Hindawi
Advances in Civil Engineering
Volume 2019, Article ID 1392684, 19 pages
https://doi.org/10.1155/2019/1392684

Research Article

BIM Use by Architecture, Engineering, and Construction (AEC) Industry in Educational Facility Projects

Cristina Moreno,[1] Svetlana Olbina ,[2] and Raja R. Issa[1]

[1]*Rinker School of Construction Management, University of Florida, Gainesville, FL, USA*
[2]*Department of Construction Management, Colorado State University, Fort Collins, CO, USA*

Correspondence should be addressed to Svetlana Olbina; svetlanaolbina@gmail.com

Received 30 January 2019; Revised 15 April 2019; Accepted 9 June 2019; Published 3 July 2019

Guest Editor: Tatjana Vilutiene

In recent years, many public and private sector owners have started to require a building information modeling (BIM) component in new construction projects. Although there has been a significant increase in industry-wide acceptance of BIM, it is still not a standard practice in the educational facility sector. This research aimed at exploring the use of BIM in educational facility projects by the architecture, engineering, and construction (AEC) disciplines. A survey that investigated BIM adoption at the company level, BIM implementation in projects, benefits of using BIM, and obstacles to using BIM was distributed to architects, site engineers, structural engineers, mechanical engineers, and contractors across the United States. The survey results showed that a majority of the respondents from all five disciplines used BIM. BIM was most commonly used for 3D visualization, automation of documentation, and clash detection. The most important benefits of BIM included better marketing and clearer understanding of projects which is crucial for clients such as school students, teachers, and principals. Lack of expertise and need for training seemed to be main obstacles to BIM use. The research contributes to the body of knowledge by showing prevalence of BIM use on educational facility projects and indicating how BIM could help improve collaborative knowledge sharing among designers, contractors, and clients, resulting in better quality educational buildings. These research findings can be used to assist AEC companies that are interested in implementing BIM in the educational facility projects.

1. Introduction

In the past years, building information modeling (BIM) has strongly impacted the architecture, engineering, and construction (AEC) industry as one of the top information and communication technologies used by the industry [1, 2].

The AEC industry uses BIM for 3D visualization, clash detection, feasibility analysis, constructability review, quantity take-off and cost estimate, 4D/scheduling, environmental/LEED analysis, creating shop drawings, and facility management [3–6]. BIM use has potential to improve construction efficiency, enhance collaboration and knowledge sharing among the team members, and support construction-related tasks [7, 8]. Using BIM throughout a project reduces risks by promoting efficiency, by minimizing errors or misinterpretations between designers, engineers, and contractors, and by requiring collaboration and knowledge sharing between all parties involved to ensure accuracy and reliability [9].

In integrated project delivery (IPD), the owner, design team, construction, and operation and maintenance professionals are involved in making decisions in all project phases starting with project programming/pre-design and ending with the operation and maintenance phase. However, in a typical office building, the owner and client are not necessarily the same entity and, thus, clients might be excluded from the design and construction process. On the contrary, in the case of educational buildings, it is important to include the client (e.g., students, teachers, principals, and superintendent) in the process of design, construction, and maintenance of the buildings in order to achieve a high-quality project that would meet the client needs [10]. Previous studies also showed the IPD creates a project environment that allows full utilization of the BIM process; as a result, the client involved in IPD can also benefit from the use of BIM on an educational project [11].

For example, BIM can be used for 3D visual communication, which is much more user-friendly in the case of, e.g., elementary school students as compared to verbal communication. During the design phase, school students can be involved in making decisions about building design by utilizing 3D walkthroughs of a school [12–14]. In addition, BIM can help in the design phase with simulating evacuation of the school occupants in the case of emergency situation (e.g., fire) [15, 16]. Students could also be involved in daylight analysis of a school project with the use of 3D BIM tools; it is important that students evaluate daylighting design as daylight is found to be very beneficial for student well-being and their learning of the course material [16–18]. Another example is the use of BIM for monitoring building energy performance [19, 20]; this process can be incorporated in a high-school curriculum (e.g., physics course) where students could utilize their school building as a living laboratory.

Regardless of all the advancements and potential applications and benefits, BIM is yet to be adopted as the industry-wide standard in the US [21, 22]. Lu et al. conducted a comprehensive review of literature published from 1998 to 2012 and showed that a rigorous research on information and communication technology applications in the AEC industry is missing [1]. Previous research pointed out the need for more research on BIM adoption in general [3] as well as for more specific research focusing on all AEC disciplines [23]. In addition, Son et al. [24] indicated that very little research had been conducted about the attitudes of architects towards BIM adoption. Lee et al. [3] also suggested additional research about correlation between BIM use and factors that affect that use.

Miettinen and Paavola [25] emphasized the need for detailed research on developing specific BIM uses in different project phases by different disciplines. Universities in the USA as facility owners have been using BIM mostly for facility management in the operation and maintenance (O&M) phase of the building life cycle [26–29], while BIM use for design, new construction, and remodeling/renovation of existing educational buildings has been limited [30, 31].

In summary, the literature review indicated a scarcity of literature on BIM use for K-12 (kindergarten to 12$^{\text{th}}$ grade) educational facility projects. It also showed that there is limited knowledge regarding the existing use of BIM within the educational facility sector of the AEC industry market. This lack of research on BIM use in educational facility projects was our motivation to conduct this study.

In addition, note that the research presented in this paper was part of a larger study that had a goal to investigate existing use of BIM for educational facilities in the USA and, based on these results, develop guidelines for integrating BIM in this kind of projects. The guidelines were proposed to be used by Florida Department of Education for design and construction of educational facilities. The motivation for this research came from a few examples of BIM standards developed to be used by universities in the USA such as the Ohio State University [32], Indiana University [33], University of Illinois [34], Western Michigan University [35], University of Southern California [36], and Virginia Commonwealth University [37].

Previous studies found that the BIM is beneficial for the entire vertical construction sector (i.e., buildings), and our study had a goal to investigate how BIM could benefit specifically educational facility projects as a subset of the vertical construction projects. To address the above-mentioned research needs, we performed a comprehensive, nationwide assessment of the existing use of BIM on educational facilities in the USA (including both K-12 and university buildings) in different life-cycle phases of projects. The goal of this research was to investigate BIM adoption and use by AEC disciplines in order to obtain a better understanding of their attitudes towards BIM use in educational facility projects. The research objectives were to determine each discipline's perceptions about BIM adoption within their companies, BIM implementation in projects, benefits of using BIM, and obstacles that impede BIM implementation in educational facility projects. More specifically, this research aimed at answering the following questions:

(i) How prevalent is BIM use in educational facility projects?

(ii) What are the BIM applications on educational facility projects?

(iii) How has BIM been used for collaborative knowledge sharing by different stakeholders on educational facility projects?

(iv) How does BIM use help designers address a lack of an efficient method to explore and evaluate different designs of educational facilities and the issues of incomplete, inaccurate, and inconsistent drawings?

(v) How does BIM use help contractors address the issues of large numbers of building system clashes and working with incomplete construction documents which increases the number of RFIs and change orders in educational facilities construction?

(vi) How could BIM help delivering better quality educational facilities for a client?

(vii) How BIM use differs on educational facility projects as compared to other buildings (e.g., commercial buildings)?

2. Literature Review

The literature review presented in this section focuses on all building types as the literature on BIM use on specifically educational facilities was very limited.

BIM as a term is used to present both a building information model and a collaborative methodology used by different project stakeholders. The National Institute of Building Sciences (NIBS) [38] has defined building information *models* as "a digital representation of physical and functional characteristics of a facility . . . [that] serves as a shared knowledge resource for information about a facility." BIM interprets and communicates the attributes of each building system simultaneously through a shared data-rich model that aids all parties involved in the project. This automated model provides easier transfer of data, interference checking, documentation, and exchange of ideas between different disciplines [39]. In addition, building information *modeling* is defined as a collaborative methodology that generates data to be used during the different phases of a building's life cycle such as design, construction, operation, and maintenance [38].

BIM adoption has been on a steady increase since 2007 [40]. In 2007, 28% of the industry adopted BIM, almost half (49%) in 2009 and 71% in 2012. In 2012, 70% of architects, 67% of engineers, and 74% of contractors were implementing BIM. Another McGraw Hill Construction [41] survey of contractors around the world reported that half of the contractors in the USA and Canada have been using BIM for 3–5 years and 8% for over 11 years. The demand for BIM from public and private owners has also been a factor that has encouraged these fast adoption rates amongst design and construction companies. In 2014, one-fourth of the owners in the USA required use of BIM while 43% encouraged but did not require BIM use [42]. Several government entities, like the US General Services Administration (GSA), have required implementation of BIM on all new projects [43].

2.1. Benefits of BIM Implementation in Projects. BIM implementation in projects is affected by willingness of project manager, field engineer, and architect to use BIM, owner's request to use BIM, and complexity of project [22]. Project size and project type [44] as well as the project delivery method and establishing collaborative work environments have significant influence on the BIM implementation in projects [45].

According to Ahn et al. [7], Gheisari and Irizarry [4], and Wang et al. [5], BIM can be implemented in the various phases of a project life cycle (planning, design, construction, operation, and demolition). Thus, the product of BIM is a digital model that provides information about, for example, the design (3D), schedule (4D), cost (5D), and lifecycle analysis (6D) [5, 46]. Gu and London [23] showed that BIM does not have to be utilized in all the project phases and activities. The level of BIM implementation on a project can vary from a complex multidisciplinary BIM use in an online collaborative environment through all project life-cycle phases to simple individual/standalone and discipline-/phase-specific building information models [23]. For example, Cao et al. [44] found that in China, almost one-third of the projects used BIM in only one project phase.

In general, use of BIM creates time and cost benefits [7, 45, 47] resulting from increased efficiency, clearer communication of information, collective efforts [6, 25, 48, 49], more accurate design estimates, and reduced number of design changes [6, 48]. More than half (58%) of the companies indicated that the biggest reward of using BIM was a significant reduction of costs due to resolving conflicts while almost half (48%) reported that the main benefit was improved project quality resulting from lower project risk and better predictability of project outcomes [50].

BIM improves decision-making, safety of construction workers, and operation and maintenance of facilities as well as decreases the number of change orders, number of claims and litigations, and uncertainty [7, 51]. Using BIM on projects means encouraging a collaborative effort from all participants and sharing of ideas and information in a more effective and organized manner than in the traditional approach [7, 25, 45, 52]. Moreover, BIM improves project task quality [44], provides better quality product [6–8, 25, 52], creates possibility of sharing information [49, 52], and improves work efficiency [6, 8, 25, 52].

