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Research Article

The role of building information modeling in enhancing public-private partnership project outcomes: Insights from Jordan and Malaysia

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ABSTRACT

Public-Private Partnerships (PPP) are crucial for infrastructure development in developing countries. PPP projects frequently face challenges, sych as inefficiencies in project management and collaboration. Building Information Modeling is capable to address these challenges, by enhancing collaboration and improving project efficiency. This study aims to evaluate the impact of BIM on PPP projects in Jordan and Malaysia. PPPs in devoloping countries play a pivotal role in infrastructure development. The study uses a questionnaire approach to achieve the objectives. A total of 1100 questionnaires were distributed to experts from public, private, and educational institutions, 441 valid responses received, which represents a 40.1% response rate. The questionnaire covered five aspects, starting with demographic data, then followed by the key aspects of BIM adoption, which are administrative, sustainability, management, tools framework, and productivity. The data was analyzed using SPSS software to assess BIM's influence on PPP project performance. The results show that BIM adoption could significantly improve performance in areas such as document management, interface management, energy efficiency, public service quality, and organizational structures, with specific increases in productivity and sustainability metrics. The experts identify that the adoption has positive impact on PPP projects in both Jordan and Malaysia. The study provides an imperical evidence of the potential of success PPP projects if and when BIM is adopted. The results shows improvements in document management, effective interface management, energy efficiency, quality and innovation of public services, and organizational structures. The study also contributes in inriching the body of literature on the context on BIM and PPPs, and showcasing the applications developting countries.

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INTRODUCTION

Public-private partnership (PPP) investments play a crucial role in driving economic growth in developing Asian countries [1]. Jordan and Malaysia have turned to PPPs to address countries' growing infrastructure needs and resource constraints [2,3]. Despite their strategic importance, PPPs encounter numerous challenges in these developing nations. In Jordan, these challenges include risk factors related to the transfer phase, organizational issues, financing, project management, and feasibility studies [4]. In Malaysia, the challenges include inflation, interest rate risks, currency fluctuations, technical expertise, and limitations in financial capacity [5].

Jordan's Public-Private Partnership (PPP) framework was established with Law No. 31 of 2014. İn 2015 Jordan created PPP by-laws council and strategy chaired by the Prime Minister [6]. Serveral Projects under the PPP procurement method are uderway in Jordan, Such as Bus Rapid Transit (BRT) Project between Amman and Zarqa, the National Broadband Network (NBN) to support digital transformation, and the King Hussein Bridge Land Border Crossing Terminal. Jordan initiated a group of projects such as the construction of 14 public schools, then a Non-revenue water project to reduce losses of water in the capital city. One more major project that to improve key roads in the country through users chargers [7].

The economic development in malaysia started in the early 1980s. The goverement engaged the private sector expertise as a national development effort [8]. However, in the early 80s, significant progress on funding PPP initiatives in the Ninth and Tenth Malaysia plans. The main goal for these plans were to improve development strategies [9]. Despite the benefits of PPP in Malaysia, obligations and critisism imposed the policies of the malaysian governement [10].

Some challenges faces the implementation of BIM in PPP Projects. Some the challenges include technological obstical, some expamples are the complexity and interoperability between different platforms [11,12].

On the other hand, BIM application faces legal and contractual challenges, such as conflection in responsibilities [13]. Another challenge is the cultural resistenace from stakeholders accustomed to traditional work, which makes communication gaps feels bigger and hinder effective collaboratios [14].

BIM helps PPP projects work smoother, by identifying risks early which provide time to mitigate the risk early in the project life. Furthermore, BIM reduces and cuts costs[15], modulate construction to address poor communications [16]. Support cost tracking standarized KPIs [17], and improve performance management systems [18]. Prior studies have explored various aspects of BIM in PPP projects, BIM impact on key performance indicators (KPIs) and risk management, but the focus if the literature mainly is on developed economies or a wider regional perspective. Prior studies lacks comprehensive assessment of the role of BIM in managing PPP projects and improving results in Jordan and Malaysia.

Building Information Modeling (BIM) is an innovative procedure that fundamentally changes the architecture, engineering and construction sectors by improving conceptualization, design, construction and overall management of constructed spaces [19–21].

BIM is seen as beneficial in the construction inducstry dues to the collaboration improvement, as well as minizing errors, reduces costs, and improving efficincy [22,23]. BIM allows somther data exchanges, that mitigates risks, and reduces projects setbacks and overruns. Although some studies have explored aspects of BIM adoption in PPP projects within developing countries, a comprehensive evaluation of its implications, especially in Jordan and Malaysia, is still lacking.

Recognizing the growing interest in BIM to improve PPP projects, various studies have explored its potential benefits [24]. For example, [12] conducted a study in Sweden, proposing a BIM implementation plan that identifies major drivers and barriers to the adoption of BIM, although it does not specifically address cost reduction. On the contrary, [15] provided a quantitative analysis from Iran, demonstrating that BIM can improve performance by 28.9% on average through improved key performance indicators (KPIs), utilizing a Copula Bayesian Network for causal analysis. Furthermore, [25] focused on China, examining how contractual flexibility in BIM-enabled PPP projects can significantly impact cost reduction during the procurement and construction phases. While these studies illuminate the potential performance benefits of BIM in PPP projects, they also underscore the need for comprehensive strategies for BIM's potential benefits.

