

A Comparison of Realized Benefits of BIM Implementation on Commercial Building and Parking Garage Projects

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The implementation of Building Information Modeling (BIM) results in realized and reported benefits for multiple stakeholders in the building design, construction, operation and maintenance industries. While this topic has been explored on complex commercial projects, comparison of the benefits of BIM implementation on simpler projects has received less attention. This study explored and compared the realized benefits of BIM implementation on commercial and parking garage projects. Specifically, differences in project stakeholder (Architects, Owners and General Contractors) perceptions of benefits realized, resultant chosen delivery method and building type, are discussed. Data were collected via an electronic survey distributed to project stakeholders in the state of Colorado. Survey results revealed that general contractors (n=59) reported a significantly ($p<0.001$) lower level of agreement that the BIM implementation was effective for Design-Bid-Build projects than did architects (n=46). General contractors reported significantly ($p<0.05$) higher levels of agreement regarding benefits such as improved labor productivity, reduced reportable safety incidence and reduced material waste when compared to architects. General contractors indicated that BIM was significantly ($p<0.05$) more beneficial on commercial building than on parking garage projects on benefits such as improved process of controlling construction costs, reduced final construction cost of projects, and increased predictability/fewer unplanned changes.

Key Words: BIM Benefits, Commercial Buildings, Parking Garages, Architects, Contractors

Introduction

Use of building information modeling (BIM) within the architecture, engineering, construction, operation and maintenance industries (AECOM) has been gradually increasing over the last decade (McGraw Hill Construction, 2012). Stakeholder awareness of the realized benefits resultant BIM implementation has further accelerated BIM utilization. Studies investigating the realized benefits of BIM implementation have been conducted on larger commercial projects. However, less attention has been given to classifying the BIM benefits realized on simpler projects and comparing these benefits to those reported on more complex commercial projects.

According to Dodge Data & Analytics (2015), hospitals, laboratories, data centers, entertainment buildings, industrial/manufacturing facilities and transportation buildings (e.g. airports, major railway stations) are considered complex structures. In the case of complex buildings, project execution is more challenging, risks may be greater and need for improvement more crucial. On the other hand, parking facilities are simple structures as they, for example, do not necessarily have to include complex mechanical, electrical and plumbing systems and building envelope; therefore, they require use of simpler execution methods and are typically less risky. In the USA, both complex and simple building projects have been utilizing building information modeling (BIM) and it is generally recognized that BIM utilization contributes to a proven and effective process using different project delivery methods such as Design-Build and Integrated Project Delivery.

The goal of this research was to explore the perceptions of different project stakeholders (Architects, General Contractors and Owners) regarding BIM implementation on two specific project types (commercial buildings and parking garages). The overarching purpose was to explore and identify if there are any differences in BIM use benefits on complex projects such as commercial buildings and simple projects such as parking garages. More specific research objectives included investigating: 1) stakeholder perceptions of effectiveness of BIM use for different project delivery methods, particularly Design-Bid-Build and Design-Build; 2) stakeholder perceptions of realized benefits due to BIM use, 3) architect perceptions of BIM benefits on commercial buildings and parking garages; and 4) general contractor perceptions of BIM benefits on commercial buildings and parking garages. In order to accomplish the research objectives a survey was distributed to the various stakeholder that were involved in the commercial building and/or parking garage projects in the state of Colorado. A McGraw Hill Construction survey investigating BIM utilization on complex building (Dodge Data & Analytics 2015) was used as a starting point to create a survey instrument. The survey responses were analyzed using various statistical tests such as frequency count, one-way ANOVA, and independent samples *t*-tests. This research contributes to the body of knowledge as there was no previous study found that conducted a comparison of project stakeholder perceptions of the realized benefits of BIM implementation on complex/commercial buildings and simple/parking garage projects.

Literature Review

National Institute of Building Sciences (NIBS) (2015) defines building information modeling (BIM) as a business process that generates data to be used during design, construction and operation/maintenance of a building throughout building life cycle. In addition, a building information model is defined as a digital representation of a facility that can be used as a shared knowledge resource by different stakeholders involved in a building project (NIBS, 2015). BIM adoption within AECOM has been steadily increasing. McGraw Hill Construction surveys of the Architecture, Engineering and Construction (AEC) industries in the US showed that the adoption rates increased by 75% in the five-year period; in 2008, about one-third (28%) of the AEC industry utilized BIM, while in 2012 more than two-thirds (71%) used BIM (McGraw Hill Construction, 2012).

