Pros and Cons of Using Building Information Modeling in the AEC Industry

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Abstract: Although a plethora of studies on building information modeling (BIM) have been conducted in the last decade, none of the previous studies collate and/or prioritize the benefits, risks, and challenges of BIM based on the data collected from a comprehensive literature review and subject matter experts (SMEs). In order to allow architecture, engineering, and construction (AEC) professionals and academics see the true potential of BIM in a wider context and help them understand its multiorganizational and multidisciplinary functions, there is an obvious necessity for identifying, classifying, and prioritizing the pros and cons of BIM; however, such a study is still currently absent in the AEC literature. The aim of this study is to identify, classify, and rank the pros and cons of BIM that address the benefits, challenges, and risks of BIM in the transition from computer-aided design (CAD). A literature review was performed and face-to-face semistructured interviews with SMEs on BIM were conducted for identification and classification purposes. A total of 41 types of benefits, 11 types of risks, and 13 types of challenges of BIM were identified via triangulation of literature review and face-to-face semistructured interviews with SMEs. The Delphi method was performed for prioritizing the benefits of BIM in terms of time, cost, and sustainability as well as the risks and challenges of BIM encountered in the transition process from CAD to BIM. The interrater agreement and significance-level statistics were performed to analyze and validate the consensus reached by the Delphi panel experts. This paper contributes to the existing body of knowledge on BIM by providing comprehensive identification and classification of the benefits, challenges, and risks of BIM, and prioritization of the benefits for BIM in terms of time, cost, and sustainability as well as the risks and challenges of BIM. The priority rankings of benefits, risks, and challenges of BIM ensure successful completion of projects and create additional value by allowing professionals to make well-informed decisions that support decreasing time and cost-related waste in the transition process from CAD to BIM. **DOI: 10.1061/(ASCE)CO.1943-7862.0001681.**

Author keywords: Building information modeling; Benefits of building information modeling (BIM); Challenges of building information modeling (BIM); Risks of building information modeling (BIM); Pros and cons of building information modeling (BIM); Delphi method.

Introduction

Projects in the architecture, engineering, and construction (AEC) industry are becoming much more intricate and difficult to manage; hence, professionals and academics have been looking for new techniques and technologies to decrease project cost and delivery time as well as increase productivity and quality (Azhar 2011; Bryde et al. 2013). Building information modeling (BIM), described as a product, process, and system by the National Building Information Modeling Standard (NBIMS) (National Institute of Building Sciences 2019), is becoming increasingly substantial and widespread in today's fast-moving competitive AEC industry. BIM promotes the constructability of the project, increases the productivity, accelerates the schedule, and ensures saving time and money as well as stimulates project quality, efficiency, and success in a consistent manner. Research conducted by Stanford University's Center for Integrated Facilities Engineering (CIFE) on 32 large-scale construction projects shows that adopting BIM provides up to 80% reduction of time spent in project budget estimation, up to 7% decrease in total project duration, up to 10% savings in contract value, and up to 40% elimination in unbudgeted change as well as estimation of total project cost with 3% margin (Azhar 2011). According to the study performed by Sacks et al. (2005), the potential benefit of adopting BIM is between 2.3% and 4.2% of total project cost for precast concrete companies. Another study conducted by Sacks and Barak (2008) on two sets of three-dimensional (3D) modeling experiments with cast-in-place reinforced concrete structures demonstrates that using BIM contributes to the increase in productivity ranging from 15% to 41%.

BIM enables professionals to create an accurate 3D digital model of a building using intelligent objects and facilitates exchange as well as interoperability of information in design, construction, and operation phases that help architects, engineers, and constructors to visualize what is to be built in a simulated environment in order to identify any potential design, construction, or operational issues. Integration of three-dimensional models in scheduling and planning helps calculation of time, resource capacities, and quantities (e.g., material and product items) in an automatic manner to determine the correct duration of the work and/or work packages in order to complete an individual task, which allows the internal content of an individual activity (e.g., components and associated materials) to become more transparent and easily accessible (Dang and Bargstädt 2016). According to a study conducted by Sacks et al. (2009), a BIM-based visualization user interface provides process transparency and identification of work packages and their relationships, which in turn assist the managers in selecting the work packages for immediate execution and determining material requirements in an automatic manner as well as compiling materials for delivery.

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Note. This manuscript was submitted on May 11, 2018; approved on January 22, 2019; published online on June 11, 2019. Discussion period open until November 11, 2019; separate discussions must be submitted for individual papers. This paper is part of the ***Journal of Construction Engineering and Management***, © ASCE, ISSN 0733-9364.

On the other hand, active use of BIM requires significant investments in technology, staff, and training, which causes stakeholders to be hesitant about implementing BIM in their new projects. Previous studies indicate that a lack of knowledgeable and experienced professionals in the AEC industry is a crucial obstacle in the adoption of BIM in projects (Kiviniemi 2006; Hartmann and Fischer 2008; Sacks and Barak 2009; Chien et al. 2014). In order to increase active use of BIM, some of the previous studies examined BIM comprehensively in terms of its (1) benefits, risks, challenges, and current and future trends as well as applications in the AEC industry (Azhar 2011; Ghaffarianhoseini et al. 2017); while others analyzed specialized aspects of BIM projects in terms of (2) their critical risk factors (Chien et al. 2014; Jin et al. 2017); (3) benefits and returns (Sacks and Goldin 2007; Azhar 2011; Hartmann et al. 2008; Lee et al. 2012, 2015; Lu and Korman 2010; Lopez and Love 2012; Bryde et al. 2013; Bynum et al. 2013; Lu et al. 2013; Francom and El Asmar 2015; Dang and Bargstädt 2016; Olawumi and Chan 2018); (4) challenges (Rekola et al. 2010; Lu and Korman 2010); (5) advantages and applications (Farnsworth et al. 2015); (6) requirements (Sacks and Barak 2009; Sacks et al. 2010b; Peterson et al. 2011; Wu et al. 2018); (7) adaptation in developing countries such as China (Cao et al. 2014, 2017; Jin et al. 2017), Korea (Lee and Yu 2016), Pakistan (Masood et al. 2014), India (Mahalingam et al. 2015), and Nigeria (Olatunji et al. 2017); and (8) applications in specific areas such as the mechanical and electrical construction industry (Hanna et al. 2014). Within this perspective, (1) *benefits* refer to the factors that contribute to successful completion of projects; (2) *challenges* refer to the factors that should be overcome to ensure successful completion of projects; (3) *risks* refer to the factors that relate to uncertain events or conditions with imminent effect on at least one project objective (PMI 2008); (4) *current and future trends* indicate the tendencies of the AEC industry particularly related to the technological advancements and developments of BIM (Azhar 2011); (5) *requirements* refer to the factors necessitated for the proper implementation of BIM in the AEC industry; (6) *returns* refer to the factors related to the benefits and added values gained from adopting BIM in the AEC industry (Jin et al. 2017); and (7) *applications* point out the utilization areas of BIM in the AEC industry that are (a) visualization, (b) fabrication or shop drawings, (c) code reviews, (d) scheduling, (e) cost estimating, (f) construction sequencing, (g) conflict, interference, and collision detection, (h) forensic analysis, (i) sustainability analysis, and (j) facility management (Azhar 2011; Ghaffarianhoseini et al. 2017).

Although a plethora of studies on BIM have been conducted in the last decade, the AEC literature is still not sufficient to see the bigger picture with all the necessary information regarding the pros and cons of BIM. None of the previous studies collate and/or prioritize the benefits, risks, and challenges of BIM based on the data collected from a comprehensive literature review and subject matter experts (SMEs). In order to allow AEC professionals and academics to see the true potential of BIM in a wider context and help them understand its multiorganizational and multidisciplinary functions, there is an obvious necessity for identifying, classifying, and prioritizing the pros and cons of BIM; however, such a study is still currently absent in the AEC literature.

This research study aims to identify, classify, and rank the pros and cons of BIM that address the benefits of BIM in terms of time, cost, and sustainability as well as the challenges and risks of BIM in the transition from computer-aided design (CAD). In this research, the benefits of BIM were prioritized in terms of time, cost, and sustainability since these three topics are the fourth (4D), fifth (5D), and sixth (6D) dimensions of BIM, respectively. In this study, sustainability refers to sustainable construction, which indicates the contribution of the built environment for the overarching vision of sustainability and addressing the ecological, social, and economic issues of a building in the context of its community (Kibert 2016).

A literature review was performed and face-to-face semistructured interviews with the SMEs on BIM were conducted for identification and classification purposes, while the Delphi method was conducted for prioritization purposes. The study subject of this paper contributes to the existing body of knowledge on BIM by providing comprehensive identification and classification of the benefits, challenges, and risks of BIM, and prioritization of the benefits for BIM in terms of time, cost, and sustainability as well as the risks and challenges of BIM. Priority rankings of the benefits, risks, and challenges of BIM can be used for making well-informed and conscious decisions that allow decreasing time- and cost-related waste in the transition process from CAD to BIM while increasing the overall success and value of projects. Accordingly, these priority rankings ensure successful completion of projects by achieving the envisioned benefits of BIM in multiple aspects while creating awareness and allowing professionals and researchers to develop practical strategies as well as suitable solutions to overcome the probable challenges and associated risks of BIM.