BIM also helps improve project productivity. Chelson [53] showed that BIM-enabled projects benefitted from field productivity improvement ranging from 5 to 40%. He proposed using the four key indicators of increased productivity such as reduced number of RFI, reduced rework, schedule compliance, and decreased change orders due to plan conflicts. He found that the overall benefit of BIM use is a net savings for the owner ranging from a few percent for competitive bid projects to over 10% for integrated projects. BIM-based projects have 10% of the RFI that a typical non-BIM project would have, leading to an average savings of 9% in management time for a contractor. Trade contractors experience 9% savings of project costs on BIM-enabled projects due to reduced rework and idle time due to site conflicts savings. In addition, Poirier et al. [54] found an increase in labor productivity ranging from 75% to 240% on BIM-enabled projects. In another study, reduced number of change orders led to a savings of 42% of standard costs, RFIs decreased 50% per tool or assembly, and decreased project duration resulted in a savings of 67% as compared to the standard duration [55]. Nath et al. [56] investigated productivity improvement of project activities in terms of total time and processing time. Quantity take-off activity had the largest productivity gain, that is, 72% for processing time and 64% for total time. An overall productivity improvement was about 36% for processing time and 38% for total time.

2.1.1. BIM Benefits to Designers. Over 40% of the professionals from all three AEC industry sectors stated that the value of BIM was crucial during the design development and construction documentation phase [50]. Architects and engineers use BIM to evaluate design options and automatically generate accurate 2D drawings from the 3D model [57]. BIM helps transfer information quickly between different design disciplines [57], and, thus, BIM use enhances their collaboration [8]. Architects also use BIM for 3D visualization and communication with owners [44, 51]. BIM helps architects minimize errors and omissions in documents, reduce rework, and decrease design time [43]. With the incorporation of BIM, architects can automate the development of construction documents, like fabrication details and shop drawings that are easily generated for many building systems from the working model. This automation of construction documents allows architects and engineers to spend more time on the design of the project rather than producing and modifying contract documents while also providing higher accuracy of drawings and diminished risk [9, 46]. Individual capabilities and production are optimized by the software because the system allows for faster modeling and simultaneous manipulation of data; one person using BIM can produce more than three people using CAD [9].

In addition, building information models provide opportunity to perform code compliance review [39], cost estimates, and sustainability analysis in the early design stages [6, 8]. A survey conducted by Bynum et al. [57] indicated that the general perception of the AEC industry is that BIM is ideal for sustainable design because it fosters collaboration between parties. BIM tools enable designers to assess the performance of each building component, the efficiency of sustainable design approaches, and their environmental impact as well [57, 58]. Engineers use BIM to determine structural loads or the requirements for the design. Features of BIM-like automated assembly and digital production are used by engineers to process manufacturing information and coordinate the sequence of different systems with fabricators and subcontractors [39].

2.1.2. BIM Benefits to Contractors. Contractors use building information models to coordinate building systems, detect clashes, and immediately communicate these problems with the parties responsible for the errors [7, 39, 44]. This analysis increases cost and time savings in the construction phase due to discovering design errors in the project and eliminating clashes early on in the project, that is, before any construction starts [39, 59, 60]. Contractors also use BIM for calculating quantity takeoffs and estimating costs for bidding purposes, and planning out project schedules [39, 51] as well as for field management [7]. BIM also improves planning and scheduling of subcontractors. According to contractors, the top two benefits of BIM use in construction were reducing rework and marketing to owners [61]. Therefore, contractors also actively use BIM for visualization and marketing purposes [7].

BIM can be also beneficial for accessing building information models and requests for information (RFIs) on construction site, for solving any construction problems on-site as soon as they arise [7], and for visualizing the sequence of construction activities, which is particularly useful in the case of complex projects [8]. BIM is beneficial for creating a database of information that is generated on a construction site during the construction phase of the project [49]. Another benefit of BIM is that it facilitates prefabrication of the building components off-site, which again reduces the cost and duration of a project [7, 8]. Furthermore, BIM technology is being enabled on construction sites with the use of mobile devices, such as iPads and other handheld tablets. Using mobile devices, the on-site crew can generate, navigate, modify, access, and check the building information model and its attributes operating in real time. This sophisticated imaging technology can also augment on-site training and significantly impacts the way parties, including subcontractors and owners, communicate with each other [62].

2.1.3. BIM Benefits to Owners. Implementing BIM provides a competitive advantage to AEC companies by enabling them to offer new services to owners and guaranteeing owners maximum return on their investment. Public owners have noticed that BIM-based projects are yielding higher quality products and more efficient buildings that result in reduced lifecycle costs [55, 59]. BIM also increases owner engagement by providing clearer and more accurate visualizations of design [63]. This simplifies the communication with owners because realistic 3D visualization models are easier to comprehend than 2D drawings [39].

2.2. Obstacles to BIM Use. Despite all the benefits of BIM use, BIM adoption has been slow [21, 25]. The fragmented nature of the AEC industry inhibits successful adoption of BIM [23, 25]. More specifically, the lack of BIM adoption worldwide could be a result of both nontechnical factors (e.g., interoperability, investment, and training) and organizational factors (e.g., professional liability, intellectual property, and trust). In addition, several interorganizational issues such as reluctance to openly share information, lack of collaboration management tools, security risk, and problems with managing BIM master model could hinder BIM adoption [22, 51]. Moreover, lack of BIM implementation plan, need for cultural change within organization in order to adopt BIM, organizational challenges, increased risk with the use of BIM, and complexity of developing building information model are the barriers to BIM adoption [7, 51]. According to Dodge Data & Analytics' survey [47], the largest obstacles to BIM success were low level of team interest in support for BIM and low level of collaboration among team members.

Several researchers pointed out that the lack of data interoperability among different BIM applications and the lack of software integration impede adoption of BIM [4, 25, 44, 45, 51]. Lack of interoperability can result in inaccurate building information models, thus potentially leading to legal disputes [45].

Additional obstacles to BIM adoption include lack of appropriate legal environment and contracts related to BIM-based project delivery [45] as well as perceived legal matters regarding lack of clarity when determining ownership of the intellectual property and liability for design [3, 7, 8]. From a legal perspective, when all the parties are involved in a close collaboration, it is inevitable that risks and responsibilities overlap or shift from one party to another [64]. To prevent confusion and disputes, the contract should specify the duties and responsibilities of each party involved in order to clarify who faces consequences of any liable errors, inaccuracies, or discrepancies in the model [3, 23, 45].

Another major obstacle to BIM use is that the industry lacks a standard way to evaluate the quality and sustainability of a facility [22] and to assess or collect data related to the benefits of BIM [3]. It is hard to measure the impact of BIM or any other variable for a specific project because no two projects are identical and many other uncontrollable factors influence the results [25, 59]. The industry is in critical need of a standard but it is having difficulty collecting performance metrics or finding a consistent way to analyse and show the direct and indirect benefits of BIM implementation [65].

Moreover, the adoption of BIM carries an initial financial burden that causes companies to be resistant to the use of BIM because of the costs associated with buying the software and training employees [3, 4, 7, 22, 24, 51, 52]. Apart from technical issues, human factors are a critical setback for BIM. The lack of BIM-knowledgeable workers within the design and construction fields presents an obstacle to the implementation of BIM [1, 4, 7, 22, 51, 52]. Personnel who lack proper formal BIM training hinder the project success and the overall collaboration [1, 3, 4, 7, 9, 23]. The level of BIM experience from one design team member to another is uneven, and this additionally limits the potential of BIM [9]. A crucial element for successful BIM use is the level of involvement of all the key disciplines that participate in the project. If not all parties have adopted BIM use as their standard practice, then the resulting model may only have certain systems accounted for. For example, Won et al. [22] and Ahn et al. [7] indicated that lack of subcontractors that can use BIM presents a barrier to BIM adoption. An additional challenge to BIM adoption is worker resistance to new technologies and changes in traditional procedures [7, 23]. This resistance to change prevents the full adoption of BIM within company practices [1, 4, 9, 23]. Also, lack of familiarity with BIM adoption process hinders BIM utilization [3].

3. Research Methods

The goal of the study was to obtain an understanding of BIM use by designers and contractors in educational facility projects. In order to achieve this goal, a survey instrument was developed based on a literature review. The survey had a total of 32 questions on various topics concerning participant perceptions on BIM use on educational facility projects (see Appendix A). These questions were grouped in the following major sections: demographics, BIM adoption at the company level, BIM implementation at the project level, perceived benefits of BIM use, and perceived obstacles to BIM use. Based on the Institutional Review Board- (IRB-) approved survey protocol, participants were asked to consent to participate in the survey prior to commencing. Participants were informed that they were required to have experience with educational facility projects when they were asked to voluntarily agree to participate in the survey and also as part of the survey itself. Each participant was given two weeks from the initial moment of contact to consent to participate.

The survey was developed using SurveyMonkey, and the link to the survey was emailed to architects, engineers, and contractors that were the members of professional AEC societies in the USA including the American Institute of Architects (AIA), Associated Builders and Contractors (ABC), the Associated General Contractors of America (AGC), and the American Society of Civil Engineers (ASCE). A total of 1,265 participants were reached via email; 569 from architecture firms, 344 from engineering firms, and 352 from construction companies.

Eighty-eight responses to the survey were received from the architects, engineers (site, structural, and MEP), and contractors. Only the responses from 68 participants that responded to the survey question about whether or not they used BIM were included in the analysis. Responses of 53 respondents that stated they had an experience with using BIM on educational facility projects were included in the analysis of the questions related to BIM adoption at the company level and BIM implementation at the project level. However, responses of all the survey respondents (68) to the questions related to perceived benefits of BIM and obstacles to BIM implementation were included in the analysis. The survey responses were analysed using descriptive statistics. The cross-tabulation method was used to analyse responses according to the respondent's role in the design and construction process in order to determine findings by discipline. Note that, in this paper, "N" refers to the number of respondents, while "n" refers to the number of selections made in the case of "select all that apply" type of questions.

4. Results and Discussion

The five roles used to analyse the survey responses included architect, site engineer, structural engineer, MEP engineer, and contractor. About half of the 88 respondents (47, 53%) were architects, while 15 (17%) were contractors. Almost one-third of the respondents (26, 30%) were engineers comprising site engineers (7, 8%), structural engineers (14, 16%), and MEP engineers (5, 6%) (Figure 1).