One reason for this increase of BIM use is the numerous benefits that BIM provides to the stakeholders such as centralized and visual communication, early exploration of options, sustainability, efficient design, integration of disciplines, site control, and as-built documentation (NIBS, 2015). Use of BIM also facilitates decision-making, improves productivity and safety, decreases uncertainty, reduces the number of change orders, and number of claims and litigations (Ahn et al., 2016). Previous research showed that BIM utilization facilitates improved collaboration among project participants as compared to a traditional approach (Hamdi & Leite, 2014; Ahn et al., 2016).

In the McGraw Hill Construction (2012) survey, AEC professionals were asked about both long-term and short-term benefits of using BIM on building projects. The respondents reported the following long-term benefits of BIM use: maintaining repeat business, reduced project duration and cost, increased profit and reduced litigations. They also identified several short-term benefits related to BIM use on a project such as reduced errors in construction documents, reduced rework, marketing new business and offering new services, and reduced time of specific workflows (McGraw Hill Construction, 2012). Ahn et al. (2016) noted better construction drawings, reduced labor cost, and increased prefabrication as the additional short-term benefits of BIM use.

In the later survey by Dodge Data and Analytics (2015), majority of the respondents (85% and 88%, respectively) reported reduced final cost and completion time as the benefits of BIM application on complex projects. Nearly 74% of the AEC professionals experienced a 5% reduction in the number of RFIs created and addressed on project implementing BIM. AEC professionals and owners were also asked to apply 1-10 scale to rate impact of the BIM use on improving various project outcomes. Survey respondents indicated that BIM use had an impact on increased the owner's understanding of design (avg. score of 8.8) and ability to actively participate in design process (avg. score of 6.4), as well as improved cost estimate accuracy (avg. score of 5.1), increased the ability to manage project scope (avg. score of 5.1), and reduced material waste (avg. score of 3.2). (Dodge Data and Analytics, 2015)

Different stakeholders experience various benefits due to the use of BIM. According to Eastman et al. (2011), BIM is beneficial for automated generation of accurate 2D drawings from the 3D models, and for enhancing collaboration of different design disciplines. The top benefits of BIM according to the architects included reduced document errors and omissions, marketing new business and offering new services (McGraw Hill Construction, 2012).

For contractors, reduced rework was the major benefit while, similarly to the architects, the contractors indicated reduced document errors and omissions and marketing new business as some of the most important benefits of BIM implementation (McGraw Hill Construction, 2012). Ahn et al. (2016) noted that contractors could benefit from using BIM for accessing building information models and solving construction problems on site as soon as they arise. Use of BIM for visualizing the construction sequence is particularly useful in the case of complex projects (Eastman et al. 2011). In addition, BIM enables off-site prefabrication of the building components resulting in reduced cost and duration of a project (Eastman et al., 2011; Dodge Data & Analytics, 2015). The majority of the contractors indicated that BIM implementation improved constructability of the final design and that BIM use led to increased labor productivity on the complex projects (Dodge Data & Analytics, 2015).

In the same survey, the majority of the owners reported that BIM use improved their ability to plan project phasing and logistics and resulted in better construction documents (Dodge Data & Analytics, 2015). Similar to contractors, owners indicated that BIM use led to increased labor productivity and reduced site labor due to prefabrication on the complex projects (Dodge Data & Analytics, 2015). Similar to the architects, owners identified reduced document errors and omissions as the top benefit of BIM use while, similar to contractors, owners stated that they benefited from reduced rework (McGraw Hill Construction, 2012). Owners also indicated reduced project cost and duration as the important benefits due to the BIM use (McGraw Hill Construction, 2012).

Previous studies noted the effectiveness of BIM use for Design-Build and Integrated Project Delivery (IPD) projects. Integration of BIM and IPD increased the expectations of successful completion of a project (Glick & Guggemos, 2009). According to Becerik-Gerber & Kensek (2010), the large majority of the practitioners (89%) were interested in exploring the use of BIM for Integrated Project Delivery. Use of BIM in conjunction with IPD and Lean practices did facilitate teamwork and contributed to better design and construction products (Dossick et al., 2013). BIM use enhanced collaboration on the project and, thus, optimized construction and fabrication (McGraw Hill Construction, 2014).

