

Perceived benefits of and barriers to Building Information Modelling (BIM) implementation in construction: The case of Hong Kong

Abstract

BIM has experienced an increasing appeal in its adoption and implementation in the built environment worldwide in recent years. The current research study aims to identify and assess the perceived benefits of and barriers to BIM implementation in the Hong Kong construction industry. The study adopted a quantitative research design using a structured empirical questionnaire survey. Also, a comparative analysis of the perceptions of the respondents' groupings was conducted. The major barriers to BIM adoption are related to the inherent resistance to change by construction stakeholders, inadequate organizational support and structure to support BIM and lack of BIM standard in Hong Kong. Meanwhile, the key benefits include better cost estimation and control, efficient construction planning and management, and improvement in design and project quality. Practical and insightful recommendations were suggested for policymakers, local authorities, construction firms, and other key stakeholders to increase the uptake of BIM in construction projects as well as to aid them in the quest for full adoption of BIM in the built environment. The practical implications of the research findings were also presented and discussed.

Keywords: BIM implementation, benefits, barriers, construction stakeholders, Hong Kong

1. Introduction

The adoption and implementation of BIM are steadily increasing in the built environment [1]. One of the key reasons for BIM adoption is to maintain a proper balance among the project management triangle of scope (features & quality), cost and time [2,3]; which is one of the vital concerns of clients in the architecture, engineering, and construction (AEC) industry. Meanwhile, through the adoption and implementation of BIM in a building project, Wong et al. [4] believed that project stakeholders could maximize benefits regarding time, cost, and quality. However, it is not easy to achieve a right balance between these three factors for the construction projects, since so many strategies and solutions are needed to accomplish it, and innovation can be one of the solutions to strike a balance between these three factors.

Therefore, innovative technology is a salient topic nowadays, and Building Information Modeling (BIM) has become the cynosure of all eyes in the recent development of the construction industry [5]. Abanda et al. [6] described BIM as a “global digital technology” which had brought about a revamp of the structure and processes of the construction industry. The Hong Kong Construction Industry Council report [7] outlined the possibilities brought along by BIM to the construction project phases, which includes it is innovative and user-friendly features among others. The council report further emphasized the dynamism of the BIM innovation and its creation of a new paradigm shift in the construction industry. Smith and Tardif [8] also observed the contribution of BIM to improving communications among business partners at the conceptual stage, and the overall reduction in the cycle time as well as lifecycle cost of a project.

The Hong Kong Institute of Building Information Modeling [9] defined BIM as “the process of generating and managing building data during its life cycle [which typically] uses three-dimensional, real-time, dynamic building modeling software to increase productivity in building design and construction.” Also, the CIC [7] stated that BIM is not just a “three-dimensional drawing tool but a new tool to holistically manage information relating to construction projects from the preparatory stage to construction and operational stages.” CIC [7] further expresses BIM as a “new way of working, using new technology to facilitate project management and execution, better construction process control, cross-disciplinary collaboration, internal coordination, external communication, problem-solving, and risk management.” From the above definitions, it can be concluded that Building Information Modeling is not just a designing tool but a system to manage the project during its life cycle.

Despite some mileage reached in the adoption of BIM in the Hong Kong construction industry, Cao et al. [10] noted that its BIM development is still at the primitive stage and calls for future research to extend its findings into the barriers to its implementation. More so, Kori

and Kiviniemi [11] observed that some tangible benefits such as efficient construction delivery had been achieved in countries such as the USA, the UK, Australia, Singapore, Hong Kong, Netherlands among others during BIM adoption. However, the study did not explore the benefits in the stated countries in-depth. The first study on BIM adoption in Hong Kong was conducted thirteen years ago by Tse et al. [12] which revealed a very low adoption of BIM in Hong Kong due to lack of demand by clients. Since the study by Tse et al. [12], BIM adoption has increased in Hong Kong [13]. Also, the position of Hong Kong as Asia's financial hub and its influence on mainland China's construction industry, adds further significance to studies exploring innovative techniques' implementation in the Hong Kong construction industry.

Given the above perspective, the current study aims to identify and assess the benefits and barriers to BIM implementation in Hong Kong's built environment. The perspective of key stakeholders in Hong Kong's construction sectors such as the clients, contractors, BIM managers, etc. will be solicited in the data collection. The study will also attempt a comparative analysis of the perceptions of the respondents' groups on each identified factor (benefits & barriers). The findings of the study are expected to be useful for policymakers, government departments, construction organizations, and other key stakeholders in their quest to improve the current uptake of BIM in the various construction projects. The paper will also discuss the current process to develop a BIM standard for Hong Kong construction industry spearhead by the HK Construction Industry Council (CIC). Also, the practical implication of the research findings will be highlighted as well as recommendations on how the full implementation of BIM can be achieved in the construction sector.

The study is structured as follows. Section 1 introduces the study and the concept of BIM implementation. Section 2 review the adoption of BIM in Hong Kong and other developed economies, and Section 3 discusses the adopted research designs and the statistical tools employed in the study. Section 4 highlights the study's significant findings and discusses the perceptions of the diverse groups of survey participants. Section 5 encapsulates the practical implications of the study while section 6 concludes the study and provides useful recommendations to increase the