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IMPACT OF BIM ON PROJECT PERFORMANCE

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Abstract

Limited studies have compared BIM's impacts on project performance via business types, working experience, and project locations. A survey was conducted and results found that (1) BIM helped with the early detection of design errors (R1), pre-construction RFIs (R2), and the number of repeat customers (R12), but negatively affected the other 9 indicators (R3~R11); (2) for R1/R2/R12, contractors, international projects, and staff (0~2 years) benefit the most; (3) for R3~R11, software vendors, non-US BIM projects, staff (0~1 and 2~5 years) benefit the most. This study contributed to presenting BIM's positive and negative impacts on project performance in the construction industry.

Introduction

Building information modeling (BIM) is widely recognized as a potential solution to improve project performance in the Architecture, Engineering, and Construction (AEC) industry. Most practitioners and professionals generally believe that using BIM can bring benefits to construction projects, such as schedule control (Zuppa et al. 2012), better productivity (Abbasnejad et al. 2021), and quality improvement of design (Jasiński 2021, Wong et al. 2018). However, the application of BIM in the industry has faced various challenges due to factors such as project characteristics, technical complexities, inadequate owner support, absence of suitable standards, contractual and legal issues, and high costs of BIM technologies (Cao et al. 2015, Costin et al. 2018, Ghaffarianhoseini et al. 2017, Koseoglu et al. 2019). These challenges have resulted in negative impacts on BIM practice, such as increased cost and legal risks (Jasiński 2021), BIM incompatibility and expensive consulting (Migilinskas et al. 2013), and coordination problems (Bryde et al. 2013). Thus, it is questionable whether current BIM adoption benefits project performance.

To test BIM's impacts, multiple aspects of project performance have been evaluated, including general indicators such as cost, quality, safety, etc. (Franz and Messner 2019, Poirier et al. 2015), and specific indicators such as change orders, request for information (RFI), and saved durations (Barlish and Sullivan 2012). Other common indicators have been addressed in recent research, such as design errors, response time, return on investment (ROI), rework, and labor productivity (Lee et al. 2012, Poirier et al. 2015, Sompolgrunk et al. 2021, Won and Lee 2016). A few studies also discussed BIM's impacts on customer satisfaction, which either focus on identifying customer satisfaction as one indicator of BIM project success (Chen et al. 2018, Suermann and Suermann 2009, Wu et al. 2018), or exploring the indicators of BIM customer/user satisfaction (Jiang et al. 2021, Song et al. 2017, Wang and Song 2017). However, only a few previous studies have made a quantitative comparison of BIM's impacts between BIM and non-BIM projects, and most studies used two or three cases to explore BIM's impacts (Barlish and Sullivan 2012, Giel and Issa 2013).

Previous quantitative studies covered multiple stakeholders in BIM projects, such as designers, clients, contractors, consultants, etc. (Demirkesen and Ozorhon 2017, Wong et al. 2018). Some explored the characteristics of companies such as firm years and the number of employees (Demirkesen and Ozorhon 2017), respondents such as working experience and education background (Wong et al. 2018), projects such as project types, duration of completion, and locations (Cao et al. 2015, Demirkesen and Ozorhon 2017, Poirier et al. 2015). However, these studies were limited to soliciting the traits of employee, companies, and projects as demographic information instead of statistical analysis. There is a lack of quantitative comparisons of BIM impact based on industry perspectives across different business types, working experience, and project locations.

This study compares BIM's impacts between BIM and non-BIM projects in terms of 12 quantifiable indicators across different business types, working experiences, and project locations. Perspectives of global industry professionals on the ratios of the 12 indicators were measured through a questionnaire survey. BIM's impacts among separate stakeholders are summarized and classified into positive and negative impacts. Research findings in this study can help professionals and academics to know the effects of current BIM adoption and determine future directions for improving project performance.

Research Methodology

To achieve the research objective, a preliminary literature review was conducted by John (2018) to conclude a list of indicators (Table 1) measuring BIM's impact on project performance. Then, a four-part questionnaire survey was designed to solicit industry professionals' information and perspectives on the ratios of these quantitative indicators between BIM and non-BIM projects.