4.1. BIM Adoption at the Company Level. The respondents were asked a series of questions regarding the BIM adoption in their companies. More than three-fourths (53, 78%) of the responding professionals used BIM. Regarding specific disciplines, majority of the mechanical engineers, structural

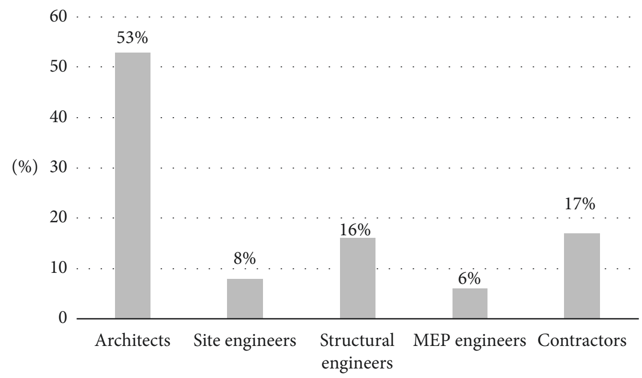

Figure 1: Distribution of the survey participants by the discipline (total $N = 88$).

engineers, architects, site engineers, and contractors claimed to use BIM in their practice (Figure 2).

When asked about the driving forces for BIM implementation in educational facility projects within their company, a majority of the architects thought that management was the main driving force, while a minority stated that the clients and competition from other companies were driving BIM implementation (Table 1). However, the majority of the structural engineers, MEP engineers, and contractors perceived clients to be the main reason for implementing BIM. This is a very important finding because it shows that owners/clients of educational facilities might be encouraging or requesting use of BIM as it most likely helps them better visualize and understand a project. All of the site engineers perceived the pressure of competing with other companies to be a driving force. Note that the respondents were asked to "select all that apply" when answering this question.

Since one of the measures of the extent of BIM adoption is the number of BIM-knowledgeable employees within a company, the average percent of BIM-knowledgeable employees within each of the five participating disciplines was calculated (Figure 3). The MEP engineers had the highest average percent of BIM-knowledgeable employees within their companies, followed by the site engineers and architects.

When asked about the business value of using BIM that their companies realized, the largest proportion of the architects along with all of the site engineers stated that their companies were just starting to see the potential value of using BIM (Table 2). The majority of the contractors and structural engineers claimed to have optimized the value of BIM use in their current use. Minority of the structural engineers and contractors perceived that their companies were just starting to see the potential value of BIM use.

The survey participants were asked about the current methods that their companies employed to encourage the use of BIM. The largest proportion of the responding architects said that their companies required the use of BIM, and more than a third of the architects claimed that their companies provided BIM training (Table 3). All the responding site engineers indicated that their companies compensated employees for continuing education as the way to encourage BIM use. The majority of the responding structural engineers and almost half of the contractors answered that their companies provide BIM training to encourage the use of BIM.

When asked about their perceptions about the best ways to provide BIM expertise, a majority of the respondents from all five disciplines suggested either providing internal training or hiring new BIM-skilled professionals (Table 4). All the responding site engineers thought that hiring new skilled BIM professionals was the best way to acquire BIM expertise for the company, while majority of the MEP engineers, structural engineers, and contractors and the largest proportion of the architects thought that internal training was the best way to acquire BIM expertise.

The respondents who claimed that their companies did not use BIM (15, 22%) were further asked about the reasons for their company's lack of BIM involvement (Table 5). The only discipline that responded that their company used BIM in the past but no longer uses it was the site engineers. None of the respondents claimed to have never heard of BIM. Surprisingly, the only disciplines that responded that their company had no interest in using BIM were the architects and contractors. However, majority of the responding contractors, structural engineers, and site engineers that did not use BIM stated that these companies were interested in implementing BIM.

4.2. BIM Implementation on Educational Facility Projects. Regarding BIM implementation on projects, the survey participants were asked to estimate the percent of educational facility projects in which certain BIM applications had been used in the previous five years (Table 6). The average percent of all the responses was calculated for each application and cross tabulated with the role of the respondents to determine the existing use of BIM applications by different disciplines in different phases of the project.

All the responding disciplines indicated that BIM was used most frequently in the design phase of educational facility projects. The architects and contractors used BIM for 3D visualization and automation of documentation as well as for clash detection in the majority of the projects. Similarly, the site engineers claimed to use BIM for 3D visualization and structural analysis in almost all of their

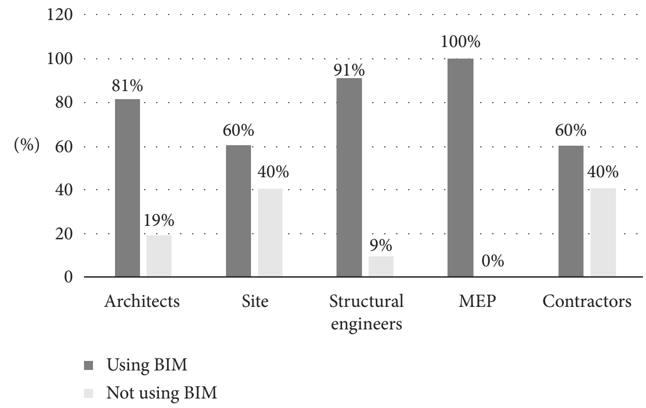

Figure 2: Relationship between the role of the respondent and the company's use of BIM (total $N = 68$).

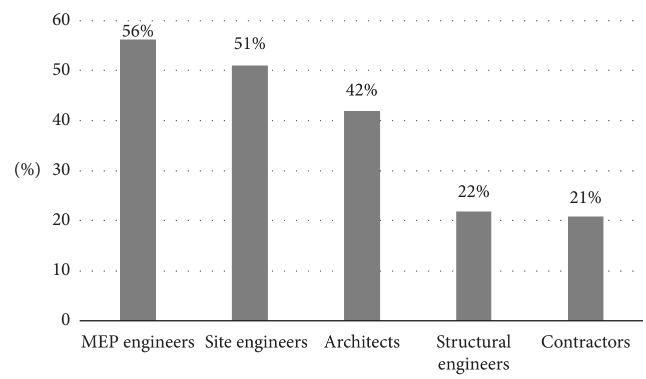

Figure 3: BIM-knowledgeable employees within disciplines ($N = 52$).

Table 1: Relationship between the role of the respondent and the perceived driving force for BIM implementation in educational facility projects*.

Perceived BIM implementation drivers	Architects $N_A = 25$ $n_A = 49$	Site engineers $N_{SE} = 3$ $n_{SE} = 6$	Structural engineers $N_{STE} = 10$ $n_{STE} = 19$	MEP engineers $N_{MEPE} = 5$ $n_{MEPE} = 9$	Contractors $N_C = 9$ $n_C = 19$
Clients	11 (44%)	0 (0%)	9 (90%)	4 (80%)	9 (100%)
Subcontractors	1 (4%)	1 (33%)	1 (10%)	0 (0%)	0 (0%)
Management	13 (52%)	1 (33%)	2 (20%)	1 (20%)	3 (33%)
Manufacturers/fabricators	2 (8%)	1 (33%)	1 (10%)	0 (0%)	0 (0%)
Government permitting agencies	3 (12%)	0 (0%)	2 (20%)	0 (0%)	0 (0%)
Competition from other companies	10 (40%)	3 (100%)	4 (40%)	2 (40%)	6 (66.6%)
Other	9 (36%)	0 (0%)	0 (0%)	2 (40%)	1 (11.1%)

Note. *Select all that apply. Percent (%) = number of selections divided by number of respondents for a specific discipline. Total $N = 52$ and total $n = 102$.

Table 2: Relationship between the role of the respondent and their company's perceived current business value of using BIM.

Perceived business value of using BIM	Architects $N_A = 25$ (48.1%)	Site engineers $N_{SE} = 3$ (5.8%)	Structural engineers $N_{STE} = 10$ (19.2%)	MEP engineers $N_{MEPE} = 5$ (9.6%)	Contractors $N_C = 9$ (17%)
We have optimized the value of BIM in our current use	9 (36%)	0 (0%)	5 (50%)	2 (40%)	7 (78%)
We are just starting to see the potential value of using BIM	10 (40%)	3 (100%)	4 (40%)	1 (20%)	2 (22%)
We are getting no meaningful value from BIM	6 (24%)	0 (0%)	1 (10%)	2 (40%)	0 (0%)

Note. Total $N = 52$.

Table 3: Relationship between the role of the respondent and their company's method for encouraging BIM use.

Methods companies use to encourage the use of BIM	Architects $N_A = 25$ (48%)	Site engineers $N_{SE} = 3$ (6%)	Structural engineers $N_{STE} = 10$ (19%)	MEP engineers $N_{MEPE} = 5$ (10%)	Contractors $N_C = 9$ (17%)
It does not encourage use of BIM	2 (8%)	0 (0%)	1 (10%)	1 (20%)	1 (11.1%)
It provides training	9 (36%)	0 (0%)	6 (60%)	2 (40%)	4 (44.4%)
It requires it	10 (40%)	0 (0%)	3 (30%)	2 (40%)	3 (33.3%)
It compensates employees for their continuing education	0 (0%)	3 (100%)	0 (0%)	0 (0%)	1 (11.1%)
Other	4 (16%)	0 (0%)	0 (0%)	0 (0%)	0 (0%)

Note. Total $N = 52$.

Table 4: Relationship between the role of the respondent and the best method for acquiring BIM expertise.

The best method for acquiring BIM expertise	Architects $N_A = 25$ (48%)	Site engineers $N_{SE} = 3$ (6%)	Structural engineers $N_{STE} = 10$ (19%)	MEP engineers $N_{MEPE} = 5$ (10%)	Contractors $N_C = 9$ (17%)
Hire new BIM-skilled professionals	8 (32%)	3 (100%)	3 (30%)	0 (0%)	3 (33.3%)
Internal training	12 (48%)	0 (0%)	6 (60%)	5 (100%)	5 (55.6%)
Online seminar	1 (4%)	0 (0%)	0 (0%)	0 (0%)	0 (0%)
Outside training	2 (8%)	0 (0%)	0 (0%)	0 (0%)	1 (11.1%)
Other	2 (8%)	0 (0%)	1 (10%)	0 (0%)	0 (0%)

Note. Total $N = 52$.

