An empirical analysis of barriers to building information modelling (BIM) implementation in construction projects: Evidence from the Chinese context

Xiaozhi Ma[a,b], Amos Darko[a], Albert P.C. Chan[a], Rong Wang[c], Boyu Zhang*[a,d]

[a]*Department of Building and Real Estate, The Hong Kong Polytechnic University, Hung Hom, Kowloon, Hong Kong, China*

[b]*College of Architecture and Environment, Sichuan University, No.24 South Section 1, Yihuan Road, 610065, Chengdu, China*

[c]*China BIM Union, Beijing, No. 30 North 3rd Ring Road, Beijing, China*

[d]*Department of Standards & Codes, China Academy of Building Research, Beijing, No. 30 North 3rd Ring East Road, Beijing, China*

Corresponding author:* *Boyu.zhang@connect.polyu.hk*

ABSTRACT

Although building information modelling (BIM) applies widely in the architecture, engineering, and construction (AEC) industry, its systematic implementation in AEC projects still experiences challenges. While most previous studies have investigated general BIM implementation, the present study precisely focuses on the barriers to BIM implementation at the AEC project level and explores their sources in the Chinese project context. Based on a questionnaire survey with 166 valid responses from experienced BIM practitioners as empirical evidence from the Chinese construction context, the data were processed using descriptive statistical analysis, non-parametric analysis and principal component analysis. The results of the descriptive analysis classified 14 critical barriers. The international comparison of the top five barriers indicated that the most critical barriers were similar but ranked differently in different countries. The following principal component analysis revealed six underlying factors for all the barriers, which were: *experience and capabilities*, *technical conditions*, *system inertia*, *extra input*, *change of work routines*, and *implementation risks*. The findings of this study may help the practitioners to understand BIM implementation barriers, allocate resources, and prioritize efforts in project practices. This study can also provide implications for BIM deployment and governance in the AEC industry.

KEYWORDS: Building information modelling (BIM); critical barriers; BIM implementation; architecture, engineering, and construction (AEC), AEC projects.

1. Introduction

Conventionally, the fragmentation of architecture, engineering, and construction (AEC) industry has led to low efficiency and wasteful use of resources (Egan 1998). In the AEC industry, the project organizes complex building works and integrates fragmented production procedures with various disciplines and teams. However, the complexity of AEC projects spells limitations on traditional building production (Williams 1999; Lu et al. 2014). Updating project practices with innovations is essential to advance building production.

To improve the efficiency of AEC, information and communication technologies (ICTs) have been continuously adopted in different procedures and contexts of the AEC industry. The application of ICTs in projects helps to manage the miscellaneous building information, improve the efficiency of related processes, and facilitate efficient building production (Froese 2010). In particular, building information modelling (BIM) enables the project actors to manage a project via a model-based cooperative approach with building information of the various disciplines (Succar et al. 2012; Miettinen and Paavola, 2014).

BIM benefits the AEC project in several ways. Firstly, the successful implementation of BIM in project reduces errors, rework, and waste (Won et al. 2016; Ngowtanasuwan and Hadikusumo 2017). Moreover, the use of BIM in AEC projects promotes multidisciplinary collaboration among different project teams (Liu et al. 2017, Oraee et al. 2017), achieves agile project control (Bryde et al. 2013; Son et al. 2017), and enhances the efficiency of the project activities (Khanzadi et al. 2020; Turk and Klinc 2019). Albeit the benefits, the systematic implementation of BIM in project practices still needs to be improved (Mancini et al. 2017).

The disruptive nature of BIM makes BIM adoption in the project a major challenge. Firstly, BIM changes the way how building information is handled in projects (Ahn et al. 2016; Ma et al. 2018). Also, some studies (e.g., Ahn et al. 2016; Dossick and Neff 2009; Liao and Teo 2019) confirm the organizational change with the introduction of BIM in the AEC project. Furthermore, BIM establishes new workflows which the project team shall adapt to (Barison and Santos 2011; Sacks et al. 2009). The profound impact of BIM has been disseminated into different aspects of the AEC project, which causes challenges in the conventional project practice (Chong et al. 2017; Mostafa et al. 2020). Many barriers exist against the further development of BIM implementation in AEC projects.

Investigating BIM from the project perspective may benefit the systematic implementation of BIM. Due to the profound impact of BIM on the AEC project, BIM implementation is affiliated with the current practice of construction project management (Ma et al. 2019; Davies et al. 2017). Additionally, Fox (2014) revealed the inter-relations of BIM implementation factors and suggested the project be used as a framework to organize BIM. Although several studies, such as Eadie et al. (2013); Hatem et al. (2018); Al-Zwainy et al. (2017); and Banawi (2017), have investigated barriers of BIM implementation in AEC projects, very few devoted to the classification of critical barriers from the existing barriers and the exploration of their sources in the AEC project context. An in-depth investigation of existing barriers with multiple comparisons and the interpretation of their sources can benefit BIM implementation in project practices. Therefore, this study examines the existing BIM implementation barriers in AEC projects to identify the critical barriers and clarify the sources of all the barriers.