The recent studies have investigated the role of BIM in managing risks of PPP projects. [26] explored the integration of BIM and the Integrated Project Delivery (IPD) model in characteristic Chinese towns, demonstrated that this integration enhanced collaboration and reduced risks in construction projects. The same study highlighted the need to address a list of challenges related to these towns and the potential drawbacks of the BIM-based IPD model. Another study implemented in Malaysia by [11], identified six significant risk factors in PPP projects and provided insights and lessons from the UK context to improve BIM implementation in Malaysia. They used questionnaires and expert interviews to uncover critical challenges that need to be addressed in this context [14] analysed critical PPP risk factors and BIM functions, and proposed a comprehensive BIM-based risk management framework. That study identified seven critical risk factors and eight BIM functions, and noted the limited scope of critical factors and BIM n-D functions. The findings provided valuable insights into integrating BIM into PPP projects.

Studies show that BIM save energy, makes projects more envirnmently friendly, which in turn improves the operational effectiveness, and boost the productivity. Furthermore, BIM adoption has the potential to reduce CO2 emissions. These benefits suggests that BIM has the ability to support sustainable development 8, 9, 11, and 13, which advances overall construction sustainability [27]. BIM tools facilitate the improvement of building designs to substantially reduce energy consumption, leading to potential savings of up to 46% in overall energy usage [28]. Depending on BIM in Value for Money (VFM) evaluations of PPP projects could result in more scientific and accurate assessments. This also could help the long-term growth of such efforts [29]. The use of BIM in PPP projects add a high value in improving decision making, operational management, and collaborative efforts, resulting in more and more sustainable environment for all memers of the ecosystem [26].

When you look at the challenges that prevent companies in Jordan and Malaysia from using Building Information Modeling (BIM), you find a lot of obstacles. In Jordan, the main problems are that it's expensive to train people and buy the software, many people don't know much about BIM, and there aren't clear rules to follow. Also, companies have to spend a lot of money upfront, they don't get enough support from their leaders, and it's hard for them to get the right technology and frameworks. In Malaysia, it's also tough because people don't have many chances to learn about BIM, the laws are not helpful, and different systems can't work well together, which makes it hard to use BIM. All these issues make it difficult for companies in both countries to start using BIM. It's clear that both Jordan and Malaysia face unique challenges when it comes to adopting BIM [30]. If companies and governments can work together to address these issues, it might be easier for them to use BIM and improve their construction projects. This could involve creating more training programs, making clearer rules, and investing in better technology to support BIM adoption. By doing so, they can help their construction industries become more efficient and competitive [31].

A lot of researchers were motivated to investigate KPIs to evaluate the adoption of BIM in the construction industry from different point of views [32] exploreded the impact of BIM technology on safety KPIs in construction projects in Slovakia, Slovenia, and Croatia [33] analyzed the ROI value of BIM in an architectural company, emphasized on cost control improvements and workflow optimization [34] identified the primary stakeholder groups that add value from BIM adoption, including design units, facility management, contractors, and owners. In another study, [29] provided evaluation criteria for innovative constructon projects, showing that BIM improves material usage control and minimizes initial material consumption.

In our previous research [17], we identified and selected key performance indicators (KPI) related to administrative, sustainability, and management aspects for PPP projects. A framework was established for the current analysis, that allowed a comprehensive examination of the multidimensional impacts of BIM on PPP performance. Supplementary Table 1 shows the overall KPIs utilized to evaluate BIM performance in PPP Projects.

The mentioned studies emphasize the diverse benefits of BIM in PPP projects and stress the necessity for strategic implementation, quantitative analysis, and adaptable contractual agreements. Even with these insights, there is still a lack of understanding of how BIM affects cost savings in PPP projects in countries like Jordan and Malaysia. This research aims to fill that gap. BIM technology is not being used enough in many countries, especially in Jordan [35,36] and Malaysia [37,38], where it seems to be used in a random and poorly integrated way. This research investigates the influence of BIM on PPP projects within these nations, thereby addressing the existing gap.

Reduce in cost, which also means to see in to a reduction of delay, we see an improvement in quality, we see an increase in productivity, we also put forth that which is sustainable has been increased and we have better risk transfer. We put forth these points to in hope of convincing public and private sector players to adopt BIM into wider use. The current research investigates how BIM influences the success of PPP projects to foster greater adoption and to achieve more successful project benifits. It also aims to fill this gap by systematically examining the impact of BIM on the success of PPP projects in Jordan and Malaysia.

MATERIALS AND METHODS

The current study adopts a descriptive quantitative approach to systematically analyze experts' perceptions of the potential impact of BIM adoption on PPP projects. BIM and PPP projects experts were targeted in Jordan and Malaysia. The study sample included professionals of the public and private sectors, and educational institutions experts, providing a comprehensive view of industry practices and policy implications. A pilot study was conducted with 30 respondents prior to the main survey distribution in order to validated the questionnaire.

The study was conducted during 05-2023 to 01-2024, using an electronic questionnaires distributed using email, in person, and phone calls. We ensured informed consent from each participant prior to data collection. 1,100 questionnaires were distributed and 441 were responded with 40% response rate . The questionnaire was carefully designed and divided into two main sections: general demographic questions and specialized questions. The demographic section collected general information such as: gender, age, education, experience, and employment sector.

We utilized a systematic method to insure comprehenisve and reliable questionnaire design. The first step was reviewing existing literature on topics that is related to BIM and PPP, we searhced through Google Scholar, Scopus, and Web of Science databases. The aim was to idenfity key variables and themes. Followed by organizing the data into Excel spread sheed to systematically categorize the data.

