non-BIM users. It appears as though a correlation exists between company size and BIM usage. Larger companies tend to have the investment capital to purchase BIM tools and train staff to implement BIM, whereas smaller companies might have difficulties in creating the proper infrastructure to use BIM as standard company process.

The third section evaluates company experience and expertise with the use of BIM. For the remaining parts of the overall BIM

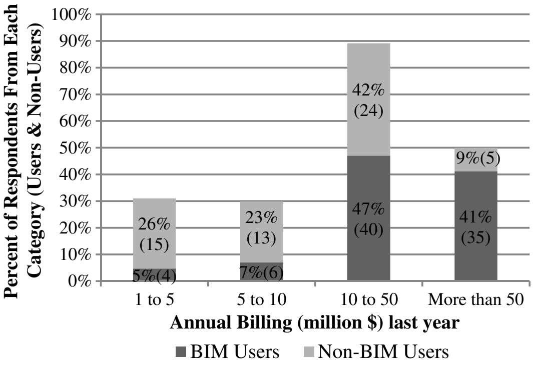

Fig. 2. Relationship between company size and implementation of BIM

use at the company-level focus area, only the responses of current BIM users are considered. Respondents were asked about the number of years that their respective companies have been involved in implementing BIM. Thirty-one percent of the companies surveyed had 5 years or more of BIM experience, 10% had 4 years of experience, 29% had 3 years of experience, 14% had 2 years, and 16% had 1 year of experience. These results suggest that mechanical and electrical contractors are relatively new in their experience with implementing BIM, provided that approximately 60% of current BIM users have only been using BIM for 3 years or less. When combining non-BIM users to evaluate the results more holistically, only 25% of the total respondents have more than 3 years of experience in using BIM.

In relation to companies' experience with BIM, companies were asked to rate their expertise, or competency, with BIM, in the following four categories: *just started*, *started but not efficient*, *advanced*, and *expert*. The respondents indicated that 13% have just started, 28% have started but are still not efficient in implementing BIM, 48% considered their companies advanced, and 11% expert. The data are further combined into two groups: (1) beginners or those that just started or started but are not efficient; and (2) experienced or those that consider themselves advanced and experts. The result is that 41% of respondents can be considered beginners in their level of BIM expertise, and 59% can be considered experienced.

After individually studying the years of BIM experience and level of expertise, the fourth section in this focus area evaluates the relationship between these two variables. Fig. 3 illustrates a key conclusion with respect to defining the level of BIM expertise and helps quantify BIM expertise through the number of years of BIM experience: beginner users of BIM typically have 1–3 years of experience in implementing BIM, whereas experienced users of BIM typically have 3 years or more of experience in implementing BIM. Three years seems to be the cutoff for mechanical and electrical construction firms to consider themselves advanced at BIM. One can see that the middle bar for Year 3 is split in half between users who consider themselves beginners at BIM, and users who consider themselves advanced at using BIM. On the left side of Year 3, one can predominantly see the dark shade of gray, representing beginner users, while on right side of Year 3, one can see the lighter shade of gray that represents advanced users. This number can help mechanical and electrical contractors put in place management plans to advance their expertise in implementing BIM.

The fifth section of this focus area is the mechanical and electrical construction firms' characterization of the business value of BIM. The characterization of the value of BIM in this paper is defined as the overarching business perception of BIM based on the companies' experiences. As illustrated in Fig. 4, only 6% of respondents using BIM indicated no meaningful value of BIM, whereas 94% indicated that BIM provides business value. Moreover, this response emphasizes the steep learning curve, because 65% of respondents indicated that there is still much to learn from the use of BIM.

The five sections in the first focus area discussed results for the overall use of BIM among mechanical and electrical construction firms. The following focus area will investigate the state of practice of BIM implementation in mechanical and electrical construction firms.

Current State of BIM Practice

The five main factors that influence the current state of BIM practice will be discussed in this focus area. These five factors are leadership of BIM coordination, amount of staff members needed to implement BIM and how that relates to project size, predominant BIM tools, cost of using BIM on a project, and associated risks when implementing BIM.