This research has both theoretical and practical implications. First, it summarizes BIM implementation barriers in existing and identify the critical barriers to BIM implementation in the Chinese construction context. The following comparison of the critical barriers within the international research community helps understand the differences of BIM implementation in the project practices across different countries. Also, the clarification of the latent factors underlying the barriers promotes the understanding of BIM implementation in the AEC industry to update its practices and improve the efficiency.

2. Literature review

Previous research clarifies the barriers and obstacles in general BIM implementation. Yan and Damian (2008) pointed out that the major obstacle in BIM implementation is the people issue. Miettinen and Paavola (2014) indicated that the adoption of BIM lies in organizations and policies. Won et al. (2013) identified a list of barriers, such as lack of organizational support and deficient data processing in BIM implementation, from organizational and inter-organizational perspectives. Dainty et al. (2017) categorized the obstacles to adopt BIM into four areas, including resources, motivation, utilization, and capabilities of the technology.

These studies have analysed BIM implementation from different perspectives but not particularly the project perspective.

Recent studies from the international research community categorize the barriers to BIM implementation in different countries. For example, Banawi (2017) gained empirical evidence from BIM-based AEC projects of Saudi Arabia and identified three sources of obstacles, including process, technology, and resources. Eadie et al. (2015) resorted to the opinions of the BIM professionals of the UK's AEC industry and implied that BIM implementation barriers lay in fragmentation of practice as well as financial and legal aspects. Rogers et al. (2015) examined BIM use in the enterprises of Malaysia's AEC industry and concluded the need for technical and governmental supports such as training, guidelines, and propaganda in BIM implementation. Additionally, Abubakar et al. (2014) explored the contractors' opinions in the construction context of Nigeria and listed a few obstacles as work customs, regulatory issues, the cost of BIM infrastructure, and lack of technical support. The barriers to BIM implementation vary in different studies.

Through literature review, 18 barriers to BIM implementation are concluded as listed in Table 1. The reviewed studies include factor studies (e.g., Zhao et al. 2018; Enshassi and Abuhamra 2017; Roger et al. 2015) and qualitative field studies (e.g., Liu et al. 2017; Gledson 2016; Porwal and Hewage 2013) to gain a comprehensive insight of the barriers. They also cover financial, technical, organizational, legal, managerial, and knowledge aspects of BIM regarding the context of the AEC project. The further identification of critical barriers to BIM implementation in project practices is based on this list of barriers.

Table 1. BIM implementation barriers identified from the literature

Code	Barrier	Sources
B1	Extra investment on BIM use	Chan (2014); Abubakar et al. (2014); Rogers et al. (2015); Yan and Damian (2008)
B2	Lack of related technical personnel	Enshassi and Abuhamra (2017); Abubakar et al. (2014); Ding et al. (2015); Yan and Damian (2008)
B3	Lack of knowledge and experience for BIM implementation	Porwal and Hewage (2013); Enshassi and Abuhamra (2017); Ding et al. (2015); Almuntaser et al. (2018); Gledson (2016)
B4	Insufficient training and consultancy	Porwal and Hewage (2013); Rogers et al. (2015); Dainty et al. (2017); Almuntaser et al. (2018)
B5	Lack of support from other teams in the project	Chan (2014); Won et al. (2013); Yan and Damian (2008); Howard and Björk (2008); Jin et al. (2018)
B6	Lack of client's requirement or management support	Porwal and Hewage (2013); Enshassi and Abuhamra (2017); Almuntaser et al. (2018); Ding et al. (2015); Linderoth (2010)
B7	Lack of motivation to implement BIM in projects	Enshassis and Abuhamra (2017); Dainty et al. (2017); Ding et al. (2015)
B8	Missing evaluation and feedback for BIM implementation in projects	Barlish and Sullivan (2012); Arayici et al. (2011); Jung and Joo (2011)
B9	Missing related regulations and rules	Porwal and Hewage (2013); Abubakar et al. (2014); Linderoth (2010); Gledson (2016)
B10	Lack of technical standards and specifications	Chan (2014); Enshassi and Abuhamra (2017); Eadie et al. (2015); Zhao et al. (2018)
B11	Interoperability issues of information and data	Eadie et al. (2015); Rogers et al. (2015); Gledson (2016); Howard and Björk (2008); Zhao et al. (2018)
B12	Missing appropriate IT infrastructure	Porwal and Hewage (2013); Abubakar et al. (2014); Rogers et al. (2015); Dainty et al. (2017)
B13	Possible defects of engineering data and information	Won et al. (2013); Gu and London (2010); Chan (2014)
B14	Extra work for BIM application	Chan (2014); Yan and Damian (2008); Rogers et al. (2015)

B15	Mismatch of BIM work procedures with conventional work custom	Chan (2014); Porwal and Hewage (2013); Yan and Damian (2008); Gledson (2016)
B16	Project risks caused by BIM	Porwal and Hewage (2013); Abubakar et al. (2014); Ding et al. (2015); Zhao et al. (2018)
B17	Lack of clear definition of organisational arrangement and responsibilities	Chan (2014); Abubakar et al. (2014); Liu et al. (2017)
B18	The immaturity of BIM technology	Succar et al. (2012); Liang et al. (2016); Smits et al. (2017); Giel and Issa (2015); Bråthen and Moum (2016)

Most of the previous research interprets the barriers and obstacles to BIM implementation in the AEC industry or organizations; few studies focus on BIM implementation in projects. However, for adopting BIM to improve the AEC practice, the identification of critical barriers refers to the implementation of BIM in projects. As the project organizes multidisciplinary works and integrates various procedures in building production, this study adopts the project perspective to investigate barriers to BIM implementation in AEC projects.