Table 5: Relationship between role of the respondent and the reason for their company's lack of BIM involvement.

Reasons for lack of BIM involvement	Architects $N_A = 6$ (40%)	Site engineers $N_{SE} = 2$ (13%)	Structural engineers $N_{STE} = 1$ (7%)	MEP engineers $N_{MEPE} = 0$ (0%)	Contractors $N_C = 6$ (40%)
My company does not use BIM but would like to implement BIM	1 (17%)	1 (50%)	1 (100%)	0 (0%)	3 (50%)
My company has used BIM in the past but no longer uses it	0 (0%)	1 (50%)	0 (0%)	0 (0%)	0 (0%)
My company outsources BIM	0 (0%)	0 (0%)	0 (0%)	0 (0%)	2 (33.3%)
My company has no interest in using BIM	5 (83%)	0 (0%)	0 (0%)	0 (0%)	1 (16.7%)
I have never heard of BIM	0 (0%)	0 (0%)	0 (0%)	0 (0%)	0 (0%)

Note. Total $N = 15$.

Table 6: Relationship between the role of the respondent and the average percentage of educational facility projects in which they have used the specific BIM applications in the previous five years by the project phase.

Building phase	Types of BIM applications used in projects (average % of projects)	Architects $N_A = 22$ (45.8%)	Site engineers $N_{SE} = 3$ (6.3%)	Structural engineers $N_{STE} = 9$ (18.7%)	MEP engineers $N_{MEPE} = 5$ (10.4%)	Contractors $N_C = 9$ (18.7%)
Design phase	Automation of documentation	64%	75%	71%	67%	61%
	3D visualization	69%	92%	66%	51%	67%
	Space planning and validation	44%	33%	34%	67%	15%
	Automated checking of code compliance	6%	20%	3%	0%	3%
	Clash detection and collision assessment	49%	75%	54%	50%	68%
	Structural analysis	44%	93%	69%	50%	39%
	MEP analysis	35%	77%	46%	60%	54%
	Sustainability analysis (LEED)	29%	39%	32%	44%	18%
Construction phase	Geographic information systems (GIS) and site-specific analysis	20%	17%	0%	33%	7%
	4D scheduling and simulation of construction activities	8%	32%	23%	17%	38%
	5D quantity take-off and cost estimate	9%	35%	20%	17%	45%

Table 6: Continued.

Building phase	Types of BIM applications used in projects (average % of projects)	Architects $N_A = 22$ (45.8%)	Site engineers $N_{SE} = 3$ (6.3%)	Structural engineers $N_{STE} = 9$ (18.7%)	MEP engineers $N_{MEPE} = 5$ (10.4%)	Contractors $N_C = 9$ (18.7%)
Operation and maintenance phase	6D facilities management and maintenance	5%	12%	20%	0%	17%
All phases	Building performance analysis	24%	32%	20%	70%	11%
	Lifecycle analysis	15%	20%	10%	31%	12%

Note. Total $N = 48$.

educational projects. Similar to the architects and contractors, the structural engineers indicated that they used BIM for automation of documentation and 3D visualization most often in their projects, and, as expected, for structural analysis. Frequent use of BIM for 3D visualization is an important finding as it indicates a potential of BIM to help clients of educational facilities (e.g., students and teachers) to better understand the project as well as to communicate their ideas and needs to the design team. The MEP engineers used BIM for space planning most frequently in their educational building projects. As expected, during the construction phase of educational projects, BIM was used primarily by contractors and mostly for quantity take-offs and estimating, and scheduling and 4D simulations of construction activities as this is the major scope of their work. All the respondents regardless of their discipline indicated less frequent use of BIM in the operations and maintenance (O&M) phase of the educational facility projects. The reason for this might be that these disciplines are not frequently involved in O&M of the buildings. As expected, the MEP engineers reported that they often used BIM for building performance analysis during the entire life cycle of educational buildings.

The relationship between the role of the respondent and the discipline these respondents primarily share BIM information with when working on the design and construction of educational facility was investigated to understand the level of collaborative knowledge sharing among project stakeholders (Table 7). The architects shared BIM information primarily with engineers and to a lesser extent with the owners of the projects and the contractors. The site engineers stated that they only shared BIM information with the architects. The structural engineers mainly shared BIM information with architects and seldom with other engineers and subcontractors. The MEP engineers only shared BIM information with architects and the owners. The finding that design disciplines collaborate and share information primarily with the architects as the central design discipline was expected because of the scope of design work and the design workflow. However, it was not expected that architects would report less frequent information sharing with contractors, although this might be expected in the case of design-bid-build delivery of the projects. The contractors indicated that they generally shared BIM information with all the other disciplines, mostly with architects, engineers, and owners. As expected, structural engineers and contractors were the only disciplines that shared BIM information with subcontractors. Overall, the survey responses indicated collaboration among the various stakeholders driven by the specific educational facility project phase and scope of the particular work.

When asked about BIM software that their company utilizes, as anticipated, the large majority of the architects responded that they used Revit™ Architecture (Table 8). The site engineers solely used the Revit™ Suite software, which includes Revit™ Architecture, Revit™ Structure, and Revit MEP™. Site engineers was the only discipline that did not use Navisworks™, which is justifiable by the fact that Navisworks™ is mostly used for coordination of buildings systems and clash detection which is out of the site engineer's scope of work. As expected, the structural engineers primarily used Revit™ Structure along with Tekla Structures™ and Navisworks™ because they meet the needs of their scope of work. The MEP engineers used mostly Revit MEP™ and Revit Structure™ followed by Navisworks™. This particular software use by MEP engineers is expected as main purpose of their use of BIM is to model MEP systems and coordinate the systems with the structure of a building. The contractors used almost equally Navisworks™ and Revit Architecture™, Revit MEP™, and Revit Structure™ which again might be explained by the BIM applications needed by the contractors such as constructability review, building system coordination, clash detection, and 4D scheduling of construction activities. In summary, the Autodesk software was the most utilized BIM software by the different disciplines. Fewer respondents used ArchiCAD™, Bentley™, VICO Construction™, Bentley Facilities Management™, and Digital Project™. Note that the respondents were asked to "select all that apply" when answering this question.

4.3. Perceived Benefits of BIM Use in Educational Facility Projects. The respondents were asked to select all the design and construction phases in which they perceived BIM use to be valuable for their company (Table 9). Note that the respondents were asked to "select all that apply" when answering this question. In addition, all the respondents regardless of whether they used BIM or not were asked to answer this question. As anticipated, the architects perceived that BIM implementation was most valuable in the design phases, i.e., in schematic design, design development, and construction documentation phases. Architects found BIM

Table 7: Relationship between the role of the respondent and the disciplines they primarily share BIM information with when working on educational facility projects.

Disciplines respondents share BIM information with	Architects $N_A = 25$ (48%)	Site engineers $N_{SE} = 3$ (6%)	Structural engineers $N_{STE} = 10$ (19%)	MEP engineers $N_{MEPE} = 5$ (10%)	Contractors $N_C = 9$ (17%)
Owner	4 (16%)	0 (0%)	0 (0%)	1 (20%)	2 (22.2%)
Architect	1 (4%)	3 (100%)	8 (80%)	4 (80%)	3 (33.3%)
Engineer	14 (56%)	0 (0%)	1 (10%)	0 (0%)	2 (22.2%)
Contractor	3 (12%)	0 (0%)	0 (0%)	0 (0%)	0 (0%)
Subcontractor	0 (0%)	0 (0%)	1 (10%)	0 (0%)	1 (11.1%)
Manufacturer	1 (4%)	0 (0%)	0 (0%)	0 (0%)	1 (11.1%)
Other	2 (8%)	0 (0%)	0 (0%)	0 (0%)	0 (0%)

Note. Total $N = 52$.

Table 8: Relationship between respondent's role and the BIM software they use in projects*.

BIM software	Architects $N_A = 24$ $n_A = 54$	Site engineers $N_{SE} = 3$ $n_{SE} = 7$	Structural engineers $N_{STE} = 10$ $n_{STE} = 33$	MEP engineers $N_{MEPE} = 5$ $n_{MEPE} = 19$	Contractors $N_C = 9$ $n_C = 41$
Revit Architecture™	22 (91.7%)	3 (100%)	3 (30%)	3 (60%)	8 (88.9%)
Revit Structure™	6 (25%)	3 (100%)	9 (90%)	5 (100%)	6 (66.7%)
Revit MEP™	8 (33.3%)	1 (33.3%)	4 (40%)	5 (100%)	7 (77.8%)
Bentley™	1 (4.2%)	0 (0%)	1 (10%)	0 (0%)	1 (11.1%)
Bentley FM™	0 (0%)	0 (0%)	1 (10%)	0 (0%)	2 (22.2%)
ArchiCAD™	2 (8.3%)	0 (0%)	0 (0%)	0 (0%)	2 (22.2%)
Digital Project™	1 (4.17%)	0 (0%)	1 (10%)	0 (0%)	0 (0%)
Tekla Structure™	0 (0%)	0 (0%)	6 (60%)	0 (0%)	2 (22.2%)
Ecotect™	5 (20.8%)	0 (0%)	1 (10%)	1 (20%)	0 (0%)
VICO Construction™	0 (0%)	0 (0%)	0 (0%)	0 (0%)	3 (33.3%)
Navisworks™	6 (25%)	0 (0%)	6 (60%)	4 (80%)	8 (88.9%)
Other	3 (12.5%)	0 (0%)	1 (10%)	1 (20%)	2 (22.2%)

Note. *Select all that apply. Percent (%) = number of selections divided by number of respondents for a specific discipline. Total $N = 51$ and total $n = 154$.

Table 9: Relationship between the role of the respondent and the perceived value of BIM in different phases of the design and construction process*.