Table 1: Quantitative indicators of BIM's impact on project performance

Code	Indicators
R1	Total number of design errors (Won and Lee 2016, Wong et al. 2018)
R2	Total number of pre-construction RFI (Giel and Issa 2013)
R3	Total number of in-construction RFI (Giel and Issa 2013)
R4	Total number of change orders (Giel and Issa 2013, Won and Lee 2016)
R5	Total cost of change orders (Barlish and Sullivan 2012, Giel and Issa 2013)
R6	Total cost of rework (Lee et al. 2012, Won and Lee 2016)
R7	Total cost of punch list items (Cox et al. 2003, Lee and Won 2014)
R8	Total number of near misses (John 2018)
R9	Total number of site accidents (Lee and Won 2014)
R10	Total number of legal claims and litigations (Lee and Won 2014)
R11	Total cost of legal claims and litigations (Li et al. 2012)
R12	Total number of repeat customers (John 2018)

Questionnaire Design

The first part collects demographic information of respondents' companies, such as business types and prior BIM experience. The second part asks about the respondents' BIM-related experience and knowledge of BIM projects, such as geographic distribution. The third part is used to quantify the ratios of 12 indicators between BIM projects and non-BIM projects. Lastly, respondents are free to leave opinions and suggestions about this research.

Data Collection

The survey was distributed to stakeholders with BIM-related experience in 2018, including owners, contractors, architects, engineers, consultants, software vendors, etc. A total of 229 valid industry responses (valid response rate: 3.6%) were received out of more than 6000 potential respondents, who were identified via industry contacts, social media such as LinkedIn, and directories of professional organizations.

Data Analysis

While the mean is commonly used to describe the central tendency of a distribution, it is sensitive to outliers and may not be appropriate for skewed samples (Hair et al. 2013). Skewness is used to evaluate to what extent the sample distributions depart from a normal distribution. A skewness value greater than 1.0 or less than -1.0 indicates a substantially skewed distribution (Hair et al. 2013), while a value between -0.5 and 0.5 indicates a fairly symmetrical sample distribution (Gawali 2022, SPC for Excel software 2016). Mean and median are close for the distribution with the skewness between -0.5 and 0.5 (Howell 2013). For skewed distribution, the median is less affected by extreme observations, making it a more robust measure of central tendency for such distributions (Moore and McCabe, 2021). Therefore, this study adopted median as the sample center.

Results of Data Analysis

Demographic Information

This study's responses came from companies in the AEC industry, including 41% contractors, 13% architects, 12% engineers, 9% consultants, 8% subcontractors, 7% owner/developers, 4% software vendors, and 6% other stakeholders. Of the 229 respondents, 59.8% (137 respondents) had BIM-working experience between 5 and 20 years, 8.7% more than 20 years, and 31.4% no more than five years. As seen in Figure 1, BIM projects that respondents had worked on were located in the United States (US) (48.7%), the United Kingdom (7.1%), China (4.1%), Singapore (3.2%), and other countries (33.4%). Some respondents implemented BIM projects worldwide (3.5%) and in Europe (1.5%).

Descriptive Analysis of 12 Indicators

The 12 indicators can be divided into two groups. For the first group including total number of pre-construction design errors (R1), pre-construction RFIs (R2), and repeat customers (R12), a ratio greater than 1 means improved project performance. For example, if the ratio of R2 is