3. Methodology

3.1. Research approach

This study followed a factor research approach with empirical questionnaire surveys as Figure 1 illustrates. Firstly, the study started with a research proposal to identify the research aim and define the research scope. Then, the comprehensive review of BIM literature including factor studies and qualitative field studies, as mentioned in the previous section, helped categorize a list of barriers to BIM implementation that were developed further as the survey questions. The following step involved a pilot study conducted within China BIM Union (CBU). CBU is a nation-wide organization that gathers BIM practitioners and related organizations to facilitate BIM implementation and deployment in the Chinese AEC industry (China BIM Union 2020). It also provides high-level seminars to experienced BIM professionals and promotes the integration of research and practice. In the pilot study, twelve BIM specialists from CBU helped to review, fulfil, and rationalize the questions. As most of them are practitioners and serve part-time for CBU, they have rich industry practice and demonstrate a good representation of the prospective participants. A few questions were revised through the pilot survey. For example, the academic term "leadership" was replaced with "client's requirement or management support", and the original barrier, *culture issues*, has been broken into *lack of knowledge and experience for BIM implementation* and *lack of support from other teams in the project*. Through the two steps, the final questionnaire was prepared. The answers of the questionnaire were quantified using a five-point Likert scale (1 = not important, 2 =not very important, 3 = important, 4 = very important, and 5 = extremely important) to rate the criticality of the listed barriers.