Upon identifying recurring themes across multiple studies, we consolidated these findings and categorized them into five main areas: administrative aspects, sustainability, management, tools and frameworks, and productivity. This categorization formed the basis for drafting the first version of the questionnaire. Supplementary Table 1 in the appendix shows the KPI factors selected from the literature.

For the main section, we developed questions to cover five key aspects of BIM adoption in PPP projects: Administrative (3 items), Productivity (10 items, covering manpower, machine, and materials), Management (11 items, addressing time, cost, and quality), Tools Framework (11 items, focusing on people, process, and technology), Sustainability (10 items, including environmental, economic, and social factors). We used a Likert scale from 1 to 5 for responses. Table 1 shows the distribution of the questions across different aspects.

To assess if the data is appropriate for factor analysis, we calculated Kaiser-Meyer-Olkin (KMO) measure for all question groups of the questionnaire. The KMO values range from 0 to 1. values closer to 1 indicating that the data are suitable for factor analysis. Table 1 shows that the KMO values for all aspects meet acceptable criteria.

The aim of this study is to assss the overall performance of utilizing BIM in the performance of PPP projects. We analyzed the data using SPSS software (version 25), employing a variety of statistical tests and descriptive analyzes to understand BIM's impact on PPP projects. In order to do so, we calculated means, standaard deviations, frequencies. Furthermore, we summarized the central tendencies, variablity, and distribution.

The next step was to validate and refine the final questionnaire. We started with conducting a pilot study with the preminary questionnaire with a 30 respondents. The main questionnaire after validating was distributed for around six months period. The distribution took place from May 2023 to January 2024. The distribution was done by email, in person, and through phone calls. Before distribution we ensured informed consent from each participant prior to data collection.

Questionnaire Design

To ensure the questionnaire validity and effectiveness, feedback from three experts who specialize in questionnaire design was collected and the related modifications were implemented. Three additional experts were consulted to enhance the questionnaire quality further. This process helped to address potential issues and improve the clarity and relevance. After that, a pilot study was conducted for 30 respondents to evaluate the validity and reliability. Analysis of this pilot study was used to make final adjustments to the questionnaire, ensuring that it accurately captured the intended data. The final questionnaire form is shown in Supplementary Table 2.

We distributed the finalized questionnaire to a larger sample and received 441 responses of 1100 distributed. The collected data were analyzed using SPSS, applying various statistical tests to ensure the data reliability. This process enabled to confirm that the questionnaire effectively measured the relevant constructs and provided valuable insights for the study. (Fig. 1) explains the research process framework that is adopted in this research. A quantitative research approach was employed.

Table 1. Distribution of questions in the questionnaire and the results of the Kaiser-Meyer-Olkin test

Category	Indicators	No of Questions	KMO
Administrative	Administrative	3	0.696
Productivity	Manpower	5	0.856
	Machine	2	0.500
	Material	3	0.696
Management	Time	3	0.711
	Cost	4	0.812
	Quality	4	0.800
Tools Framework	People	4	0.802
	Process	5	0.701
	Technology	2	0.500
Sustainability	Environment	3	0.690
	Economy	3	0.705
	Social	4	0.816