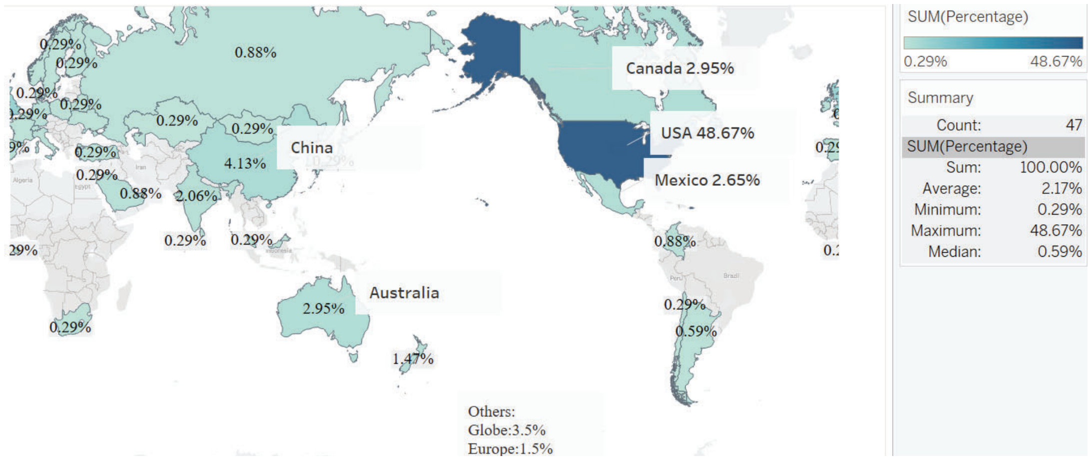

Figure 1: Geological distribution of BIM-assisted projects

greater than 1, it means more RFIs can be detected before the construction of BIM projects compared to non-BIM projects. More pre-construction RFIs contribute to project performance because they can be responded without influencing the project schedule (Giel and Issa 2013). For the second group including nine indicators (R3~R11), a ratio less than 1, equal to 1, or larger than 1, refers to BIM's positive impact, no impact, and negative impact, respectively. For example, if the ratio of the total number of change orders (R4) is greater than 1, BIM projects have more change orders than non-BIM projects. Change orders often lead to higher contract prices (Serag et al. 2010) and labor productivity (Zhao 2021).

The skewness and median of the ratio of 12 indicators between BIM and non-BIM projects were calculated, as seen in Table 2. For the first group of indicators, BIM projects had 5.55 times more detected pre-construction design errors, 4.57 times more detected pre-construction RFIs, and 3.55 times more repeat customers than non-BIM projects. For the second group of indicators, BIM adoption has led to a deterioration in overall BIM project performance. Among the nine indicators, the most significant difference is that the total number of in-construction RFIs for BIM projects is 6.22 times as high as for non-BIM projects.

Twelve indicators had skewness values greater than 1.0, indicating that the distribution for each indicator is substantially right-skewed. Among the 12 indicators, the ratios of the total cost of change orders and punch list items have the highest skewness, referring to 14.87 and 14.66, respectively. Skewness can be influenced by various factors, such as sample size (Hair et al. 2013), extreme values (Howell 2013), and the nature of the data (Howell 2013). In this study, the effect of sample size can be neglected for a sample size of 200 or more (Hair et al. 2013). The nature of data refers to the characteristics of data such as the type of data (i.e., categorical data, continuous data) and measurement scales (i.e., ratio scale, interval scale) (Howell 2013). The nature of the data in this study may vary depending on factors such as the type of business, the level of BIM experience among respondents, and the geographic distribution of BIM projects. As such, the following sections will explore how BIM impacts the twelve indicators across different types of companies, respondents with varying levels of BIM experience, and projects located in different areas.

Table 2: Median and its rank, and skewness of the ratio of 12 indicators

Indicator	Rank of Median	Median	Skewness
R1	1	6.55	6.80
R2	3	5.57	7.45
R3	2	6.22	8.44
R4	5	3.75	6.44
R5	6	3.70	14.87
R6	10	3.15	7.13
R7	7	3.64	14.66
R8	8	3.33	10.66
R9	9	3.20	7.23
R10	12	1.97	8.71
R11	11	2.03	7.98
R12	4	4.55	4.87

Analysis of R1, R2, and R12

The comparisons of the first group of indicators across different business types are shown in Figure 2. Among all companies, software vendors reported the most negative impact of BIM, with 40% fewer detected pre-construction design errors, 60% fewer detected pre-construction RFIs, and 20% fewer repeat customers compared to non-BIM projects. Architect also suffered from 20% fewer detected pre-construction design errors, 35% fewer detected pre-construction RFIs, and no change in the number of repeat customers in BIM projects compared to non-BIM projects. For the other business types, contractors are the most positively affected by adopting BIM projects, which had 6.89 times more detected pre-construction design errors, 14.62 times more detected pre-construction RFIs, and 10.66 times more repeat customers.