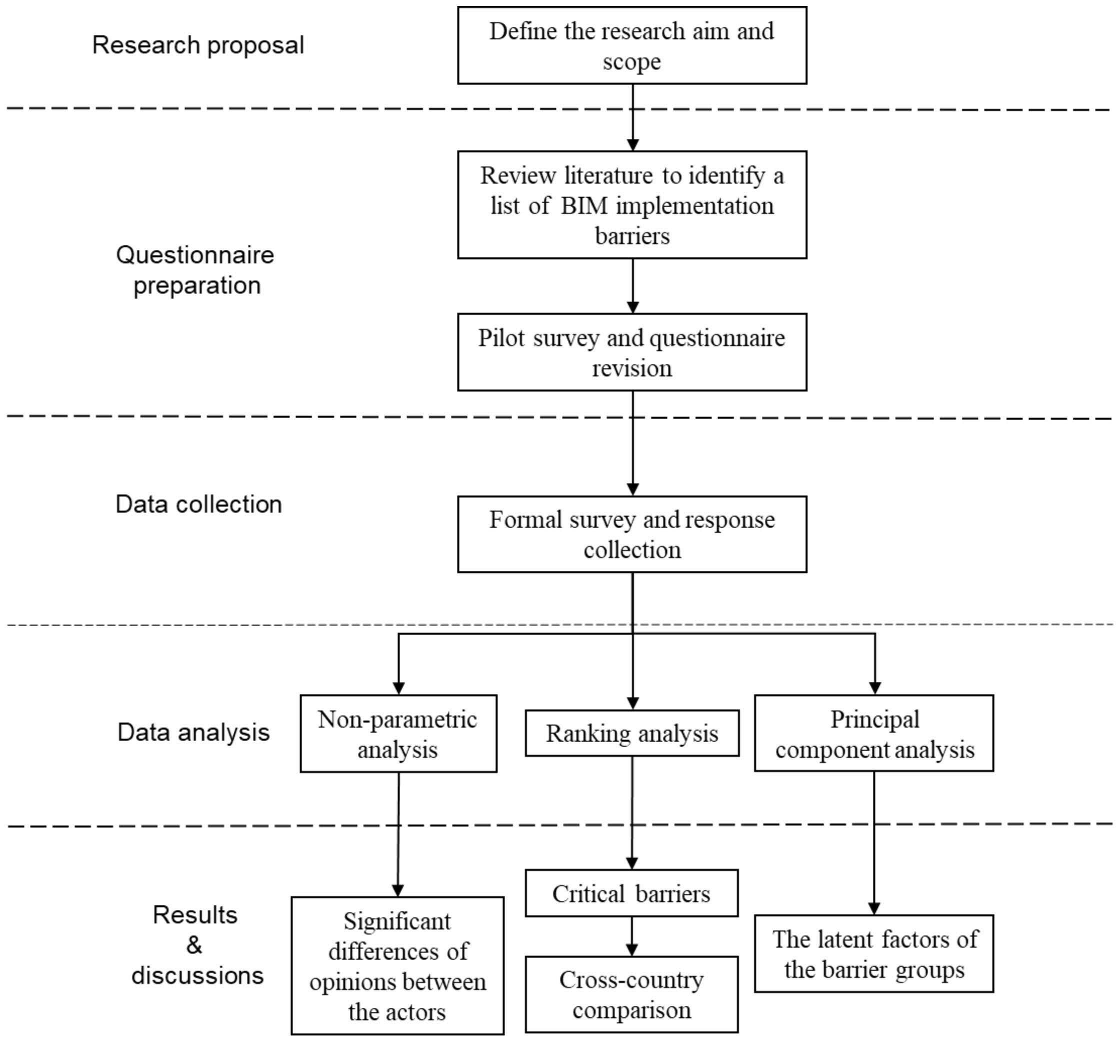

Figure 1. The research approach of this study

3.2.Data collection

The questionnaire survey was conducted via an online survey system that enables the participants to access the questionnaire via a link. The system can automatically record the time for each response and generate data from the answers. The link of the questionnaire was sent to the seminar groups of CBU consisted of 477 BIM professionals who were encouraged to complete the survey based on their experience of BIM use in AEC projects. The participants of the seminars were supposed to have several years' work experience related to BIM.

Preliminarily, 202 responses were collected from the participants. However, as the research aim of this study is to investigate barriers to BIM implementation in project practices, the responses from academic professionals, who claimed no experience in the practice of AEC projects, were eliminated. Some other responses from the authorities and industry associations were excluded as the respondents might not directly participate in project practices. Moreover, the questionnaires completed within a short time were examined to prove their reliability; those with all the same answers were also screened out. Through the previous proceedings, the final valid answers were limited to 166. As suggested by Tabachnick and Fidell (2007), the sample size should be no less than five times the number of the variables. The index for this study is 166/18=9.22, which is qualified. With the total population of 477, the effective response rate of the survey is 34.8%.

The work experience in the AEC industry and BIM use experience of the 166 BIM practitioners are presented in Table 2. With only 12.7% less than 5 years, most of them have rich experience in the industry. Considering the relatively recent prevalence of BIM in the industry, their experience in BIM use is fairly good, with 50.6% using BIM for 3-5 years and 28.9% for over 5 years. The respondents are also from different workgroups of projects to represent different actors. The background of the respondents is desirable for this survey.

Table 2. The basic background of the respondents

Work experience in the AEC industry			**BIM use experience**			**Workgroup**		
Years	N	Percentage	Years	N	Percentage	Actor	N	Percentage

1-5 years	21	12.7	1-2 years	34	20.5	Designer	41	24.7
6-10 years;	36	21.7	3-5 years	84	50.6	Contractor	58	34.9
11-15 years;	45	27.1	Over 5 years	48	28.9	Consultant	54	32.5
16-20 years;	30	18.1	Total	166	100.0	Client	13	7.8
Over 20 years	34	20.5				Total	166	100.0
Total	166	100.0						

3.3.Data analysis techniques and validation

The data analysis had proceeded in two steps with SPSS Statistics 24. A preliminary data analysis determined the ranking of the barriers, and the following principal component analysis (PCA) explored the relations of the barriers. The factors had been obtained through the grouping of barriers with PCA, as PCA with appropriate rotation can simplify the data structure and extract the key factors (Chan et al. 2010; Kim and Kim 2012). The following analysis of reliability found that the Cronbach α of the data set is 0.813. This value indicates good reliability of the survey, as the threshold is commonly acknowledged as 0.7 (Nunally and Bernstein, 1978; Kiline 2013).

Nonparametric tests, including the Kruskal-Wallis, and the Mann-Whitney, were conducted to analyse the ranking of barriers' criticality. The non-parametric test can be used to interpret the data with the non-normal distribution (Field 2013). As non-parametric tests, the Kruskal-Wallis and the Mann-Whitney compare the data by the mean rank, which is positively correlated with the mean value, to examine the discrepancies among and between independent groups respectively with random sample sizes (Salkind 2010). Field (2013) recommended the Mann-Whitney as a *post hoc* analysis following the Kruskal-Wallis to investigate differences of variables from more than two groups. Due to non-normality of the collected data, the Kruskal-Wallis and the Mann-Whitney tests were employed to examine the possible discrepancy in different project actors' opinions on the criticality of the barriers.

The PCA has a Kaiser-Meyer-Olkin (KMO) value of 0.782 and a significance of 0.000 for the Bartlett test of sphericity. According to Field (2013), the KMO value is an indicator of sampling adequacy for PCA, which is acceptable over 0.5 and good between 0.7 and 0.8. The Bartlett test of sphericity investigates the interdependence of the identified values in the correlation matrix (Field 2013). The null hypothesis for the Bartlett test of sphericity is that the variances are independent; it can be rejected with a significant value of 0.000. The indicators suggest the data is appropriate for PCA.