The first factor is identifying appropriate project-team members to lead BIM coordination processes during construction. At a 45% response rate, mechanical and electrical contractors indicated that MEP specialty trades should lead the modeling coordination process. The second most popular response was general contractors (31%) followed by the mechanical/electrical design consultants (15%), project architects (6%), and finally, outside consultants or others (3%). The MEP contractors play a vital role in model coordination with the assistance of the general contractor. After conducting several interviews, this study found that under contractual BIM protocol obligations, general contractors often guide the MEP coordination processes, letting MEP contractors lead the direct modeling efforts. General contractors are involved because they control the overall execution of the project. It was clear from the interviews that a relationship exists between those who benefit from using BIM and the team members leading the effort. When MEP contractors lead coordination, they are more likely to assure that there is adequate space for their systems.

The second factor is the appropriate number of staff needed for BIM implementation on a project. Approximately 44% indicated one individual is adequate and 42% indicated two to three individuals, whereas the remaining 14% indicated four to five staff members. From these data, it is safe to assume that dedicating three or less staff members for BIM implementation is adequate for most projects. In the data-collection process, mechanical and electrical contractors have raised questions related to the allocation of resources to properly implement BIM. This result directly addresses these industry concerns.

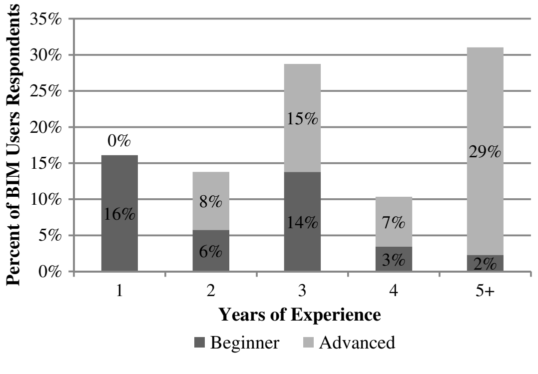

Fig. 3. Relationship between the years of experience in using BIM and the level of expertise in implementation of BIM

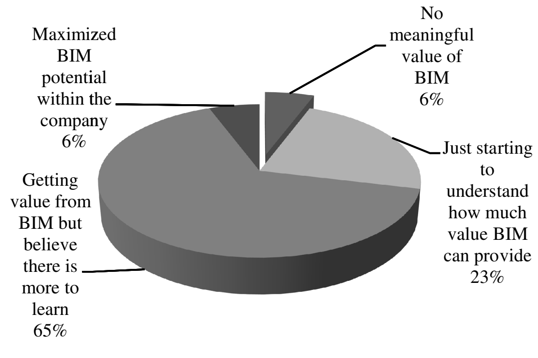

Fig. 4. Realized business value of BIM

As part of the same factor, the relationship between project size measured in total staff-hours and the number of staff that are dedicated for BIM implementation was investigated. For projects that are smaller than 10,000 staff-hours, 53% of respondents indicated that they employ one staff member for BIM, whereas 47% employ two to three staff members. For projects ranging from 10,000 to 50,000 staff-hours, 47% of respondents employ one staff member for BIM and 42% employ two to three staff members, whereas the remaining 11% employ more than three staff members. For projects ranging between 50,000 and 100,000 staff-hours, 44% of respondents employ two to three staff members for BIM, whereas the remaining respondents were divided evenly between 28% employing one staff member and 28% of respondents employing more than three staff members for BIM. Fig. 5 illustrates this result and highlights the relationship between project size and number of BIM staff. As shown in the figure, projects with sizes less than 50,000 staff-hours typically need a maximum of three staff members. One can see that the first bar in Fig. 5 is solely made up of the two shades representing one BIM staff member and two to three BIM staff members. The second bar is almost entirely made of these two shades, with an exception to five responders (approximately 10%). A very clear interpretation of these findings is that projects smaller than 50,000 staff-hours typically need a maximum of three BIM staff members. This relationship is important as it can assist mechanical and electrical contractors in determining efficient resource and budget allocation before starting a project.

Under the current state of BIM practice focus area, the third factor is identifying predominant software and tools used by mechanical and electrical construction firms. The respondents were given several choices and they were allowed to provide their own answer if none of the choices were suitable. The respondents were also allowed to choose more than one answer. Fig. 6 shows the top three software types: *Autodesk Revit MEP*, *Autodesk AutoCAD MEP*, and *Autodesk Navisworks*. It is interesting that a single software company, Autodesk, controls approximately three-fourths of the market for mechanical and electrical construction software. Other tools available but used insignificantly in the industry are *Bentley Microstation*, *TSI*, and *QuickPen*. A follow-up part of this study was interviewing several *Autodesk* software specialists to understand their reaction to the results, and most stated MEP contractors across North America have recently been requesting greater improvements to three-dimensional MEP software technologies to include enhancements in component libraries for more efficient modeling and interoperability.