Majority of the architects, contractors and owners (56%, 68%, 63%, respectively) expected increase in the use of Design-Build project delivery method in the building sector by 2017 while smaller proportion (10%, 20%, 23%, respectively) expected increase in the use of Design-Bid-Build delivery method (McGraw Hill Construction, 2014). The owners reported reduced cost and duration of the project as well as the overall satisfaction with project outcomes as the major benefits of using Design-Build project delivery method (McGraw Hill Construction, 2014). Fewer change orders and reduced project duration were the main benefits realized according to the architects while contractors also indicated fewer change orders and improved team communication due to the use of Design-Build delivery project method (McGraw Hill Construction, 2014). Interestingly, the major benefits due to Design-Build use coincide with the major benefits reported due to use of BIM on the projects (McGraw Hill Construction, 2012; McGraw Hill Construction, 2014; Dodge Data & Analytics, 2015).

Research Questions and Hypotheses

The review of literature revealed a great deal of research attention given to the effectiveness of BIM implementation given varied project delivery methods (e.g. Design-Build vs. Design-Bid-Build) as well as various stakeholder perceptions of the realized benefits of BIM on construction projects. Research questions one and two were investigated to explore these overarching themes noted in the Literature.

Further exploration of the literature revealed that a large proportion of the current BIM research focused on complex commercial projects. However, limited research exploring the realized benefits of BIM implementation on simple projects, such as parking garages, was found. Research questions three and four were conducted to compare project stakeholder perception of the realized benefits on BIM implementation given building type (commercial building vs. parking garages). Comparison between commercial buildings and parking structures was conducted using the same benefits tested by Dodge Data & Analytics (2015) to maintain identical independent variables given the dependent variable; building type.

The research questions investigated are as follows:

RQ 1: Are significant differences in stakeholder perceptions of the effectiveness of BIM implementation observed when compared by project delivery methods (Design-Build and Design-Bid-Build)? The null (H0) and alternative (H1) hypotheses were based on the equality or inequality, respectively, given stakeholder perception of the effectiveness of BIM implementation observed when compared by project delivery methods (Design-Build and Design-Bid-Build).

RQ 2: Are significant differences in the realized benefits of BIM implementation observed when compared by project stakeholder (Architect, General Contractor and Owner)? The null (H0) and alternative (H1) hypotheses were based on the equality or inequality, respectively, given stakeholder mean realized benefits of BIM implementation observed when compared by stakeholder.

RQ 3: Are significant differences in Architect perceptions of the realized benefits of BIM implementation observed by Building Type (parking garage and commercial building)? The null (H0) and alternative (H1) hypotheses were based on the equality or inequality, respectively, given Architect perceptions of mean realized benefits of BIM implementation compared by Building Type (commercial building and parking garage).

RQ 4: Are significant differences in General Contractor perceptions of the realized benefits of BIM implementation observed by Building Type (parking garage and commercial building)? The null (H0) and alternative (H1) hypotheses were based on the equality or inequality, respectively, given General Contactor perceptions of mean realized benefits of BIM implementation compared by Building Type (commercial building and parking garage).

Research Method

As noted previously, a Dodge Data & Analytics (2015) report on complex buildings was used to identify the realized benefits of BIM implementation since the stakeholders queried in the current study match those in the original report. It was also noted that the results of the Dodge Data & Analytics (2015) report were aggregated for a variety of complex buildings (hospitals, laboratories, data centers, entertainment buildings, industrial/manufacturing facilities and transportation buildings) without focusing on one particular type. This method of comparisons was chosen so that identical independent variables (i.e. benefits identified by Dodge Data & Analytics, 2015) could be compared given the dependent variable (building type; commercial buildings vs. parking structures). Since the study aim and research questions investigated differences between the perception of various stakeholder, Student t-test and Analysis of Variance (ANOVA) and appropriate Post-Hoc statistical tests for two-level and multi-level comparisons were used, respectively.