4. Analyses and findings

4.1. The ranking of the barriers and identification of critical barriers

The mean values for the criticality of the barriers referring to different actors' opinions are calculated and ranked as presented in Table 3, together with Cronbach α. The mean values of the barriers are converted into normalization values to identify the critical barriers. Barriers with normalization values over 0.5 are critical (Xu et al. 2010, Liao and Teo 2017, Chan et al., 2017). Accordingly, the critical barriers include B11(*interoperability issues of information and data*); B1(*extra investment on BIM use*); B2(*lack of related technical personnel*); B3(*lack of knowledge and experience for BIM implementation*); B9(*missing related regulations and rules*); B7(*lack of motivation to implement BIM in projects*); B8(*missing evaluation and feedback for BIM implementation in projects*); B10(*lack of technical standards and specifications*); B6(*lack* o*f client's requirement or management support)*; B5(*lack of support from other teams in the project*); B12(*missing appropriate IT infrastructure*); B17(*lack of clear definition of organizational arrangement and responsibilities*); B15(*mismatch of BIM work procedures with conventional work process*); B18(*The immaturity of BIM technology*). The critical barriers are analysed in further to provide an in-depth interpretation of their criticality.

According to the mean values of all the practitioners' assessments on the barriers, B11(4.47) is identified as the most critical barrier to BIM implementation in projects, followed by B1(4.42), B2(4.38), B3(4.27), B9 (4.21), B7 (4.19), B8 (4.14 with an deviation of 0.869), B10 (4.14 with an deviation of 0.990), B6 (4.13). These are critical barriers that have mean values over 4, which indicates they are generally above the scale "very important". This group of barriers need the most attention when BIM is systematically implemented in an AEC project. Another group of critical barriers are identified including B5(3.98); B12(3.97); B17(3.85); B15(3.73); and B18(3.69). From a scale sense, their mean values are between 3 (important) and

4 (very important) but inclined to 4. This group also requires more attention than the non-critical group of barriers.

As the questionnaire also allows the respondents to fill in other barriers, the extra barriers focus on the management and collaboration of BIM implementation. The most frequent mentioned extra barrier is that the decision-makers have weak knowledge of BIM. Furthermore, the collaboration in BIM implementation is difficult due to the project teams have different interests and perceptions in BIM use. Moreover, lack of standardization and reluctance to change of work customs are also mentioned.

Table 3. The ranking of barriers

Barrier	Total (N=166)				Designer (N=41)			Contractor (N=58)			Consultant (N=54)			Client (N=13)		
	Mean	SD[a]	Rank	NV[b]	Mean	SD	Rank	Mean	SD	Rank	Mean	SD	Rank	Mean	SD	Rank
B11	4.47	0.814	1	1.00[c]	4.54	0.745	1	4.40	1.008	2	4.43	0.690	1	4.77	0.439	1
B1	4.42	0.732	2	0.97[c]	4.49	0.746	2	4.40	0.815	2	4.39	0.685	2	4.46	0.519	3
B2	4.38	0.718	3	0.94[c]	4.34	0.728	4	4.62	0.644	1	4.11	0.744	5	4.54	0.519	2
B3	4.27	0.732	4	0.87[c]	4.29	0.750	5	4.31	0.754	4	4.22	0.744	4	4.15	0.555	6
B9	4.21	0.977	5	0.84[c]	4.37	0.915	3	4.22	0.992	6	4.09	1.051	7	4.15	0.801	6
B7	4.19	0.887	6	0.82[c]	4.29	0.814	5	4.24	0.865	5	4.09	0.875	7	4.08	1.256	8
B8	4.14	0.869	7	0.79[c]	4.12	0.872	7	4.22	0.839	6	4.11	0.839	5	4.00	1.155	11
B10	4.14	0.990	8	0.79[c]	4.15	0.963	6	4.17	1.045	8	4.04	1.045	9	4.38	0.506	4
B6	4.13	0.955	9	0.78[c]	4.07	0.818	9	4.07	1.122	9	4.24	0.867	3	4.08	0.954	8
B5	3.98	0.870	10	0.69[c]	3.95	0.805	11	4.00	0.973	11	4.04	0.846	9	3.77	0.725	12
B12	3.97	0.981	11	0.68[c]	3.95	1.094	11	4.07	0.971	9	3.85	0.920	11	4.08	0.954	8
B17	3.85	1.001	12	0.61[c]	4.00	0.975	10	3.74	1.117	12	3.76	0.930	12	4.23	0.725	5
B15	3.73	1.034	13	0.53[c]	3.83	0.972	14	3.74	1.208	12	3.72	0.940	14	3.46	0.776	15
B18	3.69	1.048	14	0.51[c]	3.76	1.135	16	3.60	1.107	14	3.76	0.930	12	3.62	1.044	13
B4	3.64	0.888	15	0.47	3.80	0.782	15	3.47	0.977	16	3.72	0.856	14	3.62	0.870	13
B14	3.57	1.005	16	0.43	3.95	0.805	11	3.50	1.080	15	3.41	0.981	16	3.31	1.109	16
B13	3.05	1.097	17	0.10	3.17	1.160	17	2.98	1.207	17	3.02	1.000	18	3.15	0.801	17
B16	2.89	1.203	18	0.00	3.02	1.255	18	2.57	1.201	18	3.13	1.065	17	2.85	1.405	18
Cronbach α	0.813				0.867			0.760			0.784			0.912		

Note: a. SD-Standard deviation; **b.** NV- Normalisation value= (mean - minimum mean)/(maximum mean - minimum mean); **c.** Critical barrier.