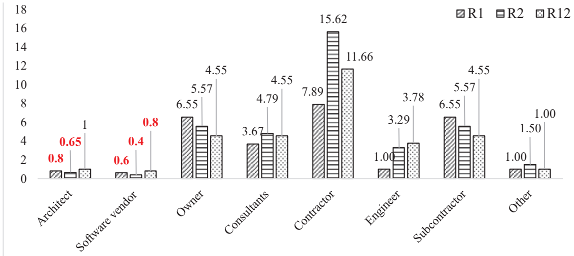

Figure 2: Ratio of R1, R2, and R12 for different business types

The impact of BIM on project performance varied depending on the project location, as seen in Table 3. The respondents in this study implemented BIM projects either in multiple countries or in one country, including both US and non-US locations. In the US, using BIM resulted in finding 20% more detected pre-construction design errors, 4.57 times more detected pre-construction RFIs and gaining 3.55 times more repeat customers compared to non-BIM projects. However, in non-US countries, BIM adoption led to reduced project performance with 22% fewer detected pre-construction design errors, 35% fewer detected pre-construction RFIs, and no improvement in the number of repeat customers. For respondents building BIM projects in multiple countries, BIM contributed to more detected design errors and RFIs before construction and attracting more repeat customers. Nevertheless, the improvement in project performance was less pronounced for projects built in multiple countries excluding the US compared to those including the US.

Table 3: Ratio of R1, R2, and R12 for different project areas

Project locations	One country		Multiple countries	
	US	non-US	With US	Without US
R1	1.20	0.78	6.55	2.95
R2	5.57	0.65	5.57	4.79
R12	4.55	1	4.55	3.00

For different working years, the ratios of pre-construction design errors, pre-construction RFIs, and repeat customers are shown in Figure 3. Among respondents with 0~2 and 5~13 years of BIM experience, BIM adoption had the most significant positive influence on three indicators: detected pre-construction design errors increased by 5.55 times, detected pre-construction RFIs by 4.54 times, and repeat customers by 3.55 times. However, participants with 2~5, 13~20, and more than 20 years of BIM experience showed a decrease in detected pre-construction design errors by 17%, 10%, and 15%, respectively.

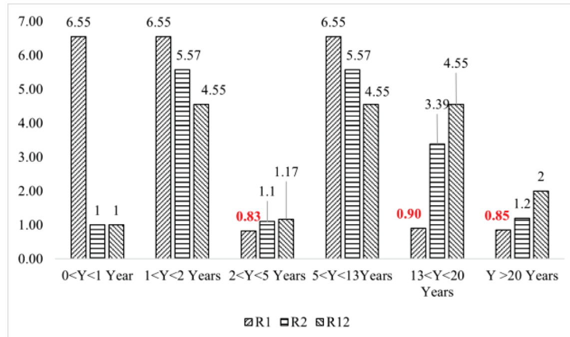

Figure 3: Ratio of R1, R2, and R12 for different working years

Analysis of Indicators from R3 to R11

Table 4 displays the ratios of the second group of indicators from R3 to R11 across different business types. The minimum and maximum ratios for each indicator are underlined and bolded, respectively. The analysis indicates that software vendors are the most positively impacted by BIM projects among all business types, with a 90% reduction in near misses compared to non-BIM projects. Architects also benefit from BIM, especially with a 50% reduction in in-construction RFIs. However, contractors experience the most negative effects of BIM adoption, particularly with the total cost of punch list items 462 times higher, the total number of in-construction RFIs 11 times higher, and the total number of near misses ten times higher than that of non-BIM projects.

Among these nine indicators, the skewness of R5 and R7 is the highest as shown in Table 2. For the ratio of R5, BIM projects resulted in a significant increase of 149.29 times in the cost of change orders for owners and subcontractors, while software vendors experienced a decrease of 82% in related costs. For R7, there was a sharp

Table 4: Ratio of indicators from R3 to R11 for different business types

Indicator	Architect	Software vendor	Owner	Consultants	Contractor	Engineer	Subcontractor	Other
R3	0.50	0.60	6.22	5.11	**12.16**	1.50	6.22	1.20
R4	0.63	0.50	**5.05**	2.92	3.75	3.00	5.05	1.60
R5	0.65	0.18	**150.29**	75.55	3.70	77.65	**150.29**	1.60
R6	0.50	0.18	3.15	2.08	**3.19**	3.15	3.15	1.00
R7	0.75	0.38	3.64	3.64	**462.66**	3.64	3.64	1.00
R8	0.75	0.10	3.33	3.33	**11.15**	3.33	3.33	1.00
R9	0.85	0.50	3.20	3.20	**4.53**	3.20	3.20	1.00
R10	0.60	0.40	1.97	1.97	**4.36**	1.97	1.97	1.00
R11	0.75	0.35	2.03	2.03	**5.13**	2.03	2.03	1.00

increase in the cost of punch list items by 461.66 times for contractors and a reduction of 68% for software vendors. This result indicates significant differences in the impact of BIM across different types of businesses, particularly between software vendors and contractors.