Project phases	Specific project phases	Architects $N_A = 30$ $n_A = 160$	Site engineers $N_{SE} = 4$ $n_{SE} = 15$	Structural engineers $N_{STE} = 11$ $n_{STE} = 44$	MEP engineers $N_{MEPE} = 5$ $n_{MEPE} = 34$	Contractors $N_C = 15$ $n_C = 78$
Design	Predesign	9 (30%)	0 (0%)	1 (9%)	3 (60%)	4 (27%)
	Schematic design	22 (73%)	2 (50%)	5 (45%)	4 (80%)	7 (47%)
	Design development	23 (77%)	3 (75%)	8 (73%)	4 (80%)	10 (67%)
	Construction documentation	23 (77%)	4 (100%)	9 (82%)	4 (80%)	12 (80%)
Construction	Bidding process	14 (47%)	0 (0%)	3 (27%)	3 (60%)	9 (60%)
	Preconstruction	15 (50%)	2 (50%)	4 (36%)	4 (80%)	10 (67%)
	Construction administration	19 (63%)	2 (50%)	6 (55%)	3 (60%)	11 (73%)
	Fabrication	15 (50%)	1 (25%)	7 (64%)	4 (80%)	6 (40%)
	Close-out/commissioning	8 (27%)	0 (0%)	0 (0%)	2 (40%)	5 (33%)
Operation and maintenance	Operation and maintenance	12 (40%)	1 (25%)	1 (9%)	3 (60%)	4 (27%)

Note. *Select all that apply. Percent (%) = number of selections divided by number of respondents for a specific discipline. Total $N = 65$ and total $n = 331$.

least valuable in the closeout phase of educational facility projects, most likely because they are not involved in this project phase. The site engineers and structural engineers perceived BIM to be most valuable in the construction documentation phase. The reason for this might be that these two disciplines are heavily involved in producing construction documents and, therefore, are able to experience BIM benefits in this phase. The MEP engineers was the only discipline that believed that BIM was consistently valuable in all phases of the design and construction process. Majority of MEP engineers found BIM beneficial in operation and maintenance (O&M) of educational facilities; the reason for this might be that MEP engineers are heavily involved in this project phase and, therefore, can benefit from BIM use in O&M. As expected, the contractors found BIM to be most valuable in the construction documentation phase, construction administration phase, and design development and preconstruction phases because these phases directly relate to their scope of work and, thus, they could experience BIM benefits in these phases. In summary, the majority of the responding disciplines found BIM beneficial in the schematic design and design development phases in which client involvement and input is very important for creating a high-quality educational project.

Next, the survey participants were asked to use a 5-point Likert scale (1 = strongly disagree, 2 = disagree, 3 = neither agree nor disagree, 4 = agree, and 5 = strongly agree) to express their agreement with the specific benefits of BIM use for the design and construction of educational facilities. For the analysis of these responses, a mean (that is, average rating score) was calculated for each of the five roles of the respondents, and the benefits were grouped according to the educational facility project phase (Table 10). For further analysis, the means were grouped into a ranking category. In this research, the means between 1.00 and 1.49 were considered as strongly disagree, means between 1.50 and 2.49 were considered as disagree, means between 2.50 and 3.49 were accounted for as neither agree nor disagree, means between 3.50 and 4.49 were considered as agree, and means above 4.50 were considered as strongly agree. Note that all the respondents regardless of whether they used BIM or not were asked to answer this question.

4.3.1. BIM Benefits in the Design Phase of Educational Facility Projects. All the responding professionals regardless of their discipline agreed that the BIM was beneficial for enabling automation of documentation. Architects and site engineers more than other disciplines agreed that BIM was beneficial for evaluating different design alternatives which is expected due to the fact that these two disciplines are focused on design. Use of BIM also allows clients (e.g., students, teachers, school administrators) to be involved in visually evaluating different designs and selecting the one that would best meet their needs. In addition, site engineers and structural engineers were the only two disciplines that agreed that the use of BIM resulted in allowing more time to be spent on design rather than on contract documentation. All the respondents from the design disciplines except the MEP engineers agreed that the BIM was beneficial for lowering project risk because it helped discovering errors, omissions, and conflicts before construction started. According to site engineers, structural engineers, and contractors, BIM provides benefit of faster reviews for approval and permits.

4.3.2. BIM Benefits in the Construction Phase of Educational Facility Projects. Contractors and site and MEP engineers agreed that BIM use is beneficial for reducing RFIs, change orders, and claims. These three disciplines also felt that the use of BIM helped reduce the project delivery time as well as material use and site waste. As expected, contractors was the only discipline that indicated that BIM helped them reduce construction and production costs since they are the primary discipline directly involved in construction and, therefore, could benefit from the BIM use in this phase. Interestingly, only site and MEP engineers indicated that BIM was beneficial for modular construction and prefabrication, while other responding disciplines were neutral regarding these benefits. Typically, a majority of MEP and site components are prefabricated and this might be a reason that these disciplines were perceiving benefits of BIM use for prefabrication. The benefits of BIM for improving construction safety were only recognized by MEP engineers; the other disciplines neither agreed nor disagreed with this BIM benefit.

4.3.3. BIM Benefits in Both Design and Construction Phases of Educational Facility Projects. Structural engineers strongly agreed and the respondents from the remaining four disciplines agreed with the statement that BIM was beneficial for increasing engagement of the educational building client (e.g., students, teachers, principals, and superintendents) and providing the client with clearer visual understanding of the 3D building information model in both design and construction of educational facilities. Respondents from all five disciplines either strongly agreed or agreed that using BIM as a new marketing tool for firms was beneficial as it might help attract clients/users of educational buildings to select their firm for a project. Site engineers and contractors were the two disciplines that agreed that BIM helps with increasing productivity and efficiency. These two disciplines are directly involved in construction of an educational building and, therefore, can experience impact of BIM on efficiency and productivity of construction. Interestingly, site engineers was the only discipline that agreed that BIM helps with sustainability efforts on the educational project. Similarly, site engineers strongly agreed and other disciplines agreed that BIM use encourages use of other information technologies such as Unity and GIS.

4.3.4. BIM Benefits in Both Construction and O&M Phases of Educational Facility Projects. Site engineers, MEP engineers, and contractors agreed that BIM was beneficial for creating accurate as-built models of educational facility. The as-built documentation is an important final project deliverable prepared by contractor and handed over to an owner to be used during the O&M phase of the project. This might be a reason for contractor opinion about this benefit. MEP engineers can be involved in the O&M phase and, thus, could be users of these as-built models and, as a result, experience this BIM benefit.

4.3.5. BIM Benefits in All the Building Phases of Educational Facility Projects. The survey respondents recognized several BIM benefits that applied to all educational project phases. For example, all the respondents except architects agreed that BIM improves collaboration among the disciplines. As expected, contractors, and interestingly, site engineers, agreed that BIM increases

Table 10: Relationship between the role of the respondent and their level of agreement with perceived benefits of using BIM in educational facility projects (mean/average rating score) by the project phase.

Project phase	BIM benefits	Architects $N_A = 30$ (47.6%)	Site engineers $N_{SE} = 4$ (6.3%)	Structural engineers $N_{STE} = 10$ (15.9%)	MEP engineers $N_{MEPE} = 5$ (7.9%)	Contractors $N_C = 14$ (22.2%)
Design phase	Evaluates the impact of different design solutions	3.50	4.00	3.10	3.40	3.43
	Allows more time to be spent on design than on contract documentation	3.03	3.75	3.60	2.80	3.36
	Lowers risk and better predicts outcomes due to discovery of errors, omissions and conflicts prior to construction	3.53	4.00	3.70	3.20	4.00
	Enables automation of documentation (better accuracy and accounts for adjustments and changes automatically)	3.63	4.25	3.60	3.60	4.00
	Enables faster reviews for approvals and permits	2.57	3.75	3.50	2.80	3.79
Construction phase	Reduces RFI’s, change orders, claims, and conflicts	3.27	4.00	3.40	3.60	4.07
	Reduces construction and production costs	2.97	3.00	3.30	3.40	4.14
	Reduces project delivery time	3.03	4.00	3.30	3.60	4.00
	Facilitates modular construction	3.13	4.25	3.10	4.00	3.43
	Increase prefabrication	3.07	3.50	3.10	3.60	3.36
	Reduces on-site waste and materials use	2.90	3.75	3.00	4.20	3.50
	Improves construction safety	2.47	3.00	2.80	3.60	3.21
Both design and construction phases	Increases client engagement and provides clearer understanding of 3D visualizations	3.97	4.00	4.60	4.20	4.36
	Increases productivity and efficiency	3.30	3.50	3.40	3.20	4.21
	Encourages consideration for sustainable building systems that conserve energy	3.03	3.75	3.30	2.60	3.36
	Serves as a new marketing tool for firms	3.77	3.75	4.50	4.60	4.36
	Encourages use of other technologies (GIS, unity, etc.)	3.07	4.50	3.20	4.00	3.43
Both construction and O&M phases	Provides more accurate as-built deliverables	3.27	3.75	3.40	3.60	4.07
All project phases	Improves collaboration and communication between disciplines due to more reliable and direct data exchange from a single resource of information	3.43	4.00	4.20	4.00	3.93
	Increases project profitability	2.97	3.75	3.10	2.80	4.07
	Allows for long-term data assessment	3.37	4.50	3.50	3.40	3.29

Note. Total $N = 63$.

project profitability in all the phases of the educational building project. Site engineers and structural engineers were only two disciplines that found BIM was beneficial for the long-term data assessment on educational facility project.

Overall, site engineers was the discipline that agreed with the majority of the listed benefits while architects agreed with only a few BIM benefits offered in the survey instrument.

4.4. Perceived Obstacles to BIM Use in Educational Facility Projects. The survey participants were asked to use a 5-point Likert scale (1 = not likely at all, 2 = somewhat likely, 3 = moderately likely, 4 = very likely, and 5 = extremely likely) to express their opinion about the obstacles that prevent BIM use on educational facility projects. For the analysis of these responses a mean (that is, average rating score) was calculated for each of the five roles of the respondents (Table 11). These means where then grouped into a ranking category as follows. In this research, the resulting means between 1.00 and 1.49 were considered as not likely at all, means between 1.50 and 2.49 were considered as somewhat likely, means between 2.50 and 3.49 were accounted for as moderately likely, means between 3.50 and 4.49 were considered as very likely, and any means above 4.50 were considered as extremely likely. Note that all the respondents regardless of whether they used BIM or not were asked to answer this question.

4.4.1. Cost. The contractors was the only discipline that thought that cost of software and hardware and cost of hiring BIM-savvy professionals were the obstacles that would very likely hinder wider implementation of BIM on educational facility projects. According to the site and structural engineers, lack of quantifiable benefits due to BIM use would very likely prevent BIM use. In addition, the site engineers and contractors indicated that it would be difficult to justify the use of BIM on fast-paced and small educational facility projects.

4.4.2. Demand. All the respondents regardless of the discipline felt that insufficient demand for BIM use by owners would either somewhat likely or moderately likely prevent the BIM use. This finding might indicate the willingness of these professionals to use BIM even if owners do not require it.