Research Methodology

The methodology of this study was designed using three approaches, literature review, face-to-face semistructured interviews, and the Delphi method, in order to (1) analyze the phenomena in a qualitative and quantitative manner; (2) reduce disadvantages of each individual approach, if any; (3) gain the advantages of each individual approach; (4) create synergy among these three approaches; (5) make them more mutually informative; (6) link aspects of different perspectives; and (7) create a multidimensional view of the subject (Fellows and Liu 2015). Data collected via these three approaches were triangulated within the entire study and within individual parts that in return enhanced the external validity, internal validity, and reliability of this research (Jick 1979).

In the first step of this study, a literature review and face-to-face semistructured interviews with the SMEs were performed and the results were triangulated to identify and classify the pros and cons of BIM that address the benefits, challenges, and risks of BIM in the transition from CAD. Literature review was selected as a data collection technique since this method allows integration and criticism of previous studies as well as identification of the central issues in the field (Cooper 2010; Creswell 2014). Face-to-face semistructured interviews were selected as the other qualitative data collection technique since interviews are the essential source of evidence (Yin 1994) and important mechanisms to build structure into the data collection process (Pettigrew 1997). Accordingly, outputs of the literature review provided more generalized results, whereas outputs of the interviews assisted in identifying specific cases, if any, and capturing in-depth information (Fellows and Liu 2015). In the literature review, with the aim of mitigating subjectivity, certain procedures based on keywords were employed in selecting and investigating publications (Betts and Lansley 1993; Creswell 2014). Publications including any of the following keywords were identified: benefits of BIM, advantages of BIM, disadvantages of BIM, challenges of BIM, barriers of BIM, obstacles of BIM, difficulties of BIM, utilization of BIM, use of BIM, challenges of BIM in the transition from CAD, risks of BIM, risks of BIM in the transition from CAD, cost impact of BIM, cost benefit of BIM, time impact of BIM, time benefit of BIM, effect of BIM on design and construction, effect of BIM on construction, effect of BIM on design, effect of BIM on operation and maintenance, effect of BIM on sustainability, effect of BIM on sustainable design, effect of BIM on sustainable construction, effect of BIM on green building design, effect of BIM on green building construction, pros of BIM, constraints of BIM, and pros and cons of BIM. Publications that were published between 1996 and 2018 were analyzed. In the review, the ASCE, Elsevier, Engineering Village, Taylor and Francis, Web of Science, and Wiley databases were used and the following sources were included: (1) articles published in highly ranked journals (e.g., journals under ASCE, Elsevier, Taylor and Francis, and Wiley), (2) conference proceedings [e.g., conferences held by ASCE and International Council for Building (CIB)], (3) technical reports (e.g., CIFE reports), (4) reviews, and (5) books. Each publication was manually reviewed to select the ones that include the benefits of BIM on time, cost, and sustainability as well as the risks and challenges of BIM. A total of 81 publications on BIM were identified.

In addition, four face-to-face semistructured interviews with the SMEs were conducted (1) to capture the benefits, challenges, and risks of BIM that are observed in real life projects and to extend the list of the benefits, challenges and risks of BIM identified in the literature review if necessary; (2) to gain insights and to understand experts' perceptions on BIM; and (3) to collect detailed information about the pros and cons of BIM for presenting enriched discussions. Three of the interviewees were architects and work as BIM managers and/or consultants. One was a structural engineer and works as a senior project engineer. Two of the SMEs have more than 10 years of experience in BIM, while two have 5–10 years of experience in BIM. Three of the SMEs have master's degree (M.Sc.) and one has a bachelor's degree (B.Sc.). The results of the literature review and face-to-face semistructured interviews were triangulated to identify and classify the benefits of BIM on time, cost, and sustainability as well as the challenges and risks of BIM in the transition process from CAD. The results were presented to the interviewees to elicit their feedback to validate the findings.

Finally, the Delphi method was used for prioritizing the benefits of BIM in terms of time, cost, and sustainability as well as the risks and challenges of BIM. The Delphi method was selected as the other data collection technique since this systematic and interactive research method allows for obtaining rational judgments from a preselected group of independent experts through a series of structured questionnaires on a specific topic (Brown 1968). This qualitative and quantitative research technique is widely used for reaching consensus in cross-field topics (Hasson et al. 2000) or for new and complex concepts (Chan et al. 2015; Yeung et al. 2009). This well-defined and highly successful research method allows (1) the experts to reach consensus through the use of controlled and anonymous feedback provided by the facilitator during multiple rounds, and (2) the facilitator to exhibit strong control over the interactions among the experts (Hallowell and Gambatese 2010). The Delphi questionnaires were prepared based on the results of the literature review and face-to-face semistructured interviews. A list of classified benefits, risks, and challenges of BIM was distributed to 12 experts for prioritizing. Two structured rounds were performed to minimize possible nonconformity and biases among the SMEs. The results were analyzed by using Microsoft Excel and were checked for convergence using standard deviation. The interrater agreement (IRA) and significance-level statistics were performed to analyze and validate the consensus reached by the Delphi panel experts (i.e., SMEs).

Identification and Classification of Benefits, Risks, and Challenges of BIM

When the data from the literature review and face-to-face semistructured interviews were triangulated, 41 types of benefits, 11 types of risks, and 13 types of challenges of BIM were identified. All benefit, risk, and challenge types that were identified in the literature review were checked and validated via the face-to-face semistructured interviews, from which no additional benefit, risk, or challenge type was introduced. Tables 1–3 provide the identified benefits, risks, and challenges of BIM and the related source of data.

Table 1. Benefits of BIM

Identifier	Benefits of BIM	Related source of data
B#1	Increasing building performance and quality	Sacks et al. (2010a), Azhar (2011), Patrick and Raja (2007), Lopez and Love (2012), Francom and El Asmar (2015), and Mahalingam et al. (2015)
B#2	Promoting productive and efficient collaboration with integrated project delivery	Rekola et al. (2010) and Sacks et al. (2009, 2010b)
B#3	Minimizing design and construction errors	Hegazy et al. (2001), Sacks et al. (2004), Acharya et al. (2006), Hartmann et al. (2008), Taylor and Bernstein (2009), Barlish and Sullivan (2012), Lee et al. (2012), Azhar et al. (2015), Lee et al. (2015), Lopez and Love (2012), Francom and El Asmar (2015), Mahalingam et al. (2015), Jin et al. (2017), and Antwi-Afari et al. (2018)
B#4	Automatic implementation of design changes into 3D CAD model	Hartmann et al. (2008), Azhar (2011), Aibinu and Venkatesh (2014), Johansson et al. (2015), Francom and El Asmar (2015), Mahalingam et al. (2015), Lopez and Love (2012), and Jin et al. (2017)
B#5	Supporting effective planning and organization of the procurement process	Hartmann et al. (2008), Sebastian and van Berlo (2010), Eastman et al. (2011), Grilo and Jardim-Goncalves (2011), Aibinu and Venkatesh (2014), and Mahalingam et al. (2015)
B#6	Trade verification from fabrication models	Lu and Korman (2010)
B#7	Minimizing potential problems in contract management	Ghaffarianhoseini et al. (2017)
B#8	Reducing time variances in the processes	Sacks and Goldin (2007), Hartmann et al. (2008), Sacks and Barak (2008), Patrick and Raja (2007), Sacks et al. (2009, 2010b), Sebastian and van Berlo (2010), Azhar (2011), Eastman et al. (2011), Lee et al. (2012), Bynum et al. (2013), Azhar et al. (2015), Mahalingam et al. (2015), and Dang and Bargstädt (2016)
B#9	Decreasing uncertainties in the processes by clarifying risks	Hartmann et al. (2008), Aranda-Mena et al. (2009), Sacks et al. (2009, 2010b, c), and Azhar et al. (2015)

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Table 1. (*Continued.*)