For different project locations, the ratios of the second group of indicators are shown in Table 5. Respondents once involved in BIM projects in the US or multiple countries faced more challenges compared to non-BIM projects, particularly experiencing a 5.22-times increase in in-construction RFIs. In each country outside of the US, BIM was found to enhance project performance across the nine indicators, with a notable 50% decrease in in-construction RFIs. This result indicated huge discrepancies in the impact of BIM adoption on project performance between the US and other countries, especially in in-construction RFIs.

Table 5: Ratio of indicators from R3 to R11 for different project locations

Project locations	One country		Multiple countries	
	US	non-US	With US	Without US
R3	6.22	0.5	6.22	3.25
R4	2.50	0.8	3.75	3.12
R5	3.70	0.8	3.70	3.70
R6	3.15	0.75	3.15	3.15
R7	3.64	0.8	3.64	3.64
R8	3.33	0.5	3.33	3.33
R9	3.20	0.7	3.20	3.20
R10	1.97	0.7	1.97	1.97
R11	2.03	0.6	2.03	2.03

For different working years, the ratios of nine indicators in the second group are shown in Table 6. Each indicator's maximum and minimum ratios are bolded and underlined, respectively. BIM improved a few aspects of project performance for respondents with less than one year, 2~5 years, and more than 20 years of working experience, while leading to worse project performance for the other respondents. Respondents with 1~2 years of working experience were most negatively impacted by BIM, with a significant increase of 9 times in the cost of punch list items. Conversely, respondents with less than one year of experience benefited the most from BIM, with improvements observed across five project performance indicators.

Discussion

Research findings suggest that BIM implementation has both positive and negative impacts on two groups of project performance indicators. Furthermore, the impacts of BIM varied significantly across different business types, employees with different working experiences, and countries within each group of indicators.

Positive BIM's Impacts

Based on the overall findings, the adoption of BIM can lead to the identification of a higher number of detected pre-construction design errors, detected pre-construction RFIs, and can also result in more repeat customers compared to non-BIM projects. This outcome is supported by R1 and R2 as the detection of design errors and submission of corresponding RFIs can provide valuable information, improving the accuracy of project estimation and design documents (Poirier et al. 2015). Although there is no quantitative research on R12, it is consistent with previous qualitative studies that BIM can improve customer-client relationships (Azhar et al. 2012), and customer preference (Kim et al. 2021).

For the first group of indicators including R1, R2, and R12, contractors across all business types derived the greatest benefits from BIM. This can be attributed to two reasons. Firstly, identifying design errors and RFIs before construction begins does not negatively affect construction activities. Secondly, many respondents indicated that BIM adoption was a requirement by owners or contracts and helped to enhance productivity and competitiveness in the industry. In addition, BIM projects in the countries including the US were improved in the first group of indicators. Two reasons can explain this result. The majority of respondents (80%) had experience building BIM projects in the US, and a significant percentage of architecture companies in the US and non-US countries (53.3% and 13.3%, respectively) had completed more than 75% of their BIM projects. Therefore, BIM projects in the US were built by more experienced architecture companies.

Furthermore, BIM contributed to the improvement of detected design errors and RFIs before construction and bringing repeat customers for most respondents with varying levels of experience, especially for those with 1~2 and 5~13 working years. Previous studies proposed that

Table 6: Ratio of indicators from R3 to R11 for different BIM-related working years

Working years	R3	R4	R5	R6	R7	R8	R9	R10	R11
0 < Y< 1	1.00	1.00	1.00	1.00	<u>0.80</u>	<u>0.80</u>	<u>0.80</u>	<u>0.70</u>	<u>0.70</u>
1 < Y< 2	**6.22**	**3.75**	**3.70**	**3.15**	**10.00**	**4.00**	**4.00**	**4.00**	**5.13**
2<Y<5	<u>0.80</u>	0.95	0.85	<u>0.68</u>	1.00	0.90	1.00	1.00	1.00
5 < Y< 13	**6.22**	**3.75**	**3.70**	**3.15**	3.64	3.33	3.20	1.97	2.03
13 < Y< 20	1.29	1.20	2.65	2.08	3.64	3.33	3.20	1.97	2.03
Y > 20	1.05	<u>0.80</u>	<u>0.80</u>	0.80	2.00	1.00	1.00	1.00	1.00

an increase in BIM experience can foster BIM adoption (Ahankoob et al. 2022). However, this study indicated that there is no significant linear relationship between BIM experience and BIM's impact on project performance.