4.2.Findings of the non-parametric tests

The assessments from the designers, the contractors, the consultants and the clients are firstly compared with the Kruskal-Wallis test, and then the Mann-Whitney. With a significance level of 0.05, the Kruskal-Wallis test identifies a few discrepancies of the assessments among the actors. Bonferroni correction applies to the *post hoc* test to avoid Type I errors; thus, the significance level of the Mann-Whitney is 0.05/n=0.0083, where n is the number of the compared pair groups that is six in this case, with all registrations of the pairs above the minimum 20 (Lindhard and Larsen 2016, Deshpande 1995, Sprent 1989). According to Table 4, the result reveals that there are significant discrepancies for B2, B14. B2 has the most significant variances regarding all the perceptions of the actors (sig=0.000). Comparing the mean ranks, the contractors suffer most with the barrier *lack of related technical personnel*, while the consultants seem to be better off than the others. The discrepancy between the contractors and the consultants is confirmed with a significance of 0.000 in the Mann-Whitney test (Table 5). The significant discrepancy of B14 lies in designers and consultants (sig=0.006). It can be inferred that designers tend to concern more on BIM training and consultancy than the consultants. Nevertheless, most of the actors' assessments of the barriers demonstrate good consistence without significant difference.

Table 4. Significant differences in assessments on barrier criticality identified by the Kruskal-Wallis test

Barrier	Actor	Mean rank by the Kruskal-Wallis	χ^2	Asymp. sig. (two-tailed)
B2	Designer	81.07	17.904	0.000
	Contractor	99.98		
	Consultant	65.86		
	Client	90.88		

B14	Designer	101.05	8.571	0.036
	Contractor	80.82		
	Consultant	75.94		
	Client	71.50		
Note: Sig. level=0.05, df=3				

Table 5. Significant discrepancies in assessments on barrier criticality identified by the *post hoc* Mann-Whitney test

Barrier	No. of registrations	Actors (mean rank by the Mann-Whitney)	Mann-Whitney U	Asymp. sig.(two-tailed)
B2	112	Contractor(67.47)/Consultant(44.71)	929.500	0.000
B14	95	Designer(56.43)/Consultant(41.60)	761.500	0.006
Note: Sig. level=0.0083				

4.3.The principal component analysis

PCA has been conducted to the barriers to explore their relations and possible latent factors. Through PCA using varimax rotation, six components are captured, with 62.558% of total variance explained, as shown in Table 6. For PCA, the loading value of an individual factor shall be no less 0.5 (Akintoye 2000, Bhupendra and Sangle 2016). All barriers demonstrating satisfactory factor loadings are retained. Drawn from the interpretation of barriers in the components, the latent factors include *system inertia*, *technical conditions*, *change of work routines*, *extra input*, *experience and capabilities*, and *implementation risks*.

Table 6. The result of PCA

Code	Barriers	Factor loadings					
		System inertia	Technical conditions	Change of work routine	Extra input	Experience and capabilities	Implementation risks
B5	Lack of support from other teams in the project	**0.687**	-0.039	0.102	-0.134	0.248	0.050
B6	Lack of client's requirement or management support	**0.681**	0.015	-0.061	0.180	0.087	0.132
B8	Missing evaluation and feedback of BIM implementation in projects	**0.662**	0.206	0.225	0.217	-0.090	-0.258
B9	Missing related regulations and rules	**0.653**	0.259	0.368	-0.029	-0.035	-0.010
B7	Lack of motivation to implement BIM in projects	**0.623**	0.166	0.193	0.467	0.042	-0.046
B4	Insufficient training and consultancy	**0.583**	0.002	-0.162	0.088	0.204	0.354
B12	Missing appropriate IT infrastructure	-0.004	**0.800**	0.049	0.085	0.079	0.119
B11	Interoperability issues of information and data	0.079	**0.786**	-0.072	0.021	0.054	-0.074
B10	Lack of technical standards and specifications	0.468	**0.602**	0.109	-0.011	0.131	0.105

B18	The immaturity of BIM technology	0.066	**0.512**	0.295	0.122	-0.405	0.130
B15	Mismatch of BIM work procedures with conventional work custom	0.084	-0.085	**0.703**	0.235	0.117	0.241
B17	Lack of clear definition of organizational arrangement and responsibilities	0.160	0.182	**0.702**	-0.184	0.012	0.029
B1	Extra investment on BIM use	0.169	0.126	-0.139	**0.713**	0.168	-0.023
B14	Extra work for BIM application	-0.004	-0.095	0.496	**0.623**	-0.081	0.204
B2	Lack of related technical personnel	0.106	0.113	-0.025	0.076	**0.865**	-0.033
B3	Lack of knowledge and experience for BIM implementation	0.352	0.055	0.295	0.089	**0.607**	-0.127
B16	Project risks caused by BIM	0.019	0.045	0.264	-0.094	-0.090	**0.804**
B13	Possible defects of engineering data and information	0.135	0.169	0.042	0.399	-0.120	**0.577**
Initial Eigenvalues		4.348	1.947	1.676	1.222	1.058	1.011
Variance Explained (%)		24.155	10.815	9.309	6.788	5.876	5.616
Cumulative (%)		24.155	34.969	44.278	51.066	56.942	62.558