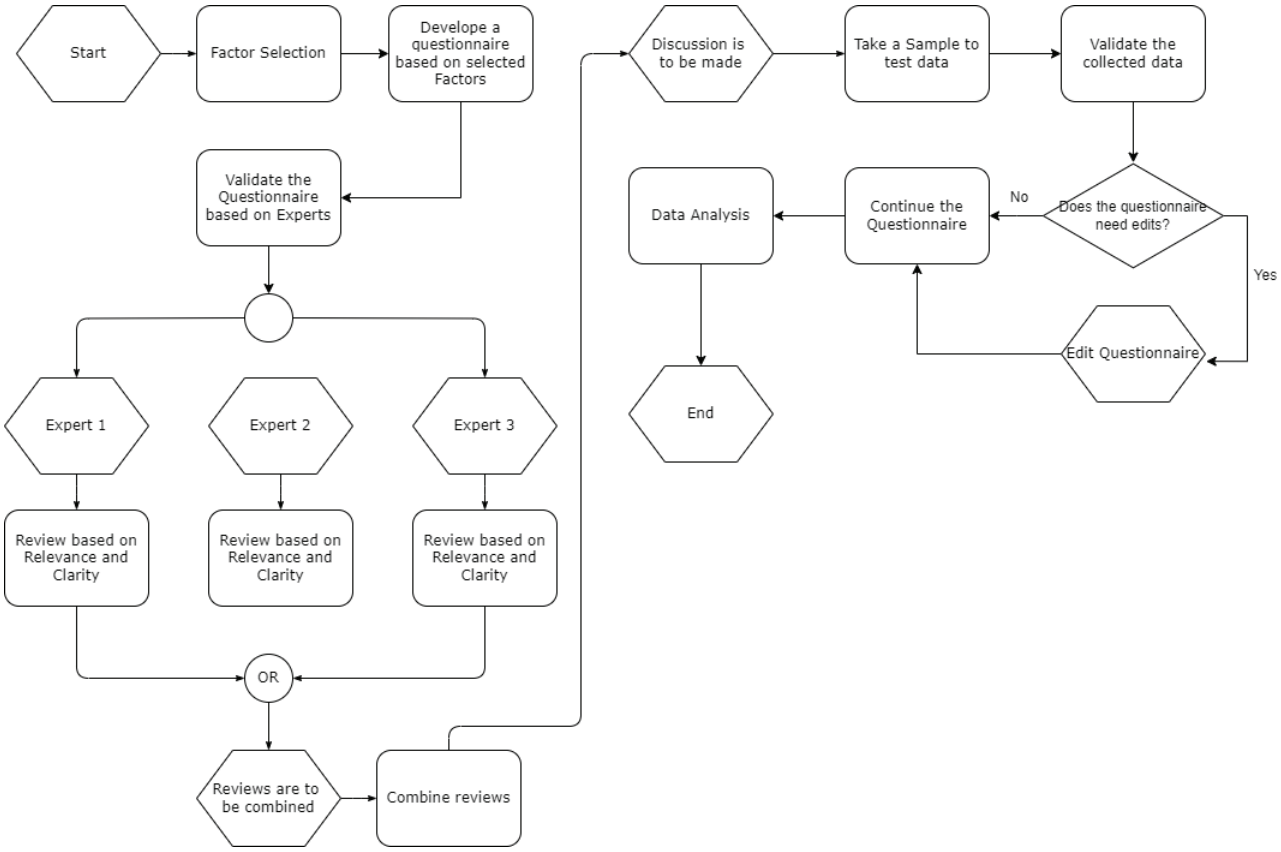

Figure 1. Research method framework.

RESULTS AND DISCUSSION

Demographic Characterstices of the Respondents

We faced significant challenges in obtaining participants with experience in PPP and BIM projects. 1,100 questionnaires have been distributed to individuals who involved in projects in Jordan and Malaysia's for both public and private sectors. To colect data, face-to-face interviews, emails, and social media platforms using Google Forms were included. The survey achieved a notable response rate, garnering 441 valid responses, which equal about 40% of the total distributed.

The research sample were selected based on their PPP and BIM projects expirience within the public and private sectors in Jordan and Malaysia. The process prioritized individuals with expertise in project management, engineering, and construction. The samples' qualifications ranged from Bachelor's to Doctorates degrees, shows diverse affiliations, including government bodies, private engineering organizatins and academic institutions as well. A purposive sampling approach was used to ensure representation for both public and private sectors, as outlined in Table 2.

The respondents screening revealed a presence of the private sector, which comprised 79.1%, while the public sector was only 20.9% of the total respondents. A higher representation of males (73.5%) than females (26.5%) was presented, reflecting broader workforce trends. Educational qualifications ranged from Bachelor's to Doctorate degrees, with 73.9% holding a Bachelor's degree, 21.3% possessing a Master's degree, and 4.8% having attained a Ph.D., indicating a diverse educational background. The responses covered a wide range of professional experience, with 1-5 years and 21-25 years being the most common, illustrating a varied pool of participants with differing levels of expertise. The demographic characteristics of the respondents are detailed in Table 2.

Descriptive Analysis

The data shown in Table 3 indicates a detailed analysis of the questionnaire responses, the questionnaire covered various dimensions, including administrative, sustainability, tools framework, management, and productivity factors. The level of agreement or disagreement with each factor.

We evaluated factors across administrative, sustainability, tools framework, management, and productivity aspects of performance. The tools framework category was ranked first, scoring 3.94±0.772, underscoring the importance of document management and clash detection, followed by productivity factors with a score of 3.93±0.783, emphasizing effective interface management and experience gains. However, sustainability factors came in third and rated

Table 2. Demographic characteristics of respondents

Background information	Parameter	Frequency	Percent
Sector	Private	349	79.1
	Public	92	20.9
	Total	441	100
Highest Academic Qualifications	Bachelor's degree	326	73.9
	Master's degree	94	21.3
	Doctoral Degree	21	4.8
	Total	441	100
Gender	Male	324	73.5
	Female	117	26.5
	Total	441	100
Years of experience	1-5	123	27.9
	6-10	68	15.4
	11-15	85	19.3
	16-20	39	8.8
	20-25	126	28.6
	Total	441	100

Table 3. Detailed analysis of the responses to the questionnaire

Measurement	S.Dis (1)	Dis. (2)	N. (3)	Ag. (4)	S.Ag (5)	Total %	Mean±SD	Rank
1- Administrative Factors					Agree		3.83±0.935	5
Organization structure	27	18	71	144	181	441	3.98±1.135	1
	6.1	4.1	16.1	32.7	41.0	100.0		
Risk of adverse changes in law, policy, or regulations	18	33	87	162	141	441	3.85±1.079	2
	4.1	7.5	19.7	36.7	32.0	100.0		
Risk of force majeure	32	40	95	157	117	441	3.65±1.174	3
	7.3	9.1	21.5	35.6	26.5	100.0		
2- Productivity Factors					Agree		3.93±0.783	2
Experience and knowledge gains	19	16	56	170	180	441	4.08±1.032	2
	4.3	3.6	12.7	38.5	40.8	100.0		
Staff training	16	24	65	168	168	441	4.02±1.037	4
	3.6	5.4	14.7	38.1	38.1	100.0		
effective interface management	12	21	62	167	179	441	4.09±0.988	1
	2.7	4.8	14.1	37.9	40.6	100.0		
Use of construction waste	11	45	97	147	141	441	3.82±1.069	8
	2.5	10.2	22.0	33.3	32.0	100.0		
Employment opportunities	26	39	92	141	143	441	3.76±1.168	10
	5.9	8.8	20.9	32.0	32.4	100.0		
Specialized expertise	14	23	74	150	180	441	4.04±1.035	3
	3.2	5.2	16.8	34.0	40.8	100.0		
Technical staff resources	17	24	80	171	149	441	3.93±1.040	5
	3.9	5.4	18.1	38.8	33.8	100.0		
Equipment condition and number	13	32	104	169	123	441	3.81±1.018	9
	2.9	7.3	23.6	38.3	27.9	100.0		