4.4.3. BIM Professionals. Regarding the obstacles related to BIM professionals, the site engineers and contractors thought that lack of expertise and need for training as well as unclear roles and responsibilities of the participants in the educational facility projects would very likely prevent BIM use. The architects, structural engineers, and MEP engineers indicated that these obstacles would moderately likely hinder the use of BIM on educational buildings. In addition, MEP engineers and architects were two disciplines that reported the largest number of BIM-savvy professionals in their firms, which might explain why they did not see this as an obstacle.

4.4.4. BIM Process. The site engineers and contractors perceived that disruption in workflow which would happen due to the implementation of new BIM-based processes would very likely hinder BIM implementation on educational facility projects. In addition, the site engineers was the only discipline that thought that lack of software interoperability would very likely obstruct BIM use. On the contrary, none of the disciplines indicated that vulnerability or security of file sharing was likely to prevent BIM implementation on educational facility projects.

4.4.5. Legal Obstacles. When asked about legal-related issues as the potential obstacles to BIM use on educational facility projects, site engineers and contractors stated that the lack of BIM standards would very likely hinder BIM implementation. Respondents from most of the surveyed disciplines felt that lack of precedence, established laws, and regulations about BIM use would moderately likely prevent BIM implementation. Only site engineers indicated that legal liabilities of the BIM process would very likely impede BIM use.

In summary, similar to the BIM benefits, the site engineers was also a discipline that experienced the most obstacles. On the contrary, architects and MEP engineers disagreed or were neutral regarding all the listed obstacles meaning that they did not perceive that these obstacles would prevent them from using BIM in their practice.

The survey participants were also asked whether they had any disputes related to BIM implementation in educational facility projects. Most of the respondents indicated that their companies have not experienced disputes while using BIM (Table 12). Of those respondents that stated that BIM use has led to certain disputes, the most commonly mentioned reason for these disputes was related to liability of system designs. The second reason for disputes was related to intellectual property ownership of the building information model; all disciplines except the MEP engineers specified that this was a problem with BIM use. One architect indicated that their firm had disputes related to adequate compensation for BIM services, while another architect stated that BIM-related disputes happened because other disciplines were not using BIM. One structural engineer indicated that disputes arose due to different levels of model accuracy. Note that the respondents were asked to "select all that apply" when answering this question.

5. Comparison of Current Findings and Previous Research

In order to answer the research question on how BIM use differs on educational facility projects as compared to other projects (e.g., commercial buildings) as well as to identify the contributions of our study, the authors performed the comparison of this research findings and previous research. Please note that our research focused on BIM use in educational facility projects and that there is very limited previous research on this topic. Therefore, we expanded our literature search on BIM use in general, that is, without focusing on a specific building type.

Table 13 shows the comparison of our study and previous research in regard to BIM benefits. The analysis of the results is performed using the data presented in Table 10. If majority of the disciplines in our study either agreed or strongly agreed (that is, mean score was larger than 3.50) with the BIM benefits shown in Table 10, the check mark was assigned to that specific benefit in Table 13. Regarding BIM benefits in the design, construction, and O&M phases, our study confirmed several benefits of using BIM on educational facility project that were very similar to BIM benefits experienced on, e.g., commercial buildings and identified by previous research. There were a few BIM

Table 11: Relationship between the role of the respondent and their perception of the obstacles preventing the use of BIM (mean/average rating score).

Obstacle category	Obstacles that prevent BIM use	Architects $N_A = 30$ (48.4%)	Site engineers $N_{SE} = 4$ (6.5%)	Structural engineers $N_{STE} = 9$ (14.5%)	MEP engineers $N_{MEPE} = 5$ (8.1%)	Contractors $N_C = 14$ (22.6%)
Cost	Cost of software and new hardware to keep up with the software	3.10	2.75	2.67	3.00	4.00
	Cost of hiring experienced staff	3.20	3.25	2.67	2.80	3.93
	Lack of substantial quantifiable benefits and evaluation methods	3.20	3.75	3.56	2.80	3.21
	Fast-paced and small-sized projects do not justify the time needed for the cost of implementing BIM	3.00	3.50	3.11	3.20	3.50
Demand	Not enough owner demand	2.90	3.25	3.30	2.20	3.43
BIM professionals	Lack of expertise and need for training	3.33	3.50	3.33	3.40	3.86
	Unclear responsibilities, assigned roles, and BIM deliverables	3.07	4.25	2.89	3.00	3.69
BIM process	Disruption in workflow to implement new BIM processes	3.21	4.25	3.44	2.40	3.79
	Vulnerability or security of file sharing	2.45	3.25	2.78	2.00	3.29
	Lack of software interoperability	3.10	4.00	3.11	2.80	3.29
Legal issues	Lack of BIM standards	3.03	3.50	3.44	2.40	3.50
	Lack of precedence, established laws, and regulations about BIM use	2.87	3.25	2.78	2.20	3.21
	Legal liabilities of the BIM process	2.97	3.75	3.22	2.40	3.07

Note. Total $N = 62$.

Table 12: Relationship between the role of the respondent and the kind of disputes their companies have encountered when implementing BIM in educational facility projects*.

Types of disputes	Architects $N_A = 25$ $n_A = 26$	Site engineers $N_{SE} = 3$ $n_{SE} = 4$	Structural engineers $N_{STE} = 10$ $n_{STE} = 12$	MEP engineers $N_{MEPE} = 5$ $n_{MEPE} = 5$	Contractors $N_C = 9$ $n_C = 9$
My company has not encountered disputes with BIM implementation	14 (56%)	3 (100%)	7 (70%)	4 (80%)	6 (67%)
Intellectual property ownership of the model o r parts thereof	2 (8%)	1 (33.3%)	1 (10%)	0 (0%)	2 (22%)
Disputes regarding liability for system designs	8 (32%)	0 (0%)	3 (30%)	1 (20%)	1 (11%)
Adequate compensation for BIM work	1 (4%)	0 (0%)	0 (0%)	0 (0%)	0 (0%)
Lack of BIM use from other disciplines	1 (4%)	0 (0%)	0 (0%)	0 (0%)	0 (0%)
Level of model accuracy	0 (0%)	0 (0%)	1 (10%)	0 (0%)	0 (0%)

Note. *Select all that apply. Percent (%) = number of selections divided by number of respondents for a specific discipline. Total $N = 52$ and total $n = 56$.

benefits that were found by previous studies on commercial buildings but were not selected by the majority of the participants in our research. Thus, our study did not find that BIM was beneficial on educational facility projects in terms of allowing more time for design instead of creating contract documents, reducing production and construction costs, improving construction safety, and encouraging sustainability efforts. Similar to the previous research on commercial buildings, our study on educational facility projects did not find BIM beneficial for encouraging use of other technologies, increasing project profitability, and allowing for long-term data assessment. On the other hand, our study contributed to the body of knowledge by identifying the following four new benefits specific to educational facility projects that were not mentioned in the previous research: BIM enabling faster reviews for approvals and permits, facilitating modular construction, reducing on-site waste and material use, and providing more accurate as-builts (see italics in Table 13).

Table 13: Comparison of current findings and previous research: benefits of BIM use.

Project phase	BIM benefits	Current findings: BIM use on educational buildings	Previous research: BIM use on general type of the buildings
Design phase	Evaluates the impact of different design solutions	✓	Bynum et al. [57]
	Allows more time to be spent on design than on contract documentation		Cefrio [9], Korman and Lu [46]
	Lowers risk and better predicts outcomes due to discovery of errors, omissions and conflicts prior to construction	✓	U.S. General Service Administration (GSA) [43]
	Enables automation of documentation (better accuracy and accounts for adjustments and changes automatically)	✓	Bynum et al.[57]
	Enables faster reviews for approvals and permits	✓	
Construction phase	Reduces RFI's, change orders, claims, and conflicts	✓	Azhar [39], Ahn et al. [7], Cao et al. [44], Porwal and Hewage [59], Kraling and Dunbar [60]
	Reduces construction and production costs		Ahn et al. [7], Hamdi and Leite [45], Dodge Data and Analytics [47]
	Reduces project delivery time	✓	Ahn et al. [7], Hamdi and Leite [45], Dodge Data and Analytics, [47]
	Facilitates modular construction	✓	
	Increase prefabrication	✓	Ahn et al. [7], Eastman et al. [8]
	Reduces on-site waste and materials use	✓	
	Improves construction safety		Ahn et al. [7], Ganbat et al. [51]
Both design and construction phases	Increases client engagement and provides clearer understanding of 3D visualizations	✓	McGraw Hill Construction [42], Ganbat et al. [51], Arayici et al. [63], Azhar [39]
	Increases productivity and efficiency	✓	Cefrio [9], Chelson [53], Poirier et al. [54], Barlish and Sullivan [55], Nath et al. [56]
	Encourages consideration for sustainable building systems that conserve energy		Bynum et al. [57]
	Serves as a new marketing tool for firms	✓	Ahn et al. [7], Bernstein [61]
	Encourages use of other technologies (GIS, unity, etc.)		
Both construction and O&M phases	*Provides more accurate as-built deliverables*	✓	
All project phases	Improves collaboration and communication between disciplines due to more reliable and direct data exchange from a single resource of information	✓	Bynum et al. [57], Eastman et al. [8]
	Increases project profitability		
	Allow for long term data assessment		

Table 14 shows the comparison of our study and previous research regarding obstacles that prevent BIM use. The analysis of the results is performed using the data presented in Table 11. Similar to the benefit comparison, if majority of the disciplines in our study thought that the obstacles shown in Table 11 are likely (that is, mean score was larger than 3.00) to impede BIM implementation, the check mark was assigned to that specific obstacle in Table 14. Six obstacles identified in previous research on commercial buildings were also confirmed by our research on BIM use in educational facility projects. There were a few obstacles to BIM use that the participants of this research did not

Table 14: Comparison of current findings and previous research: obstacles to BIM use.