Identifier	Benefits of BIM	Related source of data
B#10	Promoting interoperability of different disciplines from the beginning of the project	Sacks and Eastman (2006), Hartmann et al. (2008), Aranda-Mena et al. (2009), Sacks et al. (2010a, b), Becerik-Gerber et al. (2012), and Olatunji et al. (2017)
B#11	Decreasing delays and project completion time	Patrick and Raja (2007), Hartmann et al. (2008), Sacks and Barak (2008), Sacks et al. (2009, 2010b, c), Sebastian and van Berlo (2010), Azhar (2011), Eastman et al. (2011), Lee et al. (2012), Bynum et al. (2013), Azhar et al. (2015), Mahalingam et al. (2015), and Dang and Bargstädt (2016)
B#12	Planning the tasks and responsibilities in a timely manner	Hartmann et al. (2008), Sacks et al. (2009, 2010b), Sebastian and van Berlo (2010), Azhar (2011), Lee et al. (2012), Choi et al. (2014), Ghaffarianhoseini et al. (2017), Azhar et al. (2015), Mahalingam et al. (2015), and Dang and Bargstädt (2016)
B#13	Minimizing waste of material, equipment, and labor	Patrick and Raja (2007), Sacks et al. (2009, 2010b, c), Azhar (2011), Lee et al. (2012), Azhar et al. (2015), Lee et al. (2015), Mahalingam et al. (2015), and Dang and Bargstädt (2016)
B#14	Promoting collaboration and coordination in early design phase	Sacks and Eastman (2006), Hartmann et al. (2008), Sacks and Barak (2008), Kymmell (2008), Love et al. (2010), Laan et al. (2012), Lu et al. (2015), Popov et al. (2010), Azhar (2011), Bynum et al. (2013), Mahalingam et al. (2015), Wu and Issa (2015), and Ahn et al. (2016)
B#15	Visualization of model in early design phase	Fox and Hietanen (2007), Hartmann et al. (2008), Sacks and Barak (2008), Azhar (2011), Johansson et al. (2015), Bynum et al. (2013), Ahn et al. (2016), and Antwi-Afari (2018)
B#16	Visualization of model regarding the existing condition	Azhar (2011), Johansson et al. (2015), Bynum et al. (2013), and Ahn et al. (2016)
B#17	Using digital models for production of building elements	Sacks et al. (2004), Hartmann et al. (2008), Sacks and Barak (2008), Lu and Korman (2010), Lee et al. (2012), and Mahalingam et al. (2015)
B#18	Supporting validation of design criteria	Eastman et al. (2011), Lee et al. (2012), Johansson et al. (2015), and Zhang et al. (2013)
B#19	Promoting effective and efficient cost management	Patrick and Raja (2007), Hartmann et al. (2008, 2012), Arayici et al. (2011), Azhar (2011), Eastman et al. (2011), Olatunji et al. (2017), Bynum et al. (2013), and Aibinu and Venkatesh (2014)
B#20	Supporting strategic decision making	Sacks et al. (2010b), Won et al. (2013), Mahalingam et al. (2015), and Ghaffarianhoseini et al. (2017)
B#21	Decreasing construction waste	Krygiel and Nies (2008) and Akinade et al. (2015)
B#22	Increasing employer's satisfaction	Sacks et al. (2010c), Bryde et al. (2013), and Jin et al. (2017)
B#23	Supporting model-driven prefabrication	Hartmann et al. (2008), Lu and Korman (2010), Sebastian and van Berlo (2010), Azhar (2011), Eastman et al. (2011), and Jin et al. (2017)
B#24	Improving communication and collaboration among project teams	Acharya et al. (2006), Hartmann et al. (2008), Sacks et al. (2009, 2010b, c), Azhar (2011), Love et al. (2010), Laan et al. (2012), Choi et al. (2014), Francom and El Asmar (2015), Mahalingam et al. (2015), Jin et al. (2017), and Antwi-Afari (2018)
B#25	Fulfilling project requirements on time and within budget	Hartmann et al. (2008), Sacks et al. (2009, 2010b, c), Azhar (2011), Eastman et al. (2011), Lee et al. (2012), Aibinu and Venkatesh (2014), Azhar et al. (2015), Mahalingam et al. (2015), and Jin et al. (2017)
B#26	Providing operation and maintenance support	Becerik-Gerber et al. (2012) and Antwi-Afari (2018)
B#27	Providing interactive digital design environment where different disciplines work in collaboration	Sacks et al. (2004), Sacks and Eastman (2006), Hartmann et al. (2008), Won et al. (2013), Lee et al. (2012), Jin et al. (2017), and Antwi-Afari (2018)
B#28	Supporting identification of sustainable materials	Krygiel and Nies (2008), Cho et al. (2010), Jalaei and Jrade (2015), and Akinade et al. (2015)
B#29	Integrating life-cycle assessment strategies	Azhar (2011), Ghaffarianhoseini et al. (2017), Krygiel and Nies (2008), and Soust-Vergaduer et al. (2017)
B#30	Promoting design optimization	Sacks et al. (2004), Eastman et al. (2011), Lee et al. (2012), Azhar et al. (2015), and Sacks and Eastman (2006)
B#31	Providing visual risk analysis, safety, and logistic models	Jaselskis et al. (1996), Li et al. (2009), Benjaoran and Bhokhai (2010), Zhang et al. (2013), Jin et al. (2017), and Antwi-Afari (2018)
B#32	Promoting cost estimations and confirming appropriateness of the budget to the project in early design phase	Hartmann et al. (2008, 2012), Taylor and Bernstein (2009), Azhar (2011), Eastman et al. (2011), Bynum et al. (2013), Aibinu and Venkatesh (2014), Ghaffarianhoseini et al. (2017), and Olatunji et al. (2017)
B#33	Promoting quick and effective coordination regarding design changes	Hegazy et al. (2001), Acharya et al. (2006), Sacks and Barak (2008), Hartmann et al. (2008), Taylor and Bernstein (2009), Azhar (2011), Eastman et al. (2011), Lee et al. (2012), Barlish and Sullivan (2012), Ghaffarianhoseini et al. (2017), Azhar et al. (2015), Bynum et al. (2013), Mahalingam et al. (2015), Ahn et al. (2016), Jin et al. (2017), and Antwi-Afari (2018
B#34	Creating a structured and detailed database regarding the project delivery process	Hartmann et al. (2008), Sacks et al. (2009, 2010b, c), Lee et al. (2012), Wong et al. (2014), Olatunji et al. (2017), and Jin et al. (2017)
B#35	Tracking green building certification	Krygiel and Nies (2008), Jalaei and Jrade (2015), Wu and Issa (2015), Ghaffarianhoseini et al. (2017), and Lu et al. (2017)

Table 1. (*Continued.*)

Identifier	Benefits of BIM	Related source of data
B#36	Providing detailed energy analysis in early design phase	Krygiel and Nies (2008), Cho et al. (2010), Sebastian and van Berlo (2010), Eastman et al. (2011), Li et al. (2012), Akadiri et al. (2013), Bynum et al. (2013), Marzouk and Abdelaty (2014), Lu et al. (2017), and Antwi-Afari (2018)
B#37	Ensuring project follow-ups	Sacks et al. (2009, 2010b, c), Azhar (2011), Ghaffarianhoseini et al. (2017), and Jin et al. (2017)
B#38	Analyzing and improving sustainability and energy-efficiency level of the facility	Krygiel and Nies (2008), Sebastian and van Berlo (2010), Eastman et al. (2011), Li et al. (2012), Akadiri et al. (2013), Bynum et al. (2013), Marzouk and Abdelaty (2014), Lu et al. (2017), Olawumi et al. (2017), and Jin et al. (2017)
B#39	Preparing comprehensible and transparent project reports	Sacks et al. (2009, 2010b, c) and Azhar (2011)
B#40	Creating conceptual models in a simultaneous manner	Johansson et al. (2015)
B#41	Promoting effective and efficient facility management	Azhar (2011), Ghaffarianhoseini et al. (2017), Becerik-Gerber et al. (2012), Volk et al. (2014), and Jin et al. (2017)

Table 2. Risks of BIM

Identifier	Risks of BIM encountered in the transition from CAD	Related source of data
R#1	Utilization of data for personal benefit by some consultants and contractors	Azhar (2011) and Chien et al. (2014)
R#2	Not considering the price variations in different markets such as mines, metals, forestry, and petroleum products	Azhar (2011)
R#3	Causing problems due to lack of communication among project participants	Azhar (2011), Chien et al. (2014), and Jin et al. (2017)
R#4	Causing uncertainty due to problems with identification of the proper project participant to contribute to development of digital building model	Ghaffarianhoseini et al. (2017) and Azhar et al. (2015)
R#5	Having right of litigation due to errors and omissions in BIM projects	Aranda-Mena et al. (2009), Azhar (2011), Chien et al. (2014), and Udom (2012)
R#6	Causing uncertainty due to problems with identification of the proper project participant to be responsible for the conflict	Ghaffarianhoseini et al. (2017) and Azhar et al. (2015)
R#7	Causing license problems due to leaking building information model data by project team members except contractor and architect and engineer (A/E)	Azhar (2011)
R#8	Adaptation to BIM	Fox (2008), Azhar (2011), Cao et al. (2014), Ghaffarianhoseini et al. (2017), Chien et al. (2014), and Jin et al. (2017)
R#9	Taking the responsibility of updating and cross-checking the data regarding the building information model	Ghaffarianhoseini et al. (2017) and Azhar et al. (2015)
R#10	Causing disruptions in the procurement process due to extended payment durations for products	Azhar (2011) and Chien et al. (2014)
R#11	Unconformity between contractual schedule and budget and the actual situation	Azhar (2011), Chien et al. (2014), Azhar et al. (2015), and Jin et al. (2017)