The use of other BIM tools to enhance modeling construction process also was investigated under the same factor. Respondents were asked to state one related BIM tool they use during the construction process. Fifty-one percent of respondents indicated that Total Station technology is the most widely used BIM tool. Total Station is a technology used in modern electronic surveying devices, integrated with an electronic distance-measuring device to read slopes and distances from the device to a particular point (Gopi et al. 2007). It has become an application that takes the virtual model of BIM into the actual physical space at the jobsite (Strutz 2011). Often times, industry workers identify Total Station technology by its manufacturing brand names such as Trimble, Hilti, Leica, and others as it appears in the survey responses where some of the responses stated specifically the brand name (i.e., Trimble) instead of answering Total Station for that question.

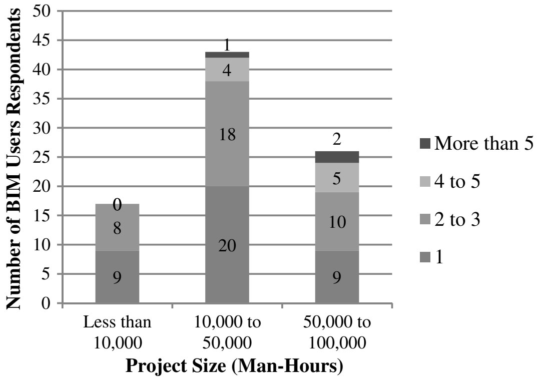

Fig. 5. Relationship between project size and number of BIM staff members

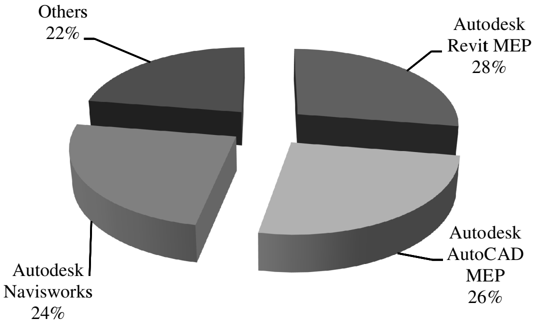

Fig. 6. BIM software used by MEP construction companies

The fourth factor in this focus area is the average cost of implementing BIM. The BIM costs are measured in percent of total project cost. Sixty-one percent of respondents indicated that implementing BIM cost them 2% or less of their total project cost. Fig. 7 shows the response rates for all ranges of BIM cost. These results can assist in the bidding process when determining the allocation of costs related to BIM implementation.

The last factor in the state of BIM practice is the risk associated with the use of BIM. Sixty-one percent of survey respondents stated the highest risk item is the lack of BIM protocols during the construction phase. A BIM protocol can be defined as a contractual guide to the BIM process, which includes stakeholders' roles and responsibilities for items such as file sharing, model ownership, model file formats, specific leading trade models, scheduled model submissions for review, and responsibility of model changes on a specific project basis (American Institute of Architects 2008). The second highest response (15%) was cost overrun with the use of BIM. The previous findings will help better allocate financial resources and staff to reduce this risk. Interestingly, the third highest response (12%) was the lack of competency

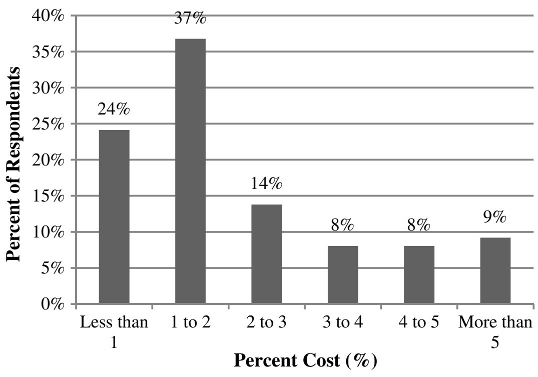

Fig. 7. BIM-implementation cost (in percent of total project cost)

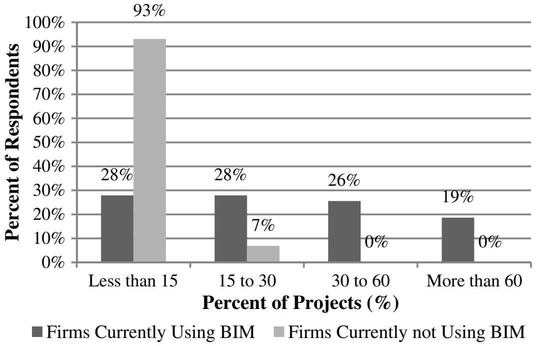

Fig. 8. Percent of projects to implement BIM in the next 2 years

of team members in using BIM. This response was not provided as one of the choices but was written by respondents. These important findings point to potential solutions to reduce project risks related to BIM, including the development of comprehensive standards and training modules for mechanical and electrical contractors to adequately implement BIM on their projects.