The first component with the total variance explained of 24.155% involves the most barriers including *lack of support from other teams in the project*, *lack of client's requirement or management support*, *missing evaluation and feedback of BIM implementation in projects*, *missing related regulations and rules*, *lack of motivation to implement BIM in projects*, *insufficient training and consultancy*. Regarding these barriers are related to goal setting, system governance, and performance enhancement of the BIM effort in the AEC project, this factor is identified as *system inertia*.

The second component with 10.815% of the total variance explained for the barriers contains *lack of technical standards and specifications*, *interoperability issues of information and data*, *missing appropriate IT infrastructure*, and *the immaturity of BIM technology*. All the barriers are related to the technical conditions that work to enable BIM in the AEC project. These barriers point to *technical conditions*.

The barriers related to the third component include *mismatch of BIM work procedures with conventional work custom* and *lack of clear definition of organizational arrangement and responsibilities*. It accounts for 9.309% of the total variance explained. These barriers probe into the changes and new arrangements of work for incorporating BIM into the AEC project. Thus, this factor is regarded as *change of work routines*.

Moreover, two barriers that are *extra financial investment on BIM use* and *extra work for BIM application* contribute to the fourth component. It explains 6.788% of the total variance. Both barriers point to extra input for the implementation of BIM in the AEC project of either financial or work capitals. Therefore, this factor refers to *extra input*.

The fifth component accounting for 5.876% of the total variance, encompasses two barriers that are *lack of related technical personnel* and *lack of knowledge and experience for BIM implementation*. The two barriers can be summarized as a factor, namely, *experience and capabilities*.

Lastly, the other two barriers *project risks caused by BIM* and *possible defects of engineering data and information* constitute the sixth component, which explains 5.616% of the total variance. Both are in relation to possible risks to the implementation of BIM and the AEC project. Thus, this factor is concluded as *implementation risks*.

The criticality of factors by mean ranks as *experience and capabilities* (4.310), *technical conditions* (4.053), *system inertia* (4.033), *extra input* (3.975), *change of work routines* (3.770), *implementation risks* (2.953). It shows that *experience and capabilities* are most crucial to BIM implementation in projects. As a basis, *system inertia* and *technical conditions* are also of great criticality to project BIM practice. All of them have mean values over 4 (very important). Meanwhile, the mean of *implementation risks* is below 3 (important) and ranks the last. It can be inferred that Chinese practitioners are willing to take risks in the implementation of BIM in projects. The other two factors have no strong tendencies. Through the analysis, it can be concluded that *experience and capabilities*, *technical conditions,* and *system inertia* are the most prominent factors for BIM implementation in projects according to the result of the survey.

5. Discussion and implications

Understanding BIM implementation barriers in the project context is the first step to enhance systematic BIM implementation in the AEC project. The next step is to tackle barriers in AEC projects. Yet, the project is not isolated from organizations and the industry. The further exploit of BIM in a broader context can help facilitate collaboration in the AEC industry. The following discussion gives more specific insights on such issues.

5.1.Discussion of barriers in the Chinese and international AEC context

The examination of discrepancies in actors' opinions helps capture some features of BIM implementation in the Chinese AEC industry. Regarding B2 and B14, both the Kruskal-Wallis and Mann-Whitney tests confirm the differences. The contractors have claimed high criticality of B2 for the lack of technical personnel while the consultant suggests less criticality of this barrier. It can be explained that the contractors have suffered more in the lack of technical BIM personnel while the consultants are better off. This finding provides evidence that the BIM talents tend to gather in the profession of consultants and also explains why BIM consultancy is important to project that adopts BIM. However, the skills shall diffuse further to contractors in the industry, as this deficiency can lead to the limited BIM use in the construction stage, which was common in other countries such as Finland, and is also phenomenal in China (Bråthen and Moum 2016, Herr and Fischer 2019). For B14, the designer indicates more extra work with BIM compared with the other three actors referring to the mean ranks of the Kruskal-Wallis test. As a few studies clarified the hybrid practices of BIM in projects (Davies et al. 2017, Harty and Whyte 2010, Gledson 2016), it can be inferred from the data that the designers are most influenced among the actors. The designers may need to prepare design visuals through both the conventional and BIM-based approaches while the contractors are apt to follow the conventional practice.

Referring to peer studies (Eadie et al 2013, Banawi 2017, Hatem et al. 2018), the barriers to BIM implementation in projects across different countries are compared. As Table 7 shows, all the countries suffer from insufficient technical capability, lack of motivation, and lack of experience or testified effect of BIM in projects. However, the Chinese AEC industry tends to experience more technical related issues than others and is more sensitive to the extra cost of BIM compared to the other countries but suffers less from the motivation issue. In contrast, BIM implementation in Iraq and Saudi Arabia was staggered by the lack of incentives from either the government or the industry but less influenced by the costs of BIM. While BIM implementation in the UK deemed to lack technical personnel and support in projects and organizations and also be affected by the motivation and cost issues. From the analysis, it can be drawn that the critical barriers for BIM implementation in project practices are similar among different countries but rank distinctively.