Table 3. Detailed analysis of the responses to the questionnaire (continued)

Measurement	S.Dis (1)	Dis. (2)	N. (3)	Ag. (4)	S.Ag (5)	Total %	Mean±SD	Rank
Use of innovative materials	12	29	93	173	134	441	3.88±1.005	7
	2.7	6.6	21.1	39.2	30.4	100.0		
Material condition and number	12	27	91	176	135	441	3.90±0.997	6
	2.7	6.1	20.6	39.9	30.6	100.0		
3- Tools Framework Factors					Agree		3.94±0.772	1
Requirements of stakeholders/goals	14	24	89	176	138	441	3.91±1.006	7
	3.2	5.4	20.2	39.9	31.3	100.0		
Change management - resistance to change	16	41	117	155	112	441	3.69±1.061	11
	3.6	9.3	26.5	35.1	25.4	100.0		
Information and knowledge sharing	15	30	75	181	140	441	3.91±1.030	6
	3.4	6.8	17.0	41.0	31.7	100.0		
Effective safety management: no. of security incidents	19	43	80	155	144	441	3.82±1.121	10
	4.3	9.8	18.1	35.1	32.7	100.0		
Document management	10	23	67	139	202	441	4.13±1.004	1
	2.3	5.2	15.2	31.5	45.8	100.0		
Updated timeline	16	22	65	162	176	441	4.04±1.036	3
	3.6	5.0	14.7	36.7	39.9	100.0		
Clash detection	12	27	63	155	184	441	4.07±1.023	2
	2.7	6.1	14.3	35.1	41.7	100.0		
Transferring risk to the private sector	15	29	100	170	127	441	3.83±1.028	9
	3.4	6.6	22.7	38.5	28.8	100.0		
Procedures for settling claims and disputes	12	31	83	177	138	441	3.90±1.010	8
	2.7	7.0	18.8	40.1	31.3	100.0		
Detail and transparent level of tendering procedure	13	28	72	159	169	441	4.00±1.034	4
	2.9	6.3	16.3	36.1	38.3	100.0		
Life-cycle management ability	11	29	71	169	161	441	4.00±1.008	5
	2.5	6.6	16.1	38.3	36.5	100.0		
4- Management Factors					Agree		3.88±0.781	4
On-time or earlier project completion	14	33	81	162	151	441	3.91±1.052	3
	3.2	7.5	18.4	36.7	34.2	100.0		
Schedule variance	16	30	81	182	132	441	3.87±1.033	9
	3.6	6.8	18.4	41.3	29.9	100.0		
Investment life cycle cost and return	15	31	84	173	138	441	3.88±1.039	6
	3.4	7.0	19.0	39.2	31.3	100.0		
Cost management	17	27	85	170	142	441	3.89±1.047	5
	3.9	6.1	19.3	38.5	32.2	100.0		
Cost variance	16	29	85	175	136	441	3.88±1.038	8
	3.6	6.6	19.3	39.7	30.8	100.0		
Completion/time delay	18	27	77	187	132	441	3.88±1.036	7
	4.1	6.1	17.5	42.4	29.9	100.0		
Construction cost overrun	18	33	93	180	117	441	3.78±1.048	11
	4.1	7.5	21.1	40.8	26.5	100.0		
Change in scope	16	25	102	186	112	441	3.80±1.000	10
	3.6	5.7	23.1	42.2	25.4	100.0		
Quality and innovation public service	11	41	68	173	148	441	3.92±1.040	1
	2.5	9.3	15.4	39.2	33.6	100.0		

Table 3. Detailed analysis of the responses to the questionnaire (continued)

Measurement	S.Dis (1)	Dis. (2)	N. (3)	Ag. (4)	S.Ag (5)	Total %	Mean±SD	Rank
The third-party assessment results	13	28	76	188	136	441	3.92±0.998	2
	2.9	6.3	17.2	42.6	30.8	100.0		
Contract management and control	13	29	83	175	141	441	3.91±1.015	4
	2.9	6.6	18.8	39.7	32.0	100.0		
5- Sustainability Factors					Agree		3.90±0.774	3
Environmental risk	13	32	96	181	119	441	3.82±1.006	9
	2.9	7.3	21.8	41.0	27.0	100.0		
Energy efficiency	7	34	73	176	151	441	3.98±0.980	1
	1.6	7.7	16.6	39.9	34.2	100.0		
Reduction of pollutant discharge	19	34	105	162	121	441	3.75±1.072	10
	4.3	7.7	23.8	36.7	27.4	100.0		
Economic development	13	40	79	178	131	441	3.85±1.041	8
	3	9	18	40	30	100		
Value for money (VFM)	8.0	28.0	94.0	173.0	138.0	441.0	3.92±0.969	7
	2	6	21	39	31	100		
Feasibility analysis	12.0	28.0	88.0	168.0	145.0	441.0	3.92±1.012	6
	3	6	20	38	33	100		
Government reputation and improvement	17.0	31.0	67.0	172.0	154.0	441.0	3.94±1.062	4
	4	7	15	39	35	100		
Trust and respect	11	28	80	179	143	441	3.94±0.991	3
	2.5	6.3	18.1	40.6	32.4	100.0		
Market interest and opportunity	11	34	74	178	144	441	3.93±1.012	5
	2.5	7.7	16.8	40.4	32.7	100.0		
Public interest	12	24	82	173	150	441	3.96±0.995	2
	2.7	5.4	18.6	39.2	34.0	100.0		

3.90±0.774, highlighting energy efficiency and government reputation, while emphasizing pollutant discharge and economic development less. Management factors were ranked fourth of all aspects, with a score of 3.88±0.781, prioritizing quality in public service and third-party assessments, but noting challenges in cost overruns and scope changes. Lastly, administrative factors, with a mean score of 3.83±0.935, highlighted organizational structure as the most critical, followed by legal and policy change risks.