The five factors discussed here provide clear insights regarding the state of practice for BIM implementation among mechanical and electrical construction firms. After evaluating these factors, the next section will investigate the future implementation of BIM.

Future Use of BIM

Two main points are discussed to evaluate the future use of BIM by mechanical and electrical construction firms. They are (1) the percentage of projects that will be implementing BIM in the next 2 years, and (2) the comparison of future BIM investments by both current BIM users and non-BIM users.

Regarding the percentage of projects that will implement BIM in the next 2 years, Fig. 8 shows the variation in responses between those who currently implement BIM and those who do not. Current BIM users show an even distribution between those who will be implementing BIM on less than 15% of their projects (24 respondents), on 15–30% of projects (24 respondents), 30–60% of projects (22 respondents), and more than 60% of their projects (16 respondents) in the next 2 years. This may appear as a relatively modest BIM use. However, it is often owners, not contractors, who tend to drive much of BIM implementation on projects. For example, it was only 2 years ago that the State of Wisconsin mandated BIM implementation for all state-construction projects (DeVries 2009). As for those who are not currently using BIM, 93% (54 respondents) of the respondents indicated that they would implement BIM in fewer than 15% of projects, and 7% (four respondents) of the respondents indicated that they would implement BIM on 15–30% of projects. These current non-BIM users may not have sufficient resources to implement BIM on a larger number of projects. As identified earlier, most non-BIM users are relatively small firms.

The second part in this focus area highlighting the future use of BIM is the comparison of the current and future BIM investments by current BIM users and non-BIM users. Table 1 shows the mean value and rank of each type of current investment for both specialties surveyed as part of this study. Separate and then combined scores of mechanical and electrical contractors are shown. The mean score for each investment is calculated using a five-point Likert scale, with 5 for *a great deal*, 4 for *quite a bit*, 3 for *some*, 2 for *a little*, and 1 for *none*. The Likert scale is a psychometric scale commonly involved in research that uses questionnaires (Chatterjee and Hadi 2006).

Contractors of both specialties currently using BIM agree on their top three current investments in BIM, which are (1) marketing BIM to customers, (2) purchasing software, and (3) training staff. Table 1 also shows statistical significance through P values. A P value less than 0.05 implies a significant difference between the means of the two groups (mechanical and electrical). One statistically significant difference was found between the mean scores of both specialties for marketing BIM to customers with electrical being higher; however, the ranking of the investment was close (first and second) in both specialties. Contradictory to other

Table 1. Current and Future Investments in BIM

	Mechanical contractors		Electrical contractors		*t*-Test		Combined score	
Investment type	Mean	Rank	Mean	Rank	P value	Significance	Mean	Rank
BIM users: current investment								
Purchasing software	3.11	1	3.04	3	0.823	—	3.07	2
Creating BIM procedures in company	2.55	5	3.02	4	0.092	—	2.82	5
Creating BIM libraries	2.71	4	2.96	5	0.382	—	2.85	4
Creating BIM procedures with other companies	2.21	6	2.39	6	0.484	—	2.31	6
Training staff	2.92	2	3.18	2	0.334	—	3.07	2
Marketing BIM to customers	2.92	2	3.55	1	0.041	SS	3.28	1
BIM users: future investment for the next 2 years								
Purchasing software	3.00	5	2.98	5	0.929	—	2.99	5
Creating BIM procedures in company	3.32	2	3.27	3	0.807	—	3.29	3
Creating BIM libraries	3.13	4	3.24	4	0.658	—	3.20	4
Creating BIM procedures with other companies	2.66	6	2.78	6	0.640	—	2.72	6
Training staff	3.29	3	3.43	2	0.591	—	3.37	2
Marketing BIM to customers	3.47	1	4.00	1	0.044	SS	3.77	1
Non-BIM users: future investment for the next 2 years								
Purchasing software	2.00	1	2.29	1	0.213	—	2.11	1
Creating BIM procedures in company	1.39	3	2.00	3	0.004	SS	1.61	3
Creating BIM libraries	1.36	4	1.76	4	0.059	CS	1.51	4
Creating BIM procedures with other companies	1.28	5	1.57	6	0.167	—	1.39	6
Training staff	1.47	2	2.05	2	0.013	SS	1.68	2
Marketing BIM to customers	1.28	5	1.67	5	0.052	CS	1.42	5