Instrumentation

An online survey was developed using Qualtrics® survey software. The survey contained two sections that were utilized in the current study. Section one included demographic items and general questions which assessed respondent agreement with statement about the effectiveness of BIM on different building design and delivery methods (i.e. "Building Information Modeling can effectively be implemented on construction projects using a Design-Bid-Build (DBB) delivery method": 1 = Strongly Disagree to 10 = Strongly Agree). Survey section one and two were separated by a qualifying item which required respondent identified that they reported BIM benefit for a parking garage project or commercial building project. Skip logic was built into the survey and participants were directed to a parking garage-specific or commercial building-specific section two of the survey. Section two of the survey contained an identical list of benefits and the survey items were only adapted by exchanging the words "parking garage" with "commercial building" (e.g. "Based on your experience with a parking garage that utilized or implemented Building Information Modeling, please identify your agreement with the following statements" was replaced with "Based on your experience with a commercial building projects that utilized or implemented Building Information Modeling, please identify your agreement with the following statements". Respondents were asked to provide their level of agreement on a 10-point Likert scale (1 = Strongly Disagree to 10 = Strongly Agree) for each benefit listed based on the prompt for parking garages "The following benefits were realized when implementing Building Information Modeling (BIM) on the parking garage project" or commercial buildings "The following benefits were realized when implementing Building Information Modeling (BIM) on the commercial building project". The survey participants were asked to rate the following BIM benefits -- increased: understanding of proposed design solutions, ability to actively participate in design process, ability to manage project scope, and predictability/fewer unplanned changes; reduced: number of RFIs, final construction cost of projects, rework, site labor due to increased offsite fabrication, reportable safety incidents, and material waste; improved: quality/function of final design, constructability of final design, process and accuracy of estimating construction costs, accuracy and completeness of bids, ability to plan construction phasing and logistics, process of controlling construction costs, achievement of planned schedule milestone dates, and labor productivity; and generating better construction documents.

Participants and Survey Administration

The potential participant pool comprised architects, engineers, consultants, general contractors, subcontractors and owners that were involved in the commercial building and/or parking garage projects in the state of Colorado. The survey URL was administered via Qualtrics® software in an online format through the email list serves of the facilities department of a large University and a commercial construction firm.

Results

Sample and Data Screening

In total 202 survey responses were received. Listwise deletion was employed to cull 41 incomplete survey responses yielding 161 responses. Participant responses were further screened using the demographic items "Have you worked on a construction project that has implemented or utilized Building Information Modeling?"; 24 respondents who answered "no" to this item were removed from the dataset. Since the target cohort for this study was general contractors, architects and owners, and given the small number of responses received form engineers (5), consultants (7) and other (1) stakeholder; these surveys were culled from the sample. In total, 82 responses were removed yielding an analysis sample of 120 participants. The demographic data of the cleaned sample is provided in Table 1.

Table 1. Demographic Characteristics (*n* = 120)

Characteristic	*n*	%
Gender		
Female	23	19.2
Male	93	77.5
Prefer not to respond	4	3.3
Stakeholder		
Architect	46	38.3
General Contractor	59	49.2
Owner	15	12.5
Building Type		
Parking Garage	31	25.8
Commercial Building	89	74.2

Addressing the Research Questions

Research question one (RQ 1): Are significant differences in stakeholder perception of the effectiveness of BIM implementation observed when compared by project delivery methods (Design-Build and Design-Bid-Build)?

One-way ANOVA (Table 2) was completed to investigate differences in stakeholder perceptions of the effectiveness of BIM implementation given project delivery method (Design-Build and Design-Bid-Build). Significant differences were observed on “Design-Bid-Build” ($p = 0.003$). The null hypothesis was rejected for Design-Bid-Build due to the significant mean difference in stakeholder perception of the effectiveness of BIM implementation given the selected project delivery method. The null hypothesis was retained for Design-Build since no significant difference was observed. Post hoc planned comparisons indicated that there were significant differences ($p < 0.001$) between Architect ($n = 46$, $M = 8.65$) and General Contractor ($n = 59$, $M = 7.14$) perception of the effectiveness of BIM implementation on Design-Bid-Build projects. Specifically, General Contractor reported a significantly lower level of agreement with the statement the BIM implementation was effective for Design-Bid-Build projects. No significant differences in the perception of the effectiveness of BIM in Design-Build and Design-Bid-Build between General Contractor and Owner, or Owner and Architect were observed.