Delphi Method

Delphi method was conducted in two rounds to prioritize the identified benefits of BIM in terms of time, cost, and sustainability as well as the risks and challenges of BIM considering the negative impacts on the project delivery process, the Delphi method was conducted in two rounds. In this method, Delphi panel experts were asked to rank the list of benefits, risks, and challenges of BIM in two rounds to ensure that a consensus is reached. Previous studies show that there is not any significant correlation between the number of panel participants and effectiveness in the Delphi method (Brockhoff 1975; Boje and Murnighan 1982). However, 8–12 qualified panel participants are suggested to obtain reliable information (Hallowell and Gambatese 2010). On the other hand, the credibility and success of a Delphi process rely upon the right set of panel participants who are experts on the subject matters (Chan et al. 2001, 2015). Hence, the first step of the Delphi method is to define the criteria for panel participants' qualifications to ensure that they have sufficient knowledge and experience in the BIM technology (Hallowell and Gambatese 2010). It is expected that Delphi panel participants meet at least one criterion from each of the following two groups: (1) knowledge and education level, and (2) experience level. Criteria for knowledge and education level are (1) to have master's degree (M.Sc.) related to information technologies in construction projects, and (2) to have at least a bachelor's degree related to construction (e.g., civil engineering, mechanical engineering), (3) to attend a BIM training program, and (4) to have a professional degree (e.g., BIM specialist). Criteria for experience level are (1) to have at least 2 years of professional experience in international construction projects used BIM, (2) to have at least 5 years of professional experience in the construction industry, and (3) to have at least 2 years of professional experience in construction projects that used BIM. Based on these criteria, 12 highly qualified panel participants (i.e., SMEs) who are experts in BIM were selected. A list of benefits, challenges, and risks of BIM was distributed to the selected SMEs for ranking. Two of the SMEs were mechanical engineers, six were architects, two were civil engineers, one was a structural engineer, and one was an electrical engineer. Four of the SMEs work as BIM managers and/or consultants, three work as BIM managers, two work as BIM coordinators, two work as BIM specialists, and one works as a senior project engineer. Seven of the SMEs have more than 10 years

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Table 3. Challenges of BIM

Identifier	Challenges of BIM encountered in the transition from CAD	Related source of data
C#1	Lack of information and experience in BIM	Kiviniemi (2006), Hartmann and Fischer (2008), Sacks et al. (2010b), Sacks and Barak (2010), Chien et al. (2014) Tulenheimo (2015), and Jin et al. (2017)
C#2	Wasting time in design phase due to lack of information and experience in BIM	Fox (2008), Sacks et al. (2010b), Ghaffarianhoseini et al. (2017), Chien et al. (2014), and Jin et al. (2017)
C#3	Spending a lot of time learning the use of BIM	Fox (2008), Ghaffarianhoseini et al. (2017), Chien et al. (2014), and Jin et al. (2017)
C#4	High cost of software and training for BIM	Cao et al. (2014), Chien et al. (2014), and Jin et al. (2017)
C#5	Coordination and interoperability of different software	Fox (2008), Chien et al. (2014), and Jin et al. (2017)
C#6	Resistance to change	Fox (2008), Azhar (2011), Ghaffarianhoseini et al. (2017), Chien et al. (2014), Tulenheimo (2015), and Jin et al. (2017)
C#7	Demotivation of employers due to the increased cost and time	Fox (2008), Tulenheimo (2015), and Jin et al. (2017)
C#8	Employers mistakenly consider that project team members have enough knowledge in BIM and do not need to develop themselves any further	Tulenheimo (2015)
C#9	Requiring design criteria and specifications to be provided	Chien et al. (2014)
C#10	Managing BIM-based resource planning and information	Sacks et al. (2010b) and Chien et al. (2014)
C#11	Lack of comprehension and awareness of project participants regarding BIM	Fox (2008), Sacks and Barak (2010), Chien et al. (2014), and Jin et al. (2017)
C#12	Adaptation of BIM to design-bid-build (DBB) project delivery method	Chien et al. (2014) and Jin et al. (2017)
C#13	Requirement for changing company culture and working style	Fox (2008), Cao et al. (2014), Chien et al. (2014), and Jin et al. (2017)

of experience in BIM, while five have 5–10 years of experience in BIM. Seven of the SMEs have master's degrees (M.Sc.), two have doctoral degrees (Ph.D.), and three have bachelor's degrees (B.Sc.). Although 10 of the selected SMEs are Turkish, they work at international companies and on projects in many different countries (e.g., Canada, the United States, the United Kingdom, Russia, Italy, and France). Four of the SMEs (i.e., three architects and a structural engineer) were the interviewees; however, this does not affect the reliability of the panel results since only the list of benefits, challenges, and risks of BIM was identified in triangulation of the literature review and face-to-face semistructured interviews.

The second step of the Delphi method is to create a questionnaire building upon the results of the literature review and face-to-face semistructured interviews. The Delphi questionnaires were distributed to the SMEs in two rounds. In the first round, a list of benefits, risks, and challenges of BIM was presented to the SMEs, who were asked to score the benefits based on their perceived effect on time, cost, and sustainability as well as the risks and challenges of BIM based on their negative impacts on the project delivery process by using a 5-point Likert scale. SMEs were instructed to consider a combination of frequency and impact of the benefits, risks, and challenges of BIM while ranking them. In the grading system for the benefits of BIM, a score of 1 indicates without any positive effect, while a score of 5 corresponds to very high positive effect. In the grading system for the risks and challenges of BIM, a score of 1 indicates without any negative effect, while a score of 5 corresponds to very high negative effect. Mean, median, and standard deviation (σ) values were calculated for each benefit, risk, and challenge of BIM based on the scores given by the SMEs (Tables 4–8). Mean and median values are the measures of central tendency

Table 4. Priority ranking for benefits of BIM in terms of cost

Rank	Identifier	Benefits of BIM	Mean	Median	σ	r_{wg}	Agreement level	Significance level
1	B#12	Planning the tasks and responsibilities in a timely manner	4.50	5.00	0.80	0.67	Strong agreement	Very important
2	B#14	Promoting collaboration and coordination in early design phase	4.42	5.00	0.90	0.75	Strong agreement	Very important
3	B#4	Automatic implementation of design changes into 3D CAD model	4.33	5.00	0.98	0.80	Strong agreement	Very important
4	B#9	Decreasing uncertainties in the processes by clarifying risks	4.25	4.00	0.87	0.56	Moderate agreement	Very important
5	B#8	Reducing time variances in the processes	4.17	4.00	0.72	0.36	Weak agreement	Very important
6	B#10	Promoting interoperability of different disciplines from the beginning of the project	4.17	4.00	0.94	0.61	Moderate agreement	Very important
7	B#19	Promoting effective and efficient cost management	4.00	4.00	0.95	0.56	Moderate agreement	Very important
8	B#15	Visualization of model in early design phase	3.83	4.00	1.03	0.59	Moderate agreement	Very important
9	B#1	Increasing building performance and quality	3.67	4.00	1.07	0.59	Moderate agreement	Very important
10	B#21	Decreasing construction waste	3.83	4.00	1.19	0.79	Strong agreement	Very important

Table 4. (*Continued*.)