Summary of Key Dimensions

The survey results indicate that respondents reported that BIM adoption could have a positive influence on PPP projects. Most of the participants agreed or strongly agreed on categories like technology, people, manpower, social, economy, quality, and administrative aspects, as illustrated by the significant portions of light blue and dark blue bars. Only a few respondents indicated strongly disagree or disagree, suggesting that negative perceptions are minimal. Some participants chose neutral responses, indicating a degree of ambivalence. In general, the data strongly endorse the positive influence of BIM on these factors. (Fig. 2) shows the survey results in detail.

However, our study ranked various project management dimensions based on the levels of agreement levels. The tools framework factors were deemed to be the most critical, followed by the sustainability and productivity factors. Management factors ranked fourth, highlighting their importance, but slightly less critical than the top three. Administrative factors were ranked the fifth, meaning that they are considered essential but not as immediately impactful as the other dimensions. These rankings reflect a consensus on the effect of BIM adoption on various aspects of performance in PPP projects. Table 4 represents a highlighted summary of the consensus on the agreement on various dimensions of the impact of BIM adoption in PPP projects on different factors.

Correlation Analysis

Linear correlation was used to explore the relationship between BIM implementation (dependent variable) and various performance indicators (independent variables). Pearson's correlation coefficient, ranges from -1 to 1,

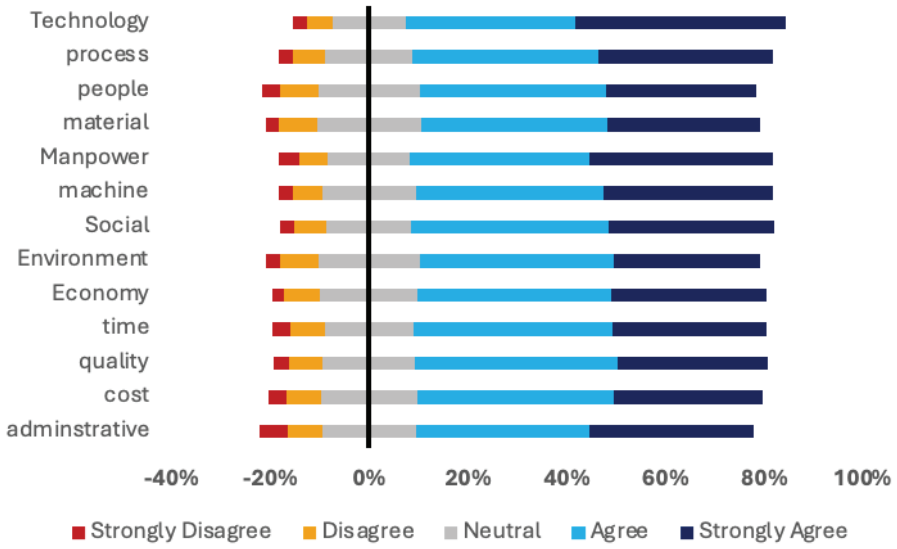

Figure 2. The survey detailed results.

Table 4. Summary of key dimensions

Dimension	Mean	SD	Rank	Scale
Tools framework factors	3.94	0.772	1	Agree
Productivity factors	3.93	0.783	2	Agree
Sustainability factors	3.90	0.774	3	Agree
Management factors	3.88	0.781	4	Agree
Administrative factors	3.83	0.935	5	Agree

Table 5. Correlation analysis of the questionnaire

Project performance factors	Overall performance (pearson correlation coefficient value)
Tools framework factors	0.948**
Management factors	0.938**
Productivity factors	0.937**
Sustainability factors	0.922**
Administrative factors	0.711**

**: Correlation is significant at the 0.01 level (2-tailed).

determines the degree and direction of these relationships. A positive value means a good relationship, while a negative value means a bad relationship. Table 5 shows that all of the factors are strongly related to each other. The factors that make up the tools framework have the strongest relationship with BIM implementation at 0.948. Next are the management factors at 0.938, the productivity factors at 0.937, the sustainability factors at 0.922, and the administrative factors at 0.711. These findings indicate that respondents believe that greater BIM adoption may improve performance in tools framework, management, sustainability, and productivity. Even though administrative factors are positively linked to BIM implementation, they are much weaker, which means the relationship is only moderate. The findings indicate that the adoption of BIM favorably influences administrative factors, albeit to a lesser extent than other variables.

Reliability Test (Cronbach's Alpha Coefficient)

Our study demonstrated a high internal consistency across the questionnaire, indicated by a Cronbach alpha

Table 6. Cronbach's Alpha coefficient for all the dimensions of the study

Dimension	Cronbach's Alpha	Interpretation	N of Items	Valid
Administrative factors	0.769	Acceptable	3	441
Productivity factors	0.915	Excellent	10	
Tools Framework factors	0.921	Excellent	11	
Management factors	0.925	Excellent	11	
Sustainability factors	0.920	Excellent	10	

of 0.975 for all items. We collected a total of 441 valid responses. Examining individual dimensions, we found that with ten items, productivity factors achieved an excellent reliability score of 0.915. Tools framework factors (11 items) and management factors (11 items) also exhibited excellent reliability, with Cronbach's alpha values of 0.921 and 0.925, respectively. Sustainability factors showed excellent reliability, with a Cronbach alpha of 0.920 over ten items. With three items, administrative factors had an acceptable reliability score of 0.769.