For the second group of indicators from R3 to R11, BIM adoption results in better project performance for software vendors and architects, non-US countries, and respondents with less than one year, 2~5 years, and more than 20 years of BIM experience. BIM technology helped software vendors and architects solve issues during and after the construction stage, especially safety (near misses) and change orders, which is consistent with previous studies (Shen and Marks 2016, Sompolgrunk et al. 2021, Won and Lee 2016). Among non-US countries, the UK, China, and Singapore make up the majority, where BIM is almost mandatory or highly recommended. Similar to the results of the first group, BIM experience is not proportional to BIM's influence on project performance.

Negative BIM's Impacts

After examining the median and skewness of indicators, it was found that the total number of in-construction RFIs, the total cost of change orders, and the total cost of punch list items are the most negatively affected by BIM. This finding contradicts previous research, which suggested that BIM adoption would result in fewer RFIs and decreased costs. However, those studies were limited to only three case studies (Barlish and Sullivan 2012, Giel and Issa 2013), whereas this study surveyed many industry professionals with extensive BIM-related experience, resulting in a new finding. This new finding highlights a common misperception among practitioners regarding BIM project success and an overestimation of the benefits of BIM in the current AEC industry.

For the first group of indicators, BIM projects have shown worse project performance after BIM implementation for software vendors and architects, non-US countries, and respondents with 2~5 years of experience. Less detected design errors and RFIs before construction are possibly due to the overreliance on BIM software and poor coordination between vendors and design team members (Hwang et al. 2019). In addition, BIM interoperability can lead to information loss and inconsistencies between different BIM software, leading to more challenging model exchange between structural and architectural designs (Wu et al. 2021). Therefore, selection of proper software and vendors is critical to ensure the functionality of software and the quality of post-sales services of vendors (Patel et al. 2021). To identify more design errors early on, strategies must focus on team structures, interaction behaviors, and error spread (Al Hattab and Hamzeh 2015). In non-US countries, BIM adoption has not led to an improvement in repeat customers, potentially due to a lower BIM adoption rate compared to the US.

For the second group of indicators, contractors' BIM projects had been confronted with noticeable increases in the cost of punch list items, in-construction RFIs, and near misses. The possible reasons for contractors' failure are unclear requirements of owners (Giel and Issa 2014), inadequate owner's support (Cao et al. 2017), misunderstanding of BIM's value (Love et al. 2014), and poor collaboration between owners and contractors (Sun et al. 2021). BIM has brought similar negative impacts on projects in the US and the globe, except for the cost of change orders. Respondents with 1~2 years of experience are the most impaired by BIM. These results indicate that future research should pay attention to the reason for the ratios' difference between different project locations and BIM experiences.

Conclusions

In this study, we aimed to quantify the impact of BIM on project performance in the AEC industry by comparing 12 indicators between BIM projects and non-BIM projects. The analysis considered the business types, respondents' experience, and geographic distribution of the projects. The results were obtained from a large sample of industry professionals with extensive BIM-related experience, mainly located in the United States.

There are three main findings in this study. Firstly, BIM has a positive impact on detecting pre-construction design errors and RFIs, as well as bringing in repeat customers compared to non-BIM projects. However, the most negative impacts include an increase in in-construction RFIs, higher cost of change orders, and higher cost of punch list items. Secondly, contractors benefit the most from BIM in terms of pre-construction design errors, pre-construction RFIs, and repeat customers, but suffer the most from in-construction RFIs, cost of punch list items, and near misses. Software vendors and architects benefit from BIM in terms of the second group of indicators but suffer from the first group of indicators. Finally, BIM experience is not directly proportional to its influence on project performance.

This study helps to reveal the specific positive and negative impacts of BIM on project performance across different business types, working experience, and countries in the current AEC industry. For future researchers, it is necessary to figure out the following problems: (1) more case studies are needed to validate these research findings; (2) why BIM leads to a notably higher cost of change orders and punch list items? (3) what strategies effectively improve BIM project performance regarding each negative impact?

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