Rank	Identifier	Benefits of BIM	Mean	Median	σ	r_{wg}	Agreement level	Significance level
11	B#11	Decreasing delays and project completion time	3.75	4.00	0.87	0.40	Weak agreement	Very important
12	B#20	Supporting strategic decision making	3.67	4.00	0.89	0.41	Weak agreement	Very important
13	B#13	Minimizing waste of material, equipment, and labor	3.58	3.50	1.16	0.68	Moderate agreement	Very important
14	B#16	Visualization of model regarding the existing condition	3.50	4.00	1.00	0.49	Weak agreement	Important
15	B#2	Promoting productive and efficient collaboration with integrated project delivery	3.50	3.50	1.09	0.58	Moderate agreement	Important
16	B#18	Supporting validation of design criteria	3.50	3.50	1.09	0.58	Moderate agreement	Important
17	B#3	Minimizing design and construction errors	3.50	3.50	1.17	0.67	Moderate agreement	Important
18	B#30	Promoting design optimization	3.50	3.50	1.00	0.49	Weak agreement	Important
19	B#5	Supporting effective planning and organization of the procurement process	3.42	3.50	1.00	0.48	Weak agreement	Important
20	B#27	Providing interactive digital design environment where different disciplines work in collaboration with each other	3.33	3.00	1.07	0.54	Moderate agreement	Important
21	B#28	Supporting identification of sustainable materials	3.33	3.00	1.07	0.54	Moderate agreement	Important
22	B#33	Promoting quick and effective coordination regarding design changes	3.33	3.00	1.15	0.63	Moderate agreement	Important
23	B#6	Trade verification from fabrication models	3.33	3.00	1.07	0.54	Moderate agreement	Important
24	B#7	Minimizing potential problems in the contract management	3.25	3.00	0.97	0.43	Weak agreement	Important
25	B#25	Fulfilling project requirements on time and within budget	3.17	3.00	0.94	0.41	Weak agreement	Important
26	B#29	Integrating life-cycle assessment strategies	3.08	3.00	1.08	0.54	Moderate agreement	Important
27	B#26	Providing operation and maintenance support	3.08	3.00	1.00	0.46	Weak agreement	Important
28	B#31	Providing visual risk analysis, safety, and logistic models	3.08	3.00	1.00	0.46	Weak agreement	Important
29	B#32	Promoting cost estimations and confirming appropriateness of the budget to the project in early design phase	2.92	3.00	0.90	0.37	Weak agreement	Important
30	B#41	Promoting effective and efficient facility management	2.75	2.50	1.42	0.94	Very strong agreement	Important
31	B#23	Supporting model-driven prefabrication	2.75	3.00	0.87	0.35	Weak agreement	Important
32	B#37	Ensuring project follow-ups	2.67	3.00	0.89	0.37	Weak agreement	Important
33	B#22	Increasing employer's satisfaction	2.58	2.50	1.16	0.65	Moderate agreement	Important
34	B#17	Using digital models for production of building elements	2.58	2.50	1.00	0.48	Weak agreement	Important
35	B#34	Creating a structured and detailed database regarding the project delivery process	2.58	2.00	1.24	0.74	Strong agreement	Important
36	B#39	Preparing comprehensible and transparent project reports	2.58	2.00	1.08	0.56	Moderate agreement	Important
37	B#40	Creating conceptual models in a simultaneous manner	2.42	2.00	0.90	0.41	Weak agreement	Somewhat important
38	B#35	Tracking green building certification	2.33	3.00	0.89	0.41	Weak agreement	Somewhat important
39	B#36	Providing detailed energy analysis in early design phase	2.33	2.50	0.78	0.31	Weak agreement	Somewhat important
40	B#24	Improving communication and collaboration among project teams	2.25	2.00	1.06	0.59	Moderate agreement	Somewhat important
41	B#38	Analyzing and improving sustainability and energy-efficiency level of the facility	1.92	2.00	0.79	0.40	Weak agreement	Somewhat important

(Dalkey 1969) and were used for ranking the variables, while the standard deviation (σ) is the measure of group consensus (Hallowell and Gambatese 2010; Seyis et al. 2016). The benefits, risks, and challenges of BIM were ranked according to the associated mean values (i.e., mean score ranking). If mean values of two benefits or risks or challenges were equal, median values were used for ranking.

Additionally, the significance-level statistics of each benefit, risk, and challenge of BIM was evaluated. Significance-level statistics were adopted for prioritization purposes, allowing the priority rankings to be more meaningful and coherent. Mean values (M) were used for performing the significance-level statistics. The significance level was denoted by the scale interval interpretation, which was adopted as follows: $M \leq 1.5$ stands for not important;

Table 5. Priority ranking for benefits of BIM in terms of time

Rank	Identifier	Benefits of BIM	Mean	Median	σ	r_{wg}	Agreement level	Significance level
1	B#4	Automatic implementation of design changes into 3D CAD model	4.58	5.00	0.89	0.97	Very strong agreement	Extremely important
2	B#8	Reducing time variances in the processes	4.58	5.00	0.51	0.32	Weak agreement	Extremely important
3	B#12	Planning the tasks and responsibilities in a timely manner	4.50	5.00	0.67	0.58	Moderate agreement	Very important
4	B#11	Decreasing delays and project completion time	4.42	4.50	0.67	0.41	Weak agreement	Very important
5	B#2	Promoting productive and efficient collaboration with integrated project delivery	4.33	4.50	0.89	0.65	Moderate agreement	Very important
6	B#9	Decreasing uncertainties in the processes by clarifying risks	4.33	4.50	0.89	0.65	Moderate agreement	Very important
7	B#10	Promoting interoperability of different disciplines from the beginning of the project	4.25	4.50	0.97	0.71	Strong agreement	Very important
8	B#14	Promoting collaboration and coordination in early design phase	4.25	4.00	0.87	0.56	Moderate agreement	Very important
9	B#15	Visualization of model in early design phase	4.08	4.00	0.90	0.53	Moderate agreement	Very important
10	B#5	Supporting effective planning and organization of the procurement process	4.08	4.00	0.79	0.41	Weak agreement	Very important
11	B#13	Minimizing waste of material, equipment, and labor	3.83	4.00	1.03	0.59	Moderate agreement	Very important
12	B#18	Supporting validation of design criteria	3.75	4.00	1.22	0.79	Strong agreement	Very important
13	B#16	Visualization of model regarding the existing condition	3.75	4.00	0.97	0.50	Weak agreement	Very important
14	B#26	Providing operation and maintenance support	3.58	3.50	0.90	0.41	Weak agreement	Very important
15	B#20	Supporting strategic decision making	3.50	4.00	0.80	0.31	Weak agreement	Important
16	B#30	Promoting design optimization	3.42	3.50	1.08	0.56	Moderate agreement	Important
17	B#33	Promoting quick and effective coordination regarding design changes	3.33	3.00	1.07	0.54	Moderate agreement	Important
18	B#6	Trade verification from fabrication models	3.25	3.00	1.22	0.69	Moderate agreement	Important
19	B#1	Increasing building performance and quality	3.17	3.50	0.83	0.32	Weak agreement	Important
20	B#28	Supporting identification of sustainable materials	3.17	3.00	1.19	0.66	Moderate agreement	Important
21	B#19	Promoting effective and efficient cost management	3.17	3.00	0.83	0.32	Weak agreement	Important
22	B#23	Supporting model-driven prefabrication	3.17	3.00	0.94	0.41	Weak agreement	Important
23	B#37	Ensuring project follow-ups	3.17	3.00	1.11	0.57	Moderate agreement	Important
24	B#3	Minimizing design and construction errors	3.08	3.00	1.24	0.71	Strong agreement	Important
25	B#25	Fulfilling project requirements on time and within budget	3.08	3.00	0.90	0.37	Weak agreement	Important
26	B#7	Minimizing potential problems in the contract management	3.08	3.00	0.90	0.37	Weak agreement	Important
27	B#40	Creating conceptual models in a simultaneous manner	2.92	3.00	1.16	0.62	Moderate agreement	Important
28	B#34	Creating a structured and detailed database regarding the project delivery process	2.92	3.00	1.08	0.54	Moderate agreement	Important
29	B#32	Promoting cost estimations and confirming appropriateness of the budget to the project in early design phase	2.92	3.00	1.00	0.46	Weak agreement	Important
30	B#39	Preparing comprehensible and transparent project reports	2.92	3.00	1.00	0.46	Weak agreement	Important
31	B#24	Improving communication and collaboration among project teams	2.83	3.00	1.03	0.49	Weak agreement	Important
32	B#21	Decreasing construction waste	2.75	3.00	1.29	0.77	Strong agreement	Important
33	B#22	Increasing employer's satisfaction	2.75	3.00	1.06	0.52	Moderate agreement	Important
34	B#27	Providing interactive digital design environment where different disciplines work in collaboration with each other	2.75	2.50	1.36	0.86	Strong agreement	Important
35	B#31	Providing visual risk analysis, safety, and logistic models	2.75	2.50	0.97	0.43	Weak agreement	Important
36	B#29	Integrating life-cycle assessment strategies	2.67	3.00	1.30	0.80	Strong agreement	Important
37	B#41	Promoting effective and efficient facility management	2.67	2.50	0.98	0.46	Weak agreement	Important

Table 5. (*Continued.*)

Rank	Identifier	Benefits of BIM	Mean	Median	σ	r_{wg}	Agreement level	Significance level
38	B#36	Providing detailed energy analysis in early design phase	2.50	2.50	0.80	0.31	Weak agreement	Somewhat important
39	B#35	Tracking green building certification	2.50	3.00	0.90	0.40	Weak agreement	Somewhat important
40	B#17	Using digital models for production of building elements	2.42	2.00	0.90	0.41	Weak agreement	Somewhat important
41	B#38	Analyzing and improving sustainability and energy-efficiency level of the facility	2.08	2.00	0.79	0.36	Weak agreement	Somewhat important