Note: CS = close to being significant; SS = statistically significant.

research results (Jones et al. 2008; Young et al. 2009), the data show that relatively little investment is currently being made in creating BIM procedures in-house and creating BIM procedures with other companies.

After evaluating the current investments of BIM users, the future investments of these current BIM users were evaluated. By looking at bold portion of Table 1, one can find that two of the top three current investments in BIM, marketing BIM to customers, and training staff, are still in the top three BIM investments anticipated for the next 2 years for both specialties surveyed. Investment in creating internal BIM procedures took over the third position from purchasing software. This is a logical next step for a company that is already using BIM; once they had made the proper software purchases and adequately trained their employees, experienced firms can create their own BIM procedures. Again, one statistically significant difference was found between the mean scores of both specialties for marketing BIM to customers; however, the ranking of the investment was the same (first) in both specialties.

An evaluation of mechanical and electrical construction firms that are currently non-BIM users shows an interesting contrast to these results, as illustrated in the last part of Table 1. Lower mean values indicate very little future investment with BIM for a given type of investment. There is an agreement in both specialties on the ranking of all types of investment, albeit some statistically significant differences in their mean scores. One major disagreement between the current BIM users (bold) and the non-BIM users is investing in marketing BIM to customers, which is ranked second to last for the non-BIM users.

To further emphasize the variation between BIM users and non-BIM users, Table 2 shows the mean score of each type of future investment to be made by both BIM and non-BIM users. A *t*-test was performed to show statistically significant differences among the mean scores. There is a reversing of the position for the first and fifth ranked investments, marketing BIM to customers, and purchasing software, with an agreement on all the remaining ranks of the investments. However, there is a difference in the scale of investment between these two groups as shown by statistically significant differences between the mean scores of all investment types.

This second part of the focus area highlighted key BIM investment types that mechanical and electrical construction firms are considering for future BIM implementation. Because current BIM users are increasing their investment in BIM, it would be interesting to understand how BIM is providing value for these companies. The added value of BIM will be investigated in the final focus area of this paper.

Added Value of BIM

Current BIM users were asked about the value generated by BIM for three different aspects of a construction project, namely, project phases, project activities, and project-performance indicators. Findings from this focus area will highlight the perceived influence of BIM on construction operations as applied to the following three aspects.

The first aspect is evaluating the added value of BIM to major project phases. Table 3 shows the mean score and rank for each project phase, both separately and combined, for both specialties. The mean values for each phase are calculated using the same five-point Likert scale discussed in the previous section: 5 for *a great deal*, 4 for *quite a bit*, 3 for *some*, 2 for *a little*, and 1 for *none*. A *t*-test also was performed to find statistically significant differences between the two specialties' scores.

There are five phases with high mean values: (1) final design, (2) construction documentation, (3) fabrication, (4) construction, and (5) shop drawings. Both specialties have these phases in the top five, with slight differences in the ranking. No statistically significant differences were found between the mean scores of the two

Table 2. Future Investments for the Next 2 Years—Current BIM Users versus Non-BIM Users

	Current BIM users		Current non-BIM users		*t*-Test results	
Investment type	Mean	Rank	Mean	Rank	*P* value	Significance
Purchasing software	2.99	5	2.11	1	<0.001	SS
Creating BIM procedures in Company	3.29	3	1.61	3	<0.001	SS
Creating BIM libraries	3.20	4	1.51	4	<0.001	SS
Creating BIM procedures with other companies	2.72	6	1.39	6	<0.001	SS
Training staff	3.37	2	1.68	2	<0.001	SS
Marketing BIM to customers	3.77	1	1.42	5	<0.001	SS

Note: SS = statistically significant.