Table 2. One-Way ANOVA Results: Perception of the effectiveness on BIM implementation by Delivery method

Variable	*df*	*SS*	*MS*	*F*	*p*
Design-Build					
Between Groups	2	0.89	0.444	0.214	0.808
Within Groups	117	243.10	2.078		
Total	119	243.99			
Design-Bid-Build					
Between Groups	2	60.383	30.192	6.017	0.003
Within Groups	117	587.083	5.018		
Total	119	647.467			

Research question two (RQ 2): Are significant differences in realized benefits of BIM implementation observed when compared by project stakeholder (Architect, General Contractor and Owner)?

One-way ANOVA (Table 3) was completed to investigate differences in perceptions of the realized benefits of BIM implementation given project stakeholder (Architect, General Contractor and Owner). Significant differences were observed on "Improved Labor Productivity" ($p = 0.019$), "Reduced Reportable Safety Incidence" ($p = 0.006$) and "Reduced Material Waste" ($p = 0.004$). The null hypothesis was rejected for the benefits listed due to the significant mean difference perception on realized benefits of BIM implementation by stakeholder. The null hypothesis was retained for all other perceptions on realized benefits of BIM implementation since no significant difference was observed. Post hoc planned comparisons revealed no significant differences in perceptions of the realized benefits of BIM implementation between General Contractors and Owners. However, significantly higher mean levels of agreement were reported by General Contractors on "Improved Labor Productivity" ($p = 0.006$), "Reduced Reportable Safety Incidence" ($p = 0.008$) and "Reduced Material Waste" ($p = 0.002$) when compared to Architects. In addition, significantly lower mean levels of agreement were reported by Owners on "Reduced Reportable Safety Incidence" ($p = 0.007$) and "Reduced Material Waste" ($p = 0.020$) when compared to General Contractors.

Table 3. One-Way ANOVA Results: realized benefits of BIM implementation by stakeholder

Variable	*df*	*SS*	*MS*	*F*	*p*
Improved Labor Productivity					
Between Groups	2	58.79	29.396	4.168	0.019
Within Groups	84	592.47	7.053		
Total	86	651.26			
Reduced Reportable Safety Incidence					
Between Groups	2	68.23	34.11	5.477	0.006
Within Groups	84	523.15	6.228		
Total	86	591.38			
Reduced Material Waste					
Between Groups	2	81.86	40.931	5.888	0.004
Within Groups	84	583.96	6.952		
Total	86	665.82			

Research question three (RQ 3): Are significant differences in Architect perceptions of the realized benefits of BIM implementation observed by Building Type (parking garage and commercial building)?

For this analysis Architect responses were aggregated based on their response to the survey item that BIM was implemented on a parking garage (n = 12) or commercial building (n = 34). One architect response was culled for this analysis since a building type was not indicated. Independent samples t-test were completed to investigate mean difference in Architect perceptions of the realized benefits of BIM implementation observed by Building Type (parking garage and commercial building). No significant differences were observed given the analysis. Therefore, the null hypothesis was retained.

Research question four (RQ 4): Are significant differences in General Contractor perceptions of the realized benefits of BIM implementation observed by Building Type (parking garage and commercial building)?

For this analysis General Contractor responses were aggregated based on their response to the survey item that BIM was implemented on a parking garage (n = 13) or commercial building (n = 34). Twelve General Contractor responses were culled for this analysis since a building type was not indicated. Independent samples t-tests (Table 4) were completed to investigate mean difference in General Contractor perceptions of realized benefits of BIM implementation observed by Building Type (parking garage and commercial building). Results reveal the significant differences in "Improved process of controlling construction costs" (p =0.006), "Reduced final construction cost of projects" (p =0.010), "Increased predictability/fewer unplanned changes" (p = 0.044). Investigation of the means revealed the General Contractors reported significantly high level of agreement that these benefit were realized on commercial buildings than on parking garages.