Table 6. Priority ranking for benefits of BIM in terms of sustainability

Rank	Identifier	Benefits of BIM	Mean	Median	σ	r_{wg}	Agreement level	Significance level
1	B#4	Automatic implementation of design changes into 3D CAD model	4.25	5.00	0.98	0.72	Moderate agreement	Very important
2	B#21	Decreasing construction waste	4.17	4.50	1.11	0.86	Strong agreement	Very important
3	B#15	Visualization of model in early design phase	4.00	4.00	0.94	0.54	Moderate agreement	Very important
4	B#28	Supporting identification of sustainable materials	3.92	4.00	1.00	0.58	Moderate agreement	Very important
5	B#18	Supporting validation of design criteria	3.88	4.00	1.08	0.67	Moderate agreement	Very important
6	B#10	Promoting interoperability of different disciplines from the beginning of the project	3.75	4.00	1.08	0.63	Moderate agreement	Very important
7	B#9	Decreasing uncertainties in the processes by clarifying risks	3.75	4.00	0.89	0.42	Weak agreement	Very important
8	B#35	Tracking green building certification	3.75	4.00	1.22	0.79	Strong agreement	Very important
9	B#13	Minimizing waste of material, equipment, and labor	3.63	4.00	1.19	0.72	Strong agreement	Very important
10	B#12	Planning the tasks and responsibilities in a timely manner	3.63	4.00	1.11	0.63	Moderate agreement	Very important
11	B#8	Reducing time variances in the processes	3.50	4.00	1.22	0.72	Strong agreement	Important
12	B#14	Promoting collaboration and coordination in early design phase	3.50	4.00	1.22	0.72	Strong agreement	Important
13	B#2	Promoting productive and efficient collaboration with integrated project delivery	3.50	4.00	1.00	0.49	Weak agreement	Important
14	B#5	Supporting effective planning and organization of the procurement process	3.50	4.00	1.00	0.49	Weak agreement	Important
15	B#36	Providing detailed energy analysis in early design phase	3.50	4.00	1.00	0.49	Weak agreement	Important
16	B#30	Promoting design optimization	3.50	3.00	0.90	0.40	Weak agreement	Important
17	B#16	Visualization of model regarding the existing condition	3.13	4.00	1.30	0.78	Strong agreement	Important
18	B#29	Integrating life-cycle assessment strategies	2.92	3.00	1.38	0.87	Strong agreement	Important
19	B#7	Minimizing potential problems in the contract management	2.88	2.00	1.24	0.71	Strong agreement	Important
20	B#41	Promoting effective and efficient facility management	2.83	2.00	1.03	0.49	Weak agreement	Important
21	B#37	Ensuring project follow-ups	2.83	3.00	0.83	0.32	Weak agreement	Important
22	B#25	Fulfilling project requirements on time and within budget	2.83	3.00	1.11	0.57	Moderate agreement	Important
23	B#33	Promoting quick and effective coordination regarding design changes	2.67	2.50	1.23	0.71	Strong agreement	Important
24	B#38	Analyzing and improving sustainability and energy-efficiency level of the facility	2.67	2.50	0.98	0.46	Weak agreement	Important
25	B#11	Decreasing delays and project completion time	2.63	3.00	0.87	0.36	Weak agreement	Important
26	B#1	Increasing building performance and quality	2.63	3.00	1.00	0.48	Weak agreement	Important
27	B#20	Supporting strategic decision making	2.58	2.50	0.90	0.39	Weak agreement	Important
28	B#34	Creating a structured and detailed database regarding the project delivery process	2.58	2.50	1.08	0.56	Moderate agreement	Important

Table 6. (*Continued*.)

Rank	Identifier	Benefits of BIM	Mean	Median	σ	r_{wg}	Agreement level	Significance level
29	B#27	Providing interactive digital design environment where different disciplines work in collaboration with each other	2.58	2.00	1.16	0.65	Moderate agreement	Important
30	B#6	Trade verification from fabrication models	2.58	2.00	1.08	0.56	Moderate agreement	Important
31	B#19	Promoting effective and efficient cost management	2.58	2.00	0.90	0.39	Weak agreement	Important
32	B#31	Providing visual risk analysis, safety, and logistic models	2.50	2.00	0.80	0.31	Weak agreement	Somewhat important
33	B#39	Preparing comprehensible and transparent project reports	2.50	2.00	1.00	0.49	Weak agreement	Somewhat important
34	B#26	Providing operation and maintenance support	2.50	2.00	1.00	0.49	Weak agreement	Somewhat important
35	B#17	Using digital models for production of building elements	2.50	3.00	0.80	0.31	Weak agreement	Somewhat important
36	B#3	Minimizing design and construction errors	2.50	2.50	1.09	0.58	Moderate agreement	Somewhat important
37	B#23	Supporting model-driven prefabrication	2.42	2.00	0.79	0.31	Weak agreement	Somewhat important
38	B#32	Promoting cost estimations and confirming appropriateness of the budget to the project in early design phase	2.33	2.00	0.98	0.50	Weak agreement	Somewhat important
39	B#22	Increasing employer's satisfaction	2.25	2.00	1.06	0.59	Moderate agreement	Somewhat important
40	B#40	Creating conceptual models in a simultaneous manner	2.08	2.00	0.79	0.36	Weak agreement	Somewhat important
41	B#24	Improving communication and collaboration among project teams	1.92	2.00	1.00	0.64	Strong agreement	Somewhat important

$1.51 \leq M \leq 2.5$ stands for somewhat important; $2.51 \leq M \leq 3.5$ stands for important; $3.51 \leq M \leq 4.5$ stands for very important; and $M \geq 4.51$ stands for extremely important (Li et al. 2013).

The standard deviation (σ) values were used for comparing the consensus at each round. When σ drops in consecutive rounds, it shows that consensus has been reached. A σ value less than 1 indicates that a high level of consensus is achieved (Vidal et al. 2011). If consensus is not achieved, another round needs to be performed for the factors that disagree with the consensus. According to the reasoning mechanism of the Delphi method, the process should be iterated in a continuous manner until a consensus among the panel participants is reached. However, two to three iterations are suggested in order to reach a consensus (Hallowell and Gambatese 2010). In this study, two structured rounds were performed to minimize possible nonconformity and biases among the SMEs. The consensus among the Delphi panel participants was analyzed and validated by the IRA statistics. The coding for the IRA (r_{wg}) was adopted as follows: $0.00 \leq r_{wg} \leq 0.30$ stands for lack of agreement; $0.31 \leq r_{wg} \leq 0.50$ stands for weak agreement; $0.51 \leq r_{wg} \leq 0.70$ stands for moderate agreement; $0.71 \leq r_{wg} \leq 0.90$ stands for strong agreement; and $0.91 \leq r_{wg} \leq 1.00$ stands for very strong agreement (Lebreton and Senter 2008). Eq. (1) shows the IRA formula that was applied to analyze and validate the consensus reached by the SMEs in the second Delphi round for each benefit, risk, and challenge of BIM (Lebreton and Senter 2008; Olawumi and Chan 2018)

$$r_{wg} = 1 - \frac{2 \times \sigma^2}{\{(A+B)M - (M^2) - (A \times B)\} \times \frac{n}{n-1}} \tag{1}$$

where r_{wg} = interrater agreement of that benefit or risk or challenge of BIM; A = maximum scale value (i.e., 5); B = minimum scale value (i.e., 1); M = mean value of that benefit or risk or challenge of BIM; n = sample size of respondents, which is 12 in this study; and σ = standard deviation value.

Results

Mean, median, and standard deviation values were calculated for each benefit, risk, and challenge of BIM based on the scores given by the Delphi panel experts (Tables 4–8). The mean values of each benefit, risk, and challenge of BIM were presented to SMEs in the second round and they scored the benefits, risks, and challenges of BIM for the second time considering the mean values. The goal of the second round was for the SMEs to reevaluate their previous scores by using findings of the first round and to reach a consensus among them if there were significant differences between the scores given by the SMEs in the first round. In the second round, SMEs also indicated the reasons when they did not agree with the given scores. The standard deviation values were expected to decrease from one round to the other; otherwise, another round should be performed (Dalkey 1969). An 8.43%–64.39% decrease in the standard deviation values (σ) was observed in the second round. According to the standard deviation values (σ) from the second round of the Delphi method, a consensus was achieved among the SMEs for all benefits, risks, and challenges of BIM. Additionally, the IRA statistics prove that results of the Delphi method are valid and reliable. Tables 4–8 show quantitative results (i.e., mean, median, σ, r_{wg}, associated agreement, and significance level) of the second round and priority rankings for the benefits, risks, and challenges of BIM.

Performing iterative rounds and providing controlled feedback from the preselected group of experts allow researchers to achieve higher reliability and quality in outputs (Mitchell 1991; Rowe et al. 1991). Accordingly, the reasoning mechanism of the Delphi method ensures that outputs attained from this qualitative procedure are not required to be tested and retested [i.e., Cronbach alpha test, *t*-test, Kendall's tau-*b*, Scheffe test (post hoc comparisons)] to control the reliability of data (Hasson and Keeney 2011; Okoli and Pawlowski 2004).