These values represent the internal consistency within each dimension. The administrative factors dimension shows an acceptable level of reliability, while sustainability factors, tools framework factors, management factors, and productivity factors exhibit excellent levels of reliability. Table 6 shows the Cronbach's Alpha coefficient for all the study dimensions.

The results showed a stronge positive correlation between the tools framework factors and BIM implementation. Management, sustainability, and productivity factors also demonstrated high positive correlations. The results underscore the critical role in enhancing project benifits for multiple dimensions.

The current research results align with the most of previous studies on BIM adoption in PPP projects. [15] demonstrated that BIM improves the performance of construction projects by an average of 28.9%, especially when it comes to feasibility studies, financial and cost performance, and risk management. While [39] stressed the importance of helping people make decisions that are worth the money in PPP projects. [12] proposed a BIM implementation plan to enhance collaboration, corroborating our assertion that successful BIM adoption markedly improves project outcomes.

This study offers valuable insights while also acknowledging specific limitations. The emphasis on Jordan and Malaysia, along with the absence of distinction among project types, may influence the generalizability of the results. It is acknowledged that the questionnaire was not widely distributed and that the use of a 5-point Likert scale may have led to biased responses. The results are interesting, but they shouldn't be used to make generalizations about other situations.

Future research on BIM adoption in PPP projects may include sector-specific analyses of various PPP procurement methods, which are crucial for comprehending BIM's impact on their efficacy. Looking at different levels of BIM maturity could help us understand the benefits better. Comparing regions, like countries with different levels of economic development, will help us understand how geography and culture affect things. Examining the amalgamation of BIM with nascent technologies can elucidate forthcoming trends in the construction sector. To improve future studies, it would be helpful to use both qualitative and quantitative data collection methods, like interviews, case studies, and surveys. This would give a full picture of BIM's effects.

CONCLUSION

With BIM the benefits of collaboration (with partners) on construction projects are enormous. It helps in organizing all the documents, prevent errors from taking place, and keeps schedules and bids transparent. Which naturally optimizes the entire process as everyone is at the same level and has the right talent. And there's an environmental side to it too: by conserving energy, the community gets added value. It makes managers less prone to misunderstanding or legal conflict. BIM is a great tool to help streamline and execute construction projects smoothly.

In order to encourage the usage of BIM by a greater number of organizations, both government and private business need to collaborate. They can accomplish this by offering training, establishing nationwide standards and incentives. They also need to ensure BIM is used from beginning to end on every project. This is one of the initial types of research to demonstrate how BIM really works in developing countries. This indicates that BIM can lead to improved performance, sustainability and service delivery. BIM aids companies to get better in a lot of things and it comes important for the success of their projects.

It recommends fostering innovation through supportive regulations, mandating BIM in large projects, strengthening collaboration with technology providers, encouraging knowledge sharing, and developing skilled professionals to ensure effective and sustainable adoption.

AUTHORSHIP CONTRIBUTIONS

Authors equally contributed to this work.

DATA AVAILABILITY STATEMENT

The authors confirm that the data that supports the findings of this study are available within the article. Raw data that support the finding of this study are available from the corresponding author, upon reasonable request.

CONFLICT OF INTEREST

The author declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

ETHICS

There are no ethical issues with the publication of this manuscript.

STATEMENT ON THE USE OF ARTIFICIAL INTELLIGENCE

Artificial intelligence was not used in the preparation of the article.

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SUPPLEMENTARY APPENDIX

Supplementary Table 1. KPIs for evaluating BIM in PPP projects

Category	Indicator	Subset	Reference
Administrative	Administrative	Risk of Adverse changes in law, policy or regulations	[14,39–43]
		Organization structure	[42,43]
		Risk of Force Majeure	[44,45]
Sustainability	Manpower	Experience and knowledge gains	[11,46–48]
		employment opportunities	[45,48–50]
		Specialized Expertise	[49,51,52]
		Technical Staff Resources	[41,50,52]
		Staff training	[11,18]
	Machine	Equipment condition and number	[18,39,50,53]
		effective interface management	[48,54,55]
	Material	Use of construction waste	[18,39,44,45,56]
		Material condition and number	[18,39,50,53]
		Use of innovative materials	[44,45]
Management	Time	on-time or earlier project completion	[41,50,57,58]
		Completion/Time Delay	[39,42,59]
		schedule variance	[46,50]
	Cost	Investment life cycle Cost and return	[11,41,44,45,47–52,53–55,57–59]
		Construction Cost overrun	[39,60]
		Cost management	[46,47]
		cost variance	[47,50]
	Quality	contract management and control	[39,40,48–50,52,54,54]
		quality and innovation public service	[47–49,58,62]
		The third-party assessment results	[18,48]
		Change in scope	[41,42]
Tools Framework	People	effective Safety management: no. of security incidents	[18,39,41,48,50,54,55,57]
		Change management - resistance to change	[11,52,61]
		Information and knowledge sharing	[18,57,61]
		Requirements of Stakeholders/Goals	[39,41]
	Process	procedures for settling claims and disputes	[25,41,42,49,55]
		Detail and transparent level of tendering procedure	[39,52,54,55]
		Clash Detection	[57,62]
		transferring risk to the private sector	[54,58]
		Life-cycle management ability	[49,60]
	Technology	Document management	[52,53,56,62]
		updated Timeline	[18,50]
Productivity	Environment	Environmental risk	[18,55,60]
		Energy efficiency (e.g., reduction of energy consumption and use of renewable energy resources)	[44,45,56]
		Reduction of pollutant discharge	[44,45]
	Economy	Value for Money (VFM)	[18,39,48,49,54,55]
		Feasibility analysis	[39,49,52,54,55]
		Economic development	[41,47]
	Social	market interest and opportunity	[39,47,54,59]
		Government reputation and improvement	[41,47]
		Trust and respect	[44,49]
		Public interest	[49,60]