Table 3. Level of Value BIM Generates for Each Project Phase

	Mechanical contractors		Electrical contractors		*t*-Test		Combined score	
Project phase	Mean	Rank	Mean	Rank	*P* value	Significance	Mean	Rank
Feasibility studies	2.35	9	2.68	9	0.377	—	2.50	9
Preliminary design	2.70	6	3.08	7	0.164	—	2.91	6
Final design	3.43	3	3.79	2	0.241	—	3.60	3
Construction documents	3.24	5	3.58	3	0.213	—	3.44	4
Bidding	1.84	11	2.13	11	0.565	—	1.92	11
Fabrication	3.89	2	3.55	4	0.155	—	3.67	2
Construction	3.95	1	4.05	1	0.440	—	4.03	1
Shop drawings	3.27	4	3.50	5	0.580	—	3.36	5
Submittals	2.19	10	2.66	10	0.175	—	2.40	10
Closeout	2.49	7	3.11	6	0.031	SS	2.85	7
Operations and maintenance	2.38	8	2.82	8	0.325	—	2.55	8

Note: CS = close to being significant; SS = statistically significant.

specialties except for the closeout phase. However, when looking at the ranking, closeout was similarly ranked by both specialties (sixth and seventh). All the top five phases are part of the construction process. Because mechanical and electrical contractors are typically only involved during construction, it is understandable that they only see the benefits BIM brings to these construction phases. The other phases that had lower values are typically phases in which the mechanical and electrical contractors are not involved in the project, and therefore, do not see directly the added value of BIM first hand. However, this may change when contractors are involved early in innovative delivery systems, especially when used for high-complexity facilities.

The second aspect of this focus area is evaluating the added value of BIM on key project activities. The choice of these activities was based on previous literature, the authors' experiences, and input from mechanical and electrical construction firms. Table 4 shows a similar format to Table 3 as applied to project activities. A *t*-test also was performed to find statistically significant differences between the scores of the mechanical and electrical specialties.

Several findings can be concluded from Table 4. There is an agreement among the survey respondents from both the mechanical and electrical specialties on the top four activities for which BIM generates value, namely, (1) clash detection, (2) visualization of facility design, (3) shop-drawing process, and (4) more efficient use of time. In addition, both specialties have project turnover and closeout and stakeholder engagement alternating for the fifth and sixth ranks. The first two activities, clash detection and visualization of facility design, have significantly higher mean values than other activities, which could be related to the coordination of complex mechanical and electrical systems. This result is in line with previous research that indicated better visualization and clash detection are top benefits when using BIM. This study confirms the same findings apply more specifically to MEP construction firms. In addition, the SmartMarket report states one of the top three benefits of BIM for MEP contractors is the shop-drawing process (Jones et al. 2008), which is reinforced by the findings of this study. The nine remaining project activities have considerably lower means, indicating less value added with the use of BIM. Some of these results were unexpected, because literature shows that BIM does bring value to project activities such as scheduling, quantity takeoff, and cost estimation (Jones et al. 2008; Young et al. 2009; Korman et al. 2008). More specifically, the SmartMarket report states that MEP contractors are likely to find value in quantity takeoff with BIM (Jones et al. 2008), whereas this activity was only ranked tenth in this study.

Finally, the third aspect in this focus area is the added value of BIM as measured by project-performance indicators. Key performance metrics were first identified based on literature describing indicators widely used by MEP construction firms (Suermann and Issa 2009; Jones et al. 2008). The list of metrics was finalized through the authors' interactions with the MEP construction industry experts. As shown in Table 5, the top six project performance measures, (1) better system coordination, (2) reduction in field conflicts, (3) reduction in cost of rework, (4) reduction in deficiency issues, (5) reduction in cost of as-built drawings, and (6) reduction in request for informations (RFIs), are significantly

Table 4. Level of Value BIM Generates for Project Activities

	Mechanical contractors		Electrical contractors		*t*-Test		Overall score	
Project activities	Mean	Rank	Mean	Rank	*P* value	Significance	Mean	Rank
Clash detection	4.11	1	4.31	1	0.300	—	4.22	1
Cost estimation for project	2.11	9	2.20	10	0.664	—	2.16	11
Energy/lighting analysis	1.57	12	2.04	12	0.027	SS	1.84	12
Facility-space planning	1.95	11	2.55	7	0.018	SS	2.29	8
More efficient use of time	2.38	4	3.04	4	0.007	SS	2.76	4
Project turnover and closeout	2.32	5	2.78	6	0.099	—	2.58	5
Quantity takeoff	2.25	7	2.20	10	0.862	—	2.22	10
Scheduling	2.05	10	2.49	8	0.059	CS	2.30	7
Shop-drawing process	2.81	3	3.06	3	0.394	—	2.95	3
Stakeholder engagement	2.26	6	2.80	5	0.066	—	2.57	6
Submittal process	2.16	8	2.39	9	0.332	—	2.29	8
Visualization of facility design	3.49	2	3.86	2	0.140	—	3.70	2

Note: CS = close to being significant; SS = statistically significant.