Obstacle category	Obstacles that prevent BIM use	Current findings: BIM use on educational buildings	Previous research: BIM use on general type of the buildings
Cost	Cost of software and new hardware to keep up with the software	✓	Lee et al. [3], Gheisari and Irizarry [4], Ahn et al. [7], Won et al. [22], Ganbat et al. [51], Samuelson and Björk [52]
	Cost of hiring experienced staff	✓	
	Lack of substantial quantifiable benefits and evaluation methods	✓	Won et al. [22], Smith [65]
	Fast-paced and small-sized projects do not justify the time needed for the cost of implementing BIM	✓	
Demand	*Not enough owner demand*	✓	
BIM professionals	Lack of expertise and need for training	✓	Lu et al. [1], Gheisari and Irizarry [4], Ahn et al. [7], Won et al. [22], Ganbat et al. [51], Samuelson and Björk [52], Lee et al. [3], Cefrio [9], Gu and London [23]
	Unclear responsibilities, assigned roles, and BIM deliverables	✓	Lee et al. [3], Gu and London [23], Hamdi and Leite [45]
BIM process	*Disruption in workflow to implement new BIM processes*	✓	
	Vulnerability or security of file sharing		Won et al. [22], Ganbat et al. [51]
	Lack of software interoperability	✓	Gheisari and Irizarry [4], Miettinen and Paavola [25], Ganbat et al. [51], Cao et al. [44], Hamdi and Leite [45]
Legal issues	*Lack of BIM standards*	✓	
	Lack of precedence, established laws, and regulations about BIM use		Hamdi and Leite [45]
	Legal liabilities of the BIM process	✓	Lee et al. [3], Ahn et al. [7], Eastman et al. [8]

identify on educational projects as compared to the previous studies. These obstacles include vulnerability or security of file sharing and lack of precedence, established laws, and regulations about BIM use. The contribution of our study is in discovering five new obstacles that the study participants thought were specific to educational facility projects and that were not mentioned in the previous research on commercial buildings. These obstacles relate to cost of hiring experienced staff, fast-paced and small-sized projects not justifying the time needed for the cost of implementing BIM, insufficient owner demand, disruption in workflow to implement new BIM processes, and lack of BIM standards (see italics in Table 14).

6. Conclusions

This study investigated the use of BIM by the AEC industry on educational facility projects in the USA. The objectives were to determine perceptions of the design and construction professionals about BIM adoption by companies, BIM implementation on projects, benefits of using BIM, and obstacles that hinder BIM adoption. A survey was sent to the members of professional organizations such as AIA, AGC, ABC, and ASCE across the USA. The five disciplines that participated in the survey were architects, site engineers, structural engineers, MEP engineers, and contractors. The survey results revealed the following:

(1) *Majority of the Respondents Use BIM.* BIM use was prevalent on educational facility projects according to the professionals from all five disciplines. The majority of those respondents who did not use BIM would be interested in implementing BIM in the future except the architects that indicated having no interest in using BIM. The MEP engineers, site engineers, and architects stated that about half of the employees in their companies were BIM-savvy while the structural engineers and contractors came from the companies with a smaller proportion of BIM-knowledgeable employees. Most of the designers perceived clients as a driving force for BIM implementation which is an important finding in the case of educational projects in which input from the clients (e.g., students, teachers, and principals) is crucial during the design phase.

(2) *The Major BIM Applications on Educational Facility Projects by All Five Disciplines Are 3D Visualizations, Automation of Documentation, and Clash Detection.* As expected, the major BIM applications by a discipline were based on the discipline's scope of work. For example, the structural and site engineers used BIM for structural analysis, the MEP engineers for MEP analysis, and the contractors used BIM for clash detection on the majority of the educational facility projects.

(3) *BIM-Based Collaborative Knowledge Sharing among the Various Project Stakeholders Is Driven by the Educational Facility Project Phase and the Discipline's Scope of the Work.* BIM as a process/methodology requires a collaborative workflow. As expected, due to this workflow and the scope of each discipline work, the large majority of the engineers and the largest proportion of contractors shared the information primarily with architects. The designers and contractors also shared the information with owners indicating that BIM creates collaborative and inclusive environment on educational projects, which also integrates clients into the process.

(4) *BIM Use Is Beneficial in All the Phases of the Educational Facility Projects.* The architects and site engineers thought that the use of BIM was providing value in the design phase of a project while the structural engineers and contractors saw the benefits of BIM use in both design and construction phases of the projects. The MEP engineers thought that BIM use was almost equally valuable in all the project phases. All disciplines agreed that the use of BIM as a new marketing tool and use of 3D models for clearer visualization and understanding of the projects by the clients are some of the most important benefits of BIM. In terms of the other potential benefits, the perceptions varied among the five disciplines due to their specific scope of work. For example, architects indicated that BIM helped them with evaluating different design alternatives and reducing numbers of errors and omissions early on in the project, while the contractors valued highly the use of BIM for increasing productivity and efficiency and decreasing cost and duration of the educational facility projects.

(5) *Regarding the Specific Obstacles That Could Prevent the BIM Use on Educational Facility Projects, the Majority of Respondents Indicated a Few Obstacles as Compared to BIM Benefits.* The architects, site engineers, and MEP engineers thought that BIM-related personnel issues would hinder BIM use, while for the contractors, the cost of BIM implementation was the major barrier to BIM use. According to the structural engineers, lack of substantial quantifiable benefits and evaluation methods would very likely hinder BIM use. Regarding legal disputes related to BIM use, most of the respondents stated that their companies have not encountered disputes with BIM implementation.

(6) *Comparison of the Findings of Our Study That Focused on Educational Facility Projects and the Previous Research That Investigated All Building Project Types Showed That Most of Our Findings on BIM Benefits and Obstacles to BIM Use Correspond to the Findings of Previous Research That Investigated All the Building Types.* However, our study identified four new benefits (i.e., BIM enables faster reviews for approvals and permits, facilitates modular construction, reduces on-site waste and material use, and provides more accurate as-builts) as well as five new obstacles (i.e., cost of hiring experienced staff, fast-paced and small-sized projects not justifying the use of BIM, insufficient owner demand, disruption in workflow to implement new BIM processes, and lack of BIM standards). These factors are specific to the educational facility projects and their discovery represents one of the major contributions of our study.

The contribution of this research is in filling the gap in literature that relates to BIM use specifically on educational facility projects. The study showed prevalence of BIM use on educational projects, possible applications, and how BIM could improve collaborative knowledge sharing among architects, engineers, contractors, and clients, leading to better quality educational buildings. The findings of the study could be utilized by AEC companies in their efforts to implement BIM on educational facility projects.

Data Availability

The data used to support the findings of this study are available from the corresponding author upon request.

Conflicts of Interest

There are no conflicts of interest regarding the publication of this paper.

Acknowledgments

The authors would like to acknowledge support for the article processing fee from the University of Florida and the Colorado State University libraries open access research and scholarship fund.

Supplementary Materials

Supplementary materials include Appendix A, showing the survey instrument that was distributed to the participants of this research study. (*Supplementary Materials*)

References

[1] Y. Lu, L. Yongkui, M. Skibnievski, Z. Wu, R. Wang, and Y. Le, "Information and communication technology applications in architecture, engineering, and construction organizations: a 15-year review," *Journal of Management in Engineering*, vol. 31, no. 1, article A4014010, 2015.

[2] C. Botton and D. Forgues, "Practices and processes in BIM projects: an exploratory case study," *Advances in Civil Engineering*, vol. 2018, Article ID 7259659, 12 pages, 2018.

[3] S. Lee, J. Yu, and D. Jeong, "BIM acceptance model in construction organizations," *Journal of Management in Engineering*, vol. 31, no. 3, article 04014048, 2015.

[4] M. Gheisari and J. Irizarry, "Investigating human and technological requirements for successful implementation of a BIM-based mobile augmented reality environment in facility management practices," *Facilities*, vol. 34, no. 1/2, pp. 69–84, 2016.

[5] J. Wang, X. Wang, J. Wang, P. Yung, and G. Jun, "Engagement of facilities management in design stage through BIM:

framework and a case study," *Advances in Civil Engineering*, vol. 2013, Article ID 189105, 8 pages, 2013.

[6] Y. Liu, S. van Nederveen, C. Wu, and M. Hertogh, "Sustainable infrastructure design framework through integration of rating systems and building information modeling," *Advances in Civil Engineering*, vol. 2018, Article ID 8183536, 13 pages, 2018.

[7] Y. Ahn, H. Kwak, and J. Suk, "Contractors' transformation strategies for adopting building information modeling," *Journal of Management in Engineering*, vol. 32, no. 1, article 05015005, 2016.

[8] C. Eastman, P. Teicholz, R. Sacks, and K. Liston, *BIM Handbook: A Guide to Building Information Modeling for Owners, Managers, Designers, Engineers, and Contractors*, John Wiley and Sons, Hoboken, NJ, USA, 2nd edition, 2011.

[9] Cefrio, *Improving Efficiency and Productivity in the Construction Sector through the Use of Information Technologies*, NRC Industrial Research Assistance Program, Quebec, Canada, 2011.

[10] R. Borden, *"Taking School Design to Students", National Clearinghouse for Educational Facilities*, National Institute of Building Sciences, Washington, DC, USA, 2004.

[11] J. Cohen, *Integrated Project Delivery: Case Studies*, AIA California Council, Sacramento, CA, USA, 2010.

[12] Neasden Primary School, *Application of BIM in Energy Management of Individual Departments Occupying University Facilities*, Neasden Primary School, Hull, UK, 2019, https://neasdenprimary.org.uk/school-new-build/.

[13] Dezeen, *Visual Arts Building Animation*, Iowa University School of Art & Art History, Iowa City, IA, USA, 2019, https://vimeo.com/76039896.

[14] Tigard-Tualatin School District, *Video Walkthrough Released for Tualatin HS Design*, Tigard-Tualatin School District, Tigard, OR, USA, 2019, https://www.ttsdschools.org/site/default.aspx?PageType=3&DomainID=21&ModuleInstanceID=10379&ViewID=6446EE88-D30C-497E-9316-3F8874B3E108&RenderLoc=0&FlexDataID=16640&PageID=63.

[15] J. Zhang and R. Issa, "Collecting fire evacuation performance data using BIM-based immersive serious games for performance-based fire safety design," in *Proceedings of the 2015 International Workshop on Computing in Civil Engineering*, pp. 612–619, Austin, TX, USA, June 2015.

[16] E. Vaughan, *"Elementary School", Whole Building Design Guide*, National Institute of Building Sciences, Washington, DC, USA, 2017, available at: https://www.wbdg.org/building-types/education-facilities/elementary-school.

[17] H. Eckerlin, "An Evaluation of Daylighting in Four Schools in the Research Triangle Area of North Carolina," A Summary Report, North Carolina State University, Raleigh, NC, USA, 2005.

[18] Innovative Design, *Guide for Daylighting Schools, Lighting Research Center*, Rensselaer Polytechnic Institute, Troy, NY, USA, 2004.