Supplementary Table 2. The overall questionnaire form

1. Adopting BIM in PPP Projects can enhance and modify organizational structures to better align with the project›s requirements.
2. Adopting BIM in PPP Projects can effectively decrease and alleviate the risk of unfavorable law, policy, or regulation alterations.
3. Adopting BIM in PPP Projects can reduce force majeure risks.
4. BIM adoption in PPP projects will improve the overall experience and knowledge gains due to BIM integration.
5. BIM adoption in PPP projects can improve the quality of staff training by introducing interdisciplinary training and the operability of information.
6. BIM adoption in PPP projects will make it easier to get information by using effective interface management.
7. Adopting BIM in PPP Projects facilitates the efficient assessment and utilization of waste materials.
8. Adopting BIM in PPP Projects can generate employment opportunities or productive jobs by meeting the growing knowledge and demand for such expertise.
9. BIM adoption in PPP projects will produce more specialized expertise when compared to traditional PPP procurement.
10. BIM adoption in PPP projects will attract more qualified technical staff resources.
11. BIM adoption in PPP projects has vast resource allocation potential by keeping records of Machines› conditions and numbers.
12. Better use of innovative materials through design and implementation can be achieved by adopting BIM in PPP projects.
13. BIM adoption in PPP projects has vast resource allocation potential by keeping records of Materials conditions and numbers.
14. BIM adoption in PPP Projects will better meet stakeholders› diverse requirements and Goals in performance management.
15. BIM adoption in PPP Projects can reduce resistance to change among team members and stakeholders.
16. The adoption of BIM in PPP Projects promotes the effective sharing of information and knowledge and an interoperability framework.
17. BIM adoption in PPP Projects is more effective in Safety management on construction sites and can reduce security incidents.
18. Data and documents used in PPP projects that adopt BIM have everything sorted in digital folders and archives to be quickly and effectively created, managed, and shared.
19. BIM Adoption in PPP projects makes timeline updates quicker and more efficient, including design, construction, and in-use operational information.
20. BIM Adoption in PPP projects has the potential to utilize smart technology for better coordination and Clash Detection.
21. BIM adoption in PPP Projects helps transfer the boundaries of risk and insurability to the private sector, leveraging risk mitigation and prevention affordability.
22. BIM adoption in PPP Projects simplifies claims management by identifying potential claims, information consistency, data storage, and improved collaboration.
23. BIM adoption in PPP Projects can help create a more detailed and transparent level of tendering procedure due to the integration and clearness of the project.
24. BIM adoption in PPP Projects has the tools for smoother and more efficient Life-cycle management throughout projects› life cycle stages.
25. BIM adoption in PPP Projects increases efficiency and thus increases the chances of on-time or earlier project completion.
26. BIM adoption in PPP Projects can notify early warnings on schedule indicators, resulting in fewer schedule variances.
27. BIM adoption in PPP Projects will result in a better investment Cost and return throughout the project›s life cycle.
28. BIM adoption in PPP projects improves cost management by estimating the total price reasonably based on the specific expenses required for each part of the project quantity.
29. BIM adoption in PPP Projects can notify early warnings on cost indicators and result in fewer cost variances.
30. BIM adoption in PPP Projects increases efficiency and thus reduces the chances of project time delays.
31. Adopting BIM in PPP construction Projects can significantly contribute to cost overrun mitigation.
32. BIM adoption in PPP projects helps meet the score or requirements, making a change in scope (scope creep) less likely to happen.
33. BIM adoption in PPP Projects can test and try different design alternatives to improve public service quality and innovation.
34. By adopting BIM in PPP projects, the third-party assessment process can be made more efficient and streamlined, leading to improved results and higher quality outcomes.
35. BIM Adopted in PPP projects helps in ensuring that the terms and conditions contained within the contract are adhered to and that all party's contractual obligations are met satisfactorily.
36. BIM adoption in PPP projects can allow designers to run an automated assessment of the environmental impact of their design choices immediately.
37. BIM adoption in PPP projects significantly impacts increasing efficiency during a project›s design and construction phases.
38. BIM adoption in PPP projects can help create business models that reduce the overall pollutant discharge by enabling environmental performance in building design and operation.

39. BIM adoption in PPP projects has the potential for better, more affordable, and quicker project alternatives to help economic development.

40. BIM adoption in PPP projects can achieve better Value for Money (VfM) than traditional PPP procurement.

41. BIM adoption in PPP projects creates a more detailed and accurate feasibility analysis reflecting the project life cycle stages.

42. Adopting BIM in PPP projects can facilitate more effective project completion and enhance project improvements, which, in turn, can bolster the reputation of government agencies involved in such projects.

43. Adopting BIM in PPP projects holds the potential to cultivate greater trust and respect among project teams and stakeholders.

44. Adopting BIM in PPP projects facilitates fulfilling market needs and realizing project opportunities by enhancing the comprehension of project details through BIM implementation.

45. The adoption of BIM in PPP projects has the potential to generate greater public interest in more advanced and complex projects.