Table 5. Level of Value BIM Generates on Ten Performance Indicators

	Mechanical contractors		Electrical contractors		*t*-Test		Overall score	
Performance indicator	Mean	Rank	Mean	Rank	*P* value	Significance	Mean	Rank
Reduction in RFIs	2.97	6	3.10	5	0.596	—	3.05	6
Reduction in Resubmittals	2.62	9	2.59	9	0.897	—	2.60	9
Reduction in field conflicts	3.95	2	4.08	2	0.476	—	4.02	2
Reduction in deficiency issues	3.11	5	3.27	4	0.545	—	3.20	4
Reduction in punch-list items	2.84	8	2.94	7	0.689	—	2.90	7
Reduction in cost of rework	3.27	3	3.51	3	0.345	—	3.41	3
Reduction in cost of as-built drawings	3.24	4	3.08	6	0.551	—	3.15	5
Reduction in change orders	2.86	7	2.90	8	0.887	—	2.88	8
Shorter processing time for change orders	2.38	10	2.24	10	0.618	—	2.30	10
Better coordination	4.05	1	4.14	1	0.659	—	4.10	1

Note: CS = close to being significant; SS = statistically significant.

improved (mean score > 3) when mechanical and electrical construction firms implemented BIM. Both specialties agreed in the ranking of the top three performance indicators, and alternated rankings of the next three (the fourth, fifth, and sixth indicators) with no statistically significant differences among mean scores between mechanical and electrical contractors. The two greatest improvements as shown by mean values from both specialties are better systems coordination and reductions in field conflicts. This finding confirms that mechanical and electrical contractors behave similarly to other parties, as shown in previous literature, which underlines the significant improvements that BIM brings in resolving field conflicts and improving systems coordination. Moreover, when conducting interviews, many MEP contractors, who keep measures of performance, stated that BIM positively impacts their labor productivity and material efficiency. The findings of this study highlight major performance improvements related to BIM, and help build momentum for mechanical and electrical contractors to adopt BIM.

Conclusion

The "Survey Results" section highlighted some key findings. The first finding is the existence of three correlations, namely, (1) company size and BIM usage, (2) project size and number of staff to implement BIM, and (3) BIM experience measured in years versus level of expertise or competency. The second finding is that the majority of mechanical and electrical firms apply 1–2% of total project cost toward BIM implementation. The third finding is that there are three investment types that the majority of respondents will be investing in during the next 2 years for BIM usage, including creating in-house BIM procedures, training staff members, and marketing of BIM to customers. These second and third findings will help mechanical and electrical construction firms better allocate resources for BIM implementation. The fourth finding revolves around the numerous BIM benefits for mechanical and electrical project execution, including reduction in field conflicts, improved coordination, easier clash detection, and enhanced facility-design visualization. All of the key findings discussed illustrate important practices and characteristics of BIM use in the mechanical and electrical construction industries. The results of this study showcase additional aspects of the state of BIM practice among mechanical and electrical construction firms in North America, including popular BIM tools as well as main risks associated with BIM. Moreover, findings have been reached to enhance the implementation of BIM, most notably the number of staff that should be dedicated to BIM on a mechanical or electrical construction project.

Some of these findings, such as the value generated by the use of BIM, might vary based on several project factors, such as complexity of the project, owner initiatives to standardize BIM use, project size, and use of BIM protocols. Therefore, more research is needed to understand such variations. This study may lead to three main future research areas. The first is developing a cost–benefit analysis for implementing BIM on mechanical and electrical construction. The second area is to assist in the creation of BIM standards for the mechanical and electrical construction industries to help minimize the risks associated with the use of BIM. The third is increasing the sample surveyed for this study to arrive at more generalizable conclusions and to map any change in the trend of BIM adoption in the future such as the correlation between company size and its BIM usage. The results discussed show that BIM is still an evolving process that confronts many challenges. Many mechanical and electrical construction firms have yet to scratch the surface in their implementation of BIM.

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