According to the priority ranking results related to the benefits of BIM in terms of cost, 13 (B#1, B#4, B#8, B#9, B#10, B#11,

Table 7. Priority ranking for risks of BIM

Rank	İdentifier	Risks of BIM encountered in the transition from CAD	Mean	Median	σ	r_{wg}	Agreement level	Significance level
1	R#8	Adaptation to BIM	3.25	3.00	1.09	0.55	Moderate agreement	Important
2	R#5	Having right of litigation due to errors and omissions in BIM projects	2.58	2.00	1.11	0.59	Moderate agreement	Important
3	R#3	Causing problems due to lack of communication among project participants	2.25	2.00	1.01	0.54	Moderate agreement	Somewhat important
4	R#9	Taking the responsibility of updating and cross-checking the data regarding the building information model	1.92	2.00	0.86	0.48	Weak agreement	Somewhat important
5	R#1	Utilization of data for personal benefit by some consultants and contractors	1.67	1.00	0.94	0.73	Strong agreement	Somewhat important
6	R#2	Not considering the price variations in different markets such as mines, metals, forestry, and petroleum products	1.50	1.00	0.65	0.44	Weak agreement	Not important
7	R#7	Causing license problems due to leaking building information model data by project team members except contractor and architect or engineer (A/E)	1.50	1.00	0.65	0.44	Weak agreement	Not important
8	R#11	Unconformity between contractual schedule and budget and the actual situation	1.50	1.00	0.76	0.61	Moderate agreement	Not important
9	R#6	Causing uncertainty due to problems with identification of the proper project participant to be responsible for the conflict	1.33	1.00	0.47	0.33	Weak agreement	Not important
10	R#4	Causing uncertainty due to problems with identification of the proper project participant to contribute to development of digital building model	1.33	1.00	0.47	0.33	Weak agreement	Not important
11	R#10	Causing disruptions in the procurement process due to extended payment durations for products	1.25	1.00	0.60	0.69	Moderate agreement	Not important

Table 8. Priority ranking for challenges of BIM

Rank	Identifier	Challenges of BIM encountered in the transition from CAD	Mean	Median	σ	r_{wg}	Agreement level	Significance level
1	C#1	Lack of information and experience in BIM	4.58	5.00	0.67	0.55	Moderate agreement	Very important
2	C#11	Lack of comprehension and awareness of project participants regarding BIM	4.17	5.00	1.11	0.86	Strong agreement	Very important
3	C#6	Resistance to change	4.00	4.00	0.95	0.55	Moderate agreement	Very important
4	C#13	Requirement for changing company culture and working style	3.75	4.00	1.06	0.59	Moderate agreement	Very important
5	C#4	High cost of software and training for BIM	3.58	3.5	0.90	0.41	Weak agreement	Very important
6	C#8	Employees mistakenly consider that project team members have enough knowledge in BIM and do not need to develop themselves any further	3.50	3.50	1.00	0.49	Weak agreement	Important
7	C#3	Spending a lot of time learning the use of BIM	3.42	3.50	1.16	0.65	Moderate agreement	Important
8	C#2	Wasting time in design phase (due to lack of information and experience in BIM)	2.67	3.00	0.89	0.37	Weak agreement	Important
9	C#7	Demotivation of employers due to the increased cost and time	2.50	2.00	1.31	0.84	Strong agreement	Somewhat important
10	C#10	Managing BIM-based resource planning and information	2.33	2.00	1.23	0.78	Strong agreement	Somewhat important
11	C#5	Coordination and interoperability of different software	2.25	2.00	0.97	0.50	Weak agreement	Somewhat important
12	C#9	Requiring design criteria and specifications to be provided	2.00	2.00	0.85	0.44	Weak agreement	Somewhat important
13	C#12	Adaptation of BIM to design-bid-build (DBB) project delivery method	1.83	2.00	0.72	0.36	Weak agreement	Somewhat important

B#12, B#13, B#14, B#15, B#19, B#20, and B#21) were identified as very important, 23 (B#2, B#3, B#5, B#6, B#7, B#16, B#17, B#18, B#22, B#23, B#25, B#29, B#26, B#27, B#28, B#30, B#31, B#32, B#33, B#34, B#37, B#39, and B#41) were identified as important, and five (B#24, B#35, B#36, B#38, and B#40) were identified as somewhat important based on the scores given by the SMEs on BIM. In accordance with the priority ranking results regarding the benefits of BIM in terms of time, two (B#4 and B#8) were defined as extremely important, 12 (B#2, B#5, B#9, B#10, B#11, B#12, B#13, B#14, B#15, B#16, B#18, and B#26) were defined as very important, 23 (B#1, B#3, B#6, B#7, B#19, B#20, B#21, B#22, B#23, B#24, B#25, B#27, B#28, B#29, B#30, B#31, B#32, B#33, B#34, B#37, B#39, B#40, and B#41) were defined as important, and four (B#36, B#35, B#17, and B#38) were defined as somewhat important. The priority ranking results related to the benefits of BIM in terms of sustainability show that 10 (B#4, B#9, B#10, B#12, B#13, B#15, B#18, B#21, B#28, and B#35) were described as very important, 21 (B#1, B#2, B#5, B#6, B#7, B#8, B#11, B#14, B#16, B#19, B#20, B#25, B#27, B#29, B#30, B#33, B#34, B#36, B#37, B#38, and B#41) were described as important, and 10 (B#3, B#17, B#22, B#23, B#24, B#26, B#31, B#32, B#39, and B#40) were described as somewhat important. None of the benefits in terms of time, cost, and sustainability were determined as not important.

According to the priority ranking results of BIM's challenges, five (C#1, C#4, C#6, C#11, and C#13) were identified as very important, three (C#2, C#3, and C#8) were identified as important, and five (C#5, C#7, C#10, C#9, and C#12) were identified as somewhat important. On the other hand, the priority ranking results of BIM's risks show that two (R#5 and R#8) were described as important, three (R#1, R#3, and R#9) were described as somewhat important, and six (R#2, R#4, R#6, R#7, R#10, and R#11) were described as not important.

Discussion

Results of the Delphi method show that the priority rankings and scores of BIM's benefits in terms of time and cost were determined to be similar. The results also demonstrate that the benefits of BIM have much more positive impact on time and cost than sustainability. According to the SMEs' opinions, the reason for this could be that the time and cost issues are interrelated subjects and affect each other. On the other hand, the priority ranking and scores of BIM's benefits in terms of sustainability differ from the priority rankings for time and cost. In accordance with the SMEs' comments, the reason for this might be that sustainability in the construction industry is considered to be a relatively new subject and not included in the current BIM utilization areas, which in turn affect the scores of BIM's benefits.

According to the results of the Delphi method, the scores of BIM's benefits in terms of cost, time, and sustainability fluctuate over a large scale, although some of the benefits within each category have similar or the same scores. BIM's benefits in terms of cost, time, and sustainability range from 4.50 to 1.92, from 4.58 to 2.58, and from 4.25 to 1.92, respectively. Similarly, the scores of BIM's challenges fluctuate over a large scale that ranges from 4.58 to 1.83. On the other hand, the scores of BIM's risks do not fluctuate over a large scale since they stand within the range of 3.25–1.25 and some of the risks have similar or the same scores.

The benefits of BIM related to time, cost, quality, and productivity receive higher scores, while the benefits related to sustainability receive lower scores. For example, analyzing and improving sustainability and energy-efficiency level of the facility (B#38) is ranked as the last benefit of BIM in terms of time (2.08) and cost (1.92), and ranked as the 24th benefit (2.67) for sustainability. Similarly, decreasing construction waste (B#21) is ranked as the second benefit in terms of sustainability (4.17), whereas it is ranked as the 20th benefit in terms of time (3.17) and the 10th benefit in terms of cost (3.83). Supporting identification of sustainable materials (B#28) is ranked as the fourth benefit in terms of sustainability (3.92), while it is ranked as the 21st benefit in terms of cost (3.33) and 20th benefit in terms of time (3.17). In accordance with the SMEs' comments, the reason for this might be that the third, fourth, and fifth dimensions of BIM, which are related to modeling, scheduling, and estimating, are commonly used by professionals in the AEC industry, and this allows them to understand their positive impacts on quality and productivity. However, the sixth dimension of BIM, which is related to sustainability, is not commonly used by professionals in the AEC industry. SMEs also indicated that integration of BIM and energy modeling software (e.g., eQuest), life-cycle analysis software (e.g., SimaPro), and green building certification systems [e.g., Leadership in Energy and Environmental Design (LEED)] are relatively new subjects in the AEC industry; hence, professionals cannot perceive the benefits of BIM in terms of sustainability yet. Results of this research point out that automatic implementation of design changes into 3D CAD model (B#4) is the top-ranked benefit in terms of time (4.58) and sustainability (4.25), while it is ranked as the third benefit in terms of cost (4.33). According to the SMEs' opinions, the reason for this might be that design changes in green building and non-green building projects cause waste of considerable time since automatic implementation of design changes into 3D CAD model (B#4) is considered to be a more important benefit in terms of time and sustainability rather than cost.