Ranking	Barriers			
	China	Iraq (Hatem et al. 2018)	Saudi Arabia (Banawi 2017)	The UK (Eadie et al. 2013)
1	*Interoperability issues of information and data*	*Lack of incentives to implement BIM from the government*	*Lack of incentives to implement BIM in the industry*	*Lack of related technical personnel in projects*
2	*Extra investment on BIM use*	*Lack of technical personnel*	*Interoperability issues among disciplines*	*Lack of technical support from the organizations*
3	*Lack of related technical personnel*	*Lack of knowledge for BIM effect*	*Legal issues on BIM*	*Lack of Client demand*
4	*Lack of knowledge and experience for BIM implementation*	*Resistance to change*	*Training and learning costs*	*Cultural resistance*
5	*Missing related regulations and rules*	*Lack of technical personnel and training*	*Lack of leadership and teamwork*	*Extra cost*

Table 7. A cross-country comparison of BIM implementation barriers in AEC projects

5.2. *Implications to projects and collaborative process in AEC*

Through the analysis of rankings, some implications are concluded for barrier tackling. One obvious strategy is to focus on the most critical. However, BIM implementation in projects may vary for different conditions. It is important for the project management team to understand BIM implementation issues and interpret the barriers based on a specific situation. Nonetheless, some barriers are due to the current status of AEC practice, which cannot be adequately addressed and shall be considered as risks in planning relevant BIM and project activities.

According to the findings of PCA, a few suggestions can be offered for BIM implementation in AEC projects. First, experienced personnel and knowledge management are required to safeguard BIM implementation. Second, technical conditions, including hardware, software, and technical specifications, are of substantial importance to enable BIM in the AEC process. Third, the implementation of BIM in AEC projects needs overcoming system inertia with organizational and motivational strategies. Lastly, measures shall be adopted to accommodate changes in different aspects of the project caused by the implementation of BIM. As the barriers are concluded from the international research community and their prevalence is confirmed by the cross-country comparison, these suggestions can be considered in the international context.

BIM has been widely acknowledged as a disruptive initiative to the AEC project. Due to the complex mechanism of its implementation regarding various contexts (Poirier et al. 2015, Davies et al. 2017), however, its contribution to improving building production is limited. The classified system inertia in project practices partially explains this issue. Accordingly, this study limits the examination of barriers to BIM implementation within the AEC project context and provides a specific insight to help adopt BIM in AEC.

As the implementation of BIM involves different contexts such as the project, the organization, and the industry (Poirier et al. 2015), the address of some barriers needs to explore solutions from a broader sense, for example, standardization on the industry level. Yet, the barriers help to define the responsibilities and tasks of different industry parties to further develop BIM practice. This can accelerate the diffusion of BIM in AEC to facilitate efficient building production in the industry.

6. Conclusions

Although BIM has been widely adopted in the AEC industry, its implementation in AEC projects still experiences various barriers. Firstly, a list of barriers to BIM implementation in AEC has been prepared through a review of related studies on BIM practice. The following survey has investigated the empirical opinions of practitioners to identify and prioritize the critical barriers in projects. In addition, the barriers have been categorized into the six groups according to the result of PCA. The further interpretation of the groups has identified *experience and capabilities, technical conditions, system inertia, extra input, change of work routines*, and *implementation risks* as latent factors of the principal components.

This study has several contributions to building production. The ranking of the barriers prioritizes the focus of efforts to implement BIM in the AEC project. The identification of the critical barriers provides a reference list for the industry practitioners to improve BIM implementation in projects and manage the relevant BIM deployment. Meanwhile, the study clarifies critical barriers to BIM implementation in AEC projects with empirical evidence. The further cross-country comparison of the critical barriers contributes to a better understanding of BIM implementation in AEC projects in the international community. However, how these barriers influence BIM implementation within the project context remains to be clarified, which can enhance the understanding of BIM implementation and develop BIM use to improve the collaborative process in AEC. The further classification of the principal components helps to achieve in-depth interpretations and provides strategic implications for BIM implementation in AEC projects.

There are also a few limitations that future research can address. This study investigates BIM implementation barriers from the project perspective, however, as it is a systematic effort for the industry to adopt BIM. Cooperation from a broader sense can develop further understanding of BIM in projects. Additionally, the implementation of BIM is influenced by local industry practice (Rogers et al. 2015, Miettinen and Paavola 2014). In this study, data have been collected from the Chinese construction context. Peer research can be conducted to compare the critical barriers from the international community, which helps to develop a more comprehensive understanding of the barriers and benefit BIM implementation in project practices. Future research can also explore enhancing strategies from different levels and contexts for overcoming the barriers to exploit BIM in AEC projects and the industry in further.

Data Availability Statement

Data of this study can be accessed from the corresponding author by request.

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