[19] K. Tu and D. Vernatha, "Application of Building Information Modeling in energy management of individual departments occupying university facilities," *World Academy of Science, Engineering and Technology International Journal of Architectural and Environmental Engineering*, vol. 10, no. 2, 2016.

[20] H. Gocke and K. Gocke, "Integrated system platform for energy efficient building operations," *Journal of Computing in Civil Engineering*, vol. 28, no. 6, article 05014005, 2014.

[21] J. Irizarry, M. Gheisari, G. Williams, and K. Roper, "Ambient intelligence environments for accessing building information," *Facilities*, vol. 32, no. 3/4, pp. 120–138, 2014, https://doi.org/10.1108/F-05-2012-0034.

[22] J. Won, G. Lee, C. Dossick, and J. Messner, "Where to focus for successful adoption of building information modeling within organization," *Journal of Construction Engineering and Management*, vol. 139, no. 11, article 04013014, 2013.

[23] N. Gu and K. London, "Understanding and facilitating BIM adoption in the AEC industry," *Automation in Construction*, vol. 19, no. 8, pp. 988–999, 2010.

[24] H. Son, S. Lee, and C. Kim, "What drives the adoption of building information modeling in design organizations? An empirical investigation of the antecedents affecting architects' behavioral intentions," *Automation in Construction*, vol. 49, pp. 92–99, 2015.

[25] R. Miettinen and S. Paavola, "Beyond the BIM utopia: approaches to the development and implementation of building information modeling," *Automation in Construction*, vol. 43, pp. 84–91, 2014.

[26] A. Nical and W. Wodynski, "Enhancing facility management through BIM 6D," *Procedia Engineering*, vol. 164, pp. 299–306, 2016, https://www.sciencedirect.com/science/article/pii/S1877705816339649. 10.1016/j.proeng.2016.11.623.

[27] M. Kassem, G. Kelly, N. Dawood, M. Serginson, and S. Lockley, "BIM in facilities management applications: a case study of a large university complex," *Built Environment Project and Asset Management*, vol. 5, no. 3, pp. 261–277, 2015, https://doi.org/10.1108/BEPAM-02-2014-0011.

[28] J. J. McArthur, "A building information management (BIM) framework and supporting case study for existing building operations, maintenance and sustainability," *Procedia Engineering*, vol. 118, pp. 1104–1111, 2015, https://www.sciencedirect.com/science/article/pii/S1877705815021050.10.1016/j.proeng.2015.08.450.

[29] S. Lockley, *BIM for Facilities Management—University Campus*, OpenBIM, Newcastle-upon-Tyne, UK, 2013.

[30] D. Budds, *How Building Information Modeling saved one University $10 Million*, Co. Design, 2017.

[31] C. Keegan, *Building Information Modeling in Support of Space Planning and Renovation in Colleges and Universities*, Master thesis, Worcester Polytechnic Institute, Worcester, MA, USA, 2019, https://web.wpi.edu/Pubs/ETD/Available/etd-042910-162540/unrestricted/CKeegan_Thesis_BIM.pdf.

[32] B. Skripac, *Defining a Holistic, Owner-Driven BIM Project Delivery Standard at the Ohio State University*, CannonDesign, Grand Island, NE, USA, 2019, https://www.cannondesign.com/news-insights/white-papers/defining-a-holistic-owner-driven-bim-project-delivery-standard-at-the-ohio-state-university/.

[33] Indiana University, *BIM Guidelines & Standards for Architects, Engineers, and Contractors*, Indiana University, Bloomington, IN, USA, 2019, http://www.indiana.edu/~uao/docs/standards/IU%20BIM%20Guidelines%20and%20Standards.pdf.

[34] University of Illinois, *Building Information Modeling (BIM) Requirements, Version 1.1*, University of Illinois, Champaign, IL, USA, 2019, available at: http://www.fs.illinois.edu/docs/default-source/facility-standards/bim-requirements.pdf?Status=Temp&sfvrsn=4.

[35] Western Michigan University, *BIM Project Execution and Standards Guide for Western Michigan University Facility Management, V. 14*, Western Michigan University, Kalamazoo, MI, USA, 2019, http://www.fm.wmich.edu/ap/sg/guidelines/Admin_GUIDELINEs_WMU%20BIM%20Execution%20Plan_V14_current.pdf.

[36] University of Southern California, *Building Information Modeling (BIM) Guidelines, Version 1.6*, University of Southern California, Los Angeles, CA, USA, 2019, http://facilities.usc.edu/uploads/documents/cas/BIMGuidelines_VS1_6_2012.pdf.

[37] Virginia Commonwealth University, *Building Information Modeling (BIM) Guidelines and Standards for Architects, Engineers, and Contractors*, Virginia Commonwealth University, Richmond, VA, USA, 2019, https://fmd.vcu.edu/media/fmd/docs/VCUBIMGuidelines-02072014.pdf.

[38] National Institute of Building Sciences (NIBS) Buildingsmart Alliance, "National BIM standard—United States version 3," 2019, https://www.nationalbimstandard.org/.

[39] S. Azhar, "Building information modeling (BIM): trends, benefits, risks and challenges for the AEC industry," *Journal of Leadership and Management in Engineering*, vol. 11, no. 3, pp. 241–252, 2011.

[40] McGraw Hill Construction, "SmartMarket Report: the business value of BIM in North America," McGraw Hill Construction, Research & Analytics, Bedford, MA, USA, 2012.

[41] McGraw Hill Construction, "SmartMarket Report: the business value of BIM for construction in major global markets," McGraw Hill Construction, Research & Analytics, Bedford, MA, USA, 2014.

[42] McGraw Hill Construction, "SmartMarket Report: the business value of BIM for owners," McGraw Hill Construction, Research & Analytics, Bedford, MA, USA, 2014.

[43] U.S. General Service Administration (GSA), *GSA Building Information Modeling Guide Series 01—Overview*, General Services Administration, Washington, DC, USA, 2007.

[44] D. Cao, G. Wang, H. Li, M. Skitmore, T. Huang, and W. Zhang, "Practices and effectiveness of building information modelling in construction projects in China," *Automation in Construction*, vol. 49, pp. 113–122, 2015.

[45] O. Hamdi and F. Leite, "Conflicting side of building information modeling implementation in the construction industry," *Journal of Legal Affairs and Dispute Resolution in Engineering and Construction*, vol. 6, no. 3, article 03013004, 2014.

[46] T. Korman and N. Lu, "Innovations and improvements of MEP systems for modular construction using building information modeling," in *Proceedings of the Architectural Engineering Conference (AEI)*, pp. 448–455, Oakland, CA, USA, April 2011.

[47] Dodge Data and Analytics, *SmartMarket Brief: BIM Advancements*, Dodge Data and Analytics, New York, NY, USA, 2019, http://www.smartmarketbrief.com/.

[48] T. Kotwal, R. Ponoum, and J. Brodrick, "BIM for energy savings," *ASHRAE Journal*, vol. 53, pp. 81–86, 2011.

[49] D. Lee, J. Park, and S. Song, "BIM-based construction information management framework for site information management," *Advances in Civil Engineering*, vol. 2018, Article ID 5249548, 14 pages, 2018.

[50] McGraw Hill Construction, "SmartMarket report: the business value of BIM for infrastructure," McGraw Hill Construction, Research & Analytics, Bedford, MA, USA, 2012.

[51] T. Ganbat, H.-Y. Chong, P.-C. Liao, and Y.-D. Wu, "A bibliometric review on risk management and building information modeling for international construction," *Advances in Civil Engineering*, vol. 2018, Article ID 8351679, 13 pages, 2018.

[52] O. Samuelson and B.-C. Björk, "A longitudinal study of the adoption of IT technology in the Swedish building sector," *Automation in Construction*, vol. 37, pp. 182–190, 2014.

[53] D. Chelson, *The effects of building information modeling on construction site productivity*, Ph.D. Dissertation, University of Maryland, College Park, MD, USA, 2010.

[54] E. A. Poirier, S. Staub-French, and D. Forgues, "Measuring the impact of BIM on labor productivity in a small specialty contracting enterprise through action-research," *Automation in Construction*, vol. 58, pp. 74–84, 2015.

[55] K. Barlish and K. Sullivan, "How to measure the benefits of BIM—a case study approach," *Automation in Construction*, vol. 24, pp. 149–159, 2012.

[56] T. Nath, M. Attarzadeh, R. L. K. Tiong, C. Chidambaram, and Z. Yu, "Productivity improvement of precast shop drawings generation through BIM-based process re-engineering," *Automation in Construction*, vol. 54, pp. 54–68, 2015.

[57] P. Bynum, R. R. A. Issa, and S. Olbina, "Building information modeling in support of sustainable design and construction," *Journal of Construction Engineering and Management*, vol. 139, no. 1, pp. 24–34, 2013.

[58] K. Lee and S. Choo, "A hierarchy of architectural design elements for energy saving of tower buildings in Korea using green BIM simulation," *Advances in Civil Engineering*, vol. 2018, Article ID 7139196, 13 pages, 2018.

[59] A. Porwal and K. N. Hewage, "Building information modeling (BIM) partnering framework for public construction projects," *Automation in Construction*, vol. 31, pp. 204–214, 2013.

[60] R. K. Kraling and M. Dunbar, "Building information modeling and educational projects," *Engineered Systems*, vol. 28, no. 8, pp. 30–36, 2011.

[61] H. Bernstein, "New research shows contractors are big BIM users," *Engineering News-Record*, 2012.

[62] Z. Shen and L. Jiang, "An augmented 3D iPad mobile application for communication, collaboration and learning (CCL) of building MEP systems," in *Proceedings of the 2012 International Conference on Computing in Civil Engineering*, pp. 204–212, Clearwater Beach, FL, USA, June 2012.

[63] Y. Arayici, P. Coates, L. Koskela, M. Kagioglou, C. Usher, and K. O'Reilly, "Technology adoption in the BIM implementation for lean architectural practice," *Automation in Construction*, vol. 20, no. 2, pp. 189–195, 2011.

[64] D. B. Arensman and M. E. Ozbek, "Building information modeling and potential legal issues," *International Journal of Construction Education and Research*, vol. 8, no. 2, pp. 146–156, 2012.

[65] D. K. Smith, "The USC school of cinematic arts: the arrival of spring in the facilities industry," *Journal of Building Information Modeling*, vol. 2009, pp. 16-17, 2009.