Reducing time variances in the processes (B#8) has the same mean value (4.58) as B#4 in terms of time, while it is ranked as the fifth benefit in terms of cost (4.17) and the 11th benefit in terms of sustainability (3.50). Similarly, decreasing delays and project completion time (B#11) is ranked as the fourth benefit (4.42) in terms of time and the 25th benefit in terms of sustainability (2.63), while it is ranked as the 11th benefit in terms of cost (3.75). In accordance with the SMEs' comments, the reason for this might be that mitigating time variances and delays indirectly affect cost and sustainability; hence B#8 and B#11 have lower rankings and scores in terms of cost and sustainability than in terms of time.

Planning the tasks and responsibilities in a timely manner (B#12) is the top-ranked benefit (4.50) in terms of cost, while it is ranked as the third benefit (4.50) in terms of time. This result shows that planning the tasks and responsibilities in a timely manner is much more important than the other benefits that can be achieved in terms of cost. According to the SMEs' comments, the reason for this might be that waste of time in the project delivery process causes considerable cost increases; hence, planning the tasks and responsibilities in an untimely manner causes much more negative impact on cost and time.

Promoting collaboration and coordination in early design phase (B#14) is ranked as the second benefit (4.42) for cost and as the eighth benefit (4.25) for time, while it is ranked as the 12th benefit (3.50) for sustainability. The reason for this could be that collaboration and coordination in the late design phase might result in time- and cost-related waste in the project delivery process, which in turn causes time delays and additional costs.

Decreasing uncertainties in the processes by clarifying risks (B#9) is ranked as the forth benefit in terms of cost (4,25), the sixth benefit in terms of time (4.33), and the seventh benefit in terms of sustainability (3.75). In accordance with the SMEs' comments, the reason might be that unforeseen risks might have serious repercussions for projects that require them to be identified at an early stage in order to mitigate any possible negative impacts in terms of time, cost, and sustainability.

Visualization of model in early design phase (B#15) is ranked as the third benefit in terms of sustainability (4.00), while it is ranked as the eighth benefit in terms of cost (3.83) and the ninth benefit in terms of time (4.08). According to the SMEs' comments, green buildings are multidisciplinary structures; for this reason, designing a green building is much more convoluted than designing a non-green building. Visualization of the model in the early design phase allows detecting any defect in the design of a facility that hinders the achievement of sustainability-related project objectives. Hence, B#15 has a higher ranking in terms of sustainability than in terms of time and cost.

When the scores of the risks and challenges of BIM were examined, it was crystal clear that the challenges of BIM have much more negative impact on the project delivery process than the risks of BIM. In accordance with the SMEs' comments, the reason for this might be that the challenges of BIM can be considered to be the necessity for initiation of a transition process from CAD, while the risks of BIM can be considered to be probable hindrances that can be incurred throughout the process.

Results of the Delphi method show that the top-ranked risk and challenge are interconnected. Adaptation to BIM (R#8) (3.25) is the top-ranked risk of BIM in the transition from CAD, while lack of information and experience in BIM (C#1) (4.58) is the top-ranked challenge of BIM. According to the SMEs' opinions, both have the highest scores within related categories because adaptation to BIM (R#8) and lack of information and experience in BIM (C#1) might result in time- and cost-related waste in the project delivery process that in return cause cost overruns and time delays. SMEs also indicated that both are critical obstacles in the transition process from CAD to BIM.

In relation to this result, lack of comprehension and awareness of project participants regarding BIM (C#11), resistance to change (C#6), and requirement for changing company culture and working style (C#13) are ranked as the second, third, and fourth challenges of BIM and their mean values are 4.17, 4.00, and 3.75, respectively. High cost of software and training for BIM (C#4) is ranked as the fifth challenge of BIM and its mean value is 3.58. These results show that the challenges related to adaptation to a new technology are much more crucial than the investment cost of BIM. According to the SMEs' comments, the reason for this might be that dealing with C#1, C#6, C#11, and C#13 requires more time and cost as well as qualified personnel; hence, C#4 has a lower ranking and score.

Conclusions

This study classified and identified the benefits, challenges, and risks of BIM, and prioritized the benefits of BIM in terms of time, cost, and sustainability as well as the risks and challenges of BIM considering their negative impacts on the project delivery process. In order to achieve the identification and classification purposes, a literature review was performed and face-to-face semistructured interviews with four SMEs on BIM were conducted. A total of 41 types of benefits, 11 types of risks, and 13 types of challenges of BIM were identified via triangulation of the literature review and face-to-face semistructured interviews with SMEs. In order to achieve prioritization purposes, the Delphi method was performed with 12 SMEs on BIM in two rounds. The contributions of this paper to the existing body of knowledge on BIM are to provide comprehensive identification and classification of the benefits, challenges, and risks of BIM, and prioritization of the benefits for BIM in terms of time, cost, and sustainability as well as the risks and challenges of BIM in the transition from CAD. This study implemented a holistic approach and contributes to the AEC literature and industry by providing all necessary information regarding the pros and cons of BIM in order to assist professionals and academics making well-informed and conscious decisions throughout the process to alleviate the negative impacts.

One of the most significant findings of this study is that the benefits of BIM are mainly related to 3D modeling, coordination, collaboration, process improvement, cost management, time management, risk management, resource management, facility management, and sustainability applications. Results of this research also show that the priority rankings performed for the benefits of BIM in terms of time and cost were found to be similar. On the other hand, the priority ranking of benefits in terms of sustainability differs from the priority rankings for time and cost. The reason for this could be that the time and cost issues are interrelated subjects and included in the current BIM utilization areas, while sustainability in the construction industry is considered to be a relatively new subject and not included in the current BIM utilization areas.

The other important finding of this research is that the risks of BIM in the transition from CAD are mainly related to uncertainties, defaults, adaptation process, data security, cost of the technology, and legal issues, while the challenges of BIM predominantly concern demotivation, resistance to change, lack of knowledge, experience, awareness, and comprehension of project teams. Additionally, the higher scored challenges and risks of BIM are mainly related to project teams' learning and adaptation to BIM, indicating that the top-ranked risks and challenges of BIM are interconnected.

A limitation of this study is that 10 of the SMEs are Turkish; however, results of the rankings are not limited to Turkish conditions because these SMEs work at international construction companies and projects located in many different countries such as Canada, the United States, the United Kingdom, Russia, Italy, and France, which in turn provides a holistic perspective and in-depth information about the investigated topic. Another limitation of this study is that four of the Delphi panel participants (i.e., three architects and a structural engineer) were the interviewees; however, this does not affect the reliability of panel results since only the list of benefits, challenges, and risks of BIM was identified in triangulation of the literature review and face-to-face semistructured interviews.

This study qualitatively and quantitatively reveals the risks and challenges of BIM in order to create awareness, and allows professionals to develop practical strategies as well as suitable solutions to overcome such challenges. If the challenges and associated risks of BIM are solved in a systemic manner, the envisioned benefits of BIM in multiple aspects can be achieved effectively and efficiently, which in turn will promote BIM usage in the AEC industry.

The benefits of BIM, which were identified and quantitatively analyzed in terms of time, cost, and sustainability, ensure professionals and academics understand the ability of BIM to address multifaceted problems. For example, the sixth dimension of BIM, which is linked to sustainability, provides substantial and diverse benefits for project participants to fulfill the requirements of the green building project delivery process. However, using BIM with its full potential to deliver green buildings in an efficient and effective manner can only be achieved through early involvement and collaboration of project participants (Bryde et al. 2013).

Results of this study provide professionals and academics in the AEC industry with practical information about the benefits, risks, and challenges of BIM and allow them to see the true potential of BIM in a wider context as well as help them understand multiorganizational and multidisciplinary functions of BIM. Accordingly, this study may contribute to extend utilization of BIM in the AEC industry. Professionals can use the priority rankings of benefits, risks, and challenges of BIM for making well-informed and conscious decisions that allow decreasing time- and cost-related waste in the transition process from CAD to BIM while increasing the overall success and value of projects. Furthermore, academics who focus on process improvement and optimization specifically in construction projects using BIM could profit from the results and recommendations of this study by utilizing the benefits identified and mitigating potential risks and challenges of BIM to ensure successful completion of projects.

Data Availability Statement

Data generated or analyzed during the study are available from the corresponding author by request. Information regarding the *Journal*'s data-sharing policy can be found as follows: http://ascelibrary.org/doi/abs/10.1061/(ASCE)CO.1943-7862.0001263.

Acknowledgments

The author would like to thank all the experts who participated in the Delphi and interview process for their collaboration and valuable opinions, as well as Meric Altinkaya, Yusuf Okulmus, Mehmet Kutlu, and Ali Sever for their contributions.

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