Table 4. Independent Samples *t*-Test: General Contractor BIM Benefits by Building Type

Variable	*N*	*M* [95% CI]	*SD*	*t*	*df*	*p*
Improve Cost Control				2.86	45	0.006
Parking Garage	13	4.23 [2.59, 5.87]	2.71			
Commercial Building	34	6.71 [5.79, 7.63]	2.65			
Reduce Cost				2.68	45	0.010
Parking Garage	13	4.85 [3.57, 6.12]	2.12			
Commercial Building	34	6.88 [6.04, 7.72]	2.41			
Reduce Changes				2.07	45	0.044
Parking Garage	13	6.46 [4.61, 8.32]	3.07			
Commercial Building	34	8.21 [7.37, 9.04]	2.38			

Discussion

Of 120 survey participants whose responses were analyzed in this study, the large majority (77.5%) were male. Close to half of the participants were general contractors (49.2%) while 40% were architects. About three-fourths of the respondents had experience with using BIM on commercial projects while the remaining respondents (25.8%) used BIM on parking garage projects.

As expected, there was a significant difference in respondent perceptions about the effectiveness of BIM implementation on Design-Bid-Build projects. General contractors indicated that BIM was not effective for Design-Bid-Build projects and that BIM was effective on Design-Build delivery. General Contractors may look less favorably of Design-Bid-Build project due to a perception that more RFIs and change orders could be avoided if the Design-Build delivery was used in conjunction with BIM. In addition, designer and contractors use BIM for different purposes. BIM tools may be effective for design (e.g. producing 2D documents) regardless of the delivery method; however, for a contractor to use BIM effectively they must be involved early in the design phase.

In most cases, different project stakeholders (architects, contractors, and owners) agreed with the benefits realized due to the use of BIM. However, when it comes to benefits such as improved labor productivity, reduced reportable safety incidence, and reduced material waste, the general contractors reported higher level of agreement as compared to the architects. The reason for this difference in responses might be that these three benefits are typically realized in the construction phase of the projects. Therefore, only general contractor can directly experience these benefits. Interestingly, owners expressed lower level of agreement with benefits such as reduced material waste and reportable safety incidence as compared to general contractors even though material waste and accidents on the construction site can affect cost and duration of the project and, therefore, impact owners.

Further analysis of the perceptions of BIM implementation on commercial and parking garage projects revealed that the architects did not report any differences in realized benefits on parking garages and commercial buildings. However, the same analysis conducted for general contractors showed that they found BIM more beneficial on commercial projects than parking garages; particularly when it comes to improved cost control, reduced cost and reduced changes. As stated earlier, commercial buildings are more complex than parking garages, and thus involve more risk, more complex execution methods and, as a result, require improved cost control. In addition, with more complex buildings comes higher risk of errors in documentation, more clashes among the systems and, thus, more change orders.

Conclusions

The purpose of this study was to compare benefits realized due to BIM implementation on commercial building and parking garage projects. In order to explore these benefits, the survey instrument was developed and distributed to architects, engineers, consultants, general contractors, subcontractors and owners in the state of Colorado. Incomplete survey responses were culled as well as responses of the participants that indicated that they did not use BIM. Due to small number of respondents, engineers, consultants and other stakeholder were also culled. Thus, only responses from architects, general contractors and owners were analyzed.

Statistical analysis showed that Architects, General Contractors and Owners agreed on the majority of benefits that were realized due to BIM implementation. However, significant differences in the perceptions of the general contractors were observed when compared to architects and owners on three benefits experienced mostly in the construction phase of a project. These benefits included improved labor productivity, reduced reportable safety incidence, and reduced material waste. Additionally and as expected, general contractors indicated significantly lower level of agreement that BIM was effective on Design-Bid-Build project delivery as compared to the architects. General contractors also perceived different benefits of BIM utilization on commercial and parking garage projects. Specifically, General Contractors reported that BIM was more beneficial for improving cost control, reducing cost and reducing changes on commercial building projects as compared to parking garages. On the other hand, architects did not observe any differences in benefits of BIM utilization on commercial and parking garage projects.

The study had a few limitations that should be considered when interpreting the results. Specifically, a small number of the owners (12%) participated in the survey. Sub-aggregation of the sample produced small sample sizes in t-test analysis by building type (for research questions RQ3 and RQ4). The survey was conducted only among respondents in the state of Colorado; therefore, findings may not be generalizable to other samples and extrapolation on the finding herein should be completed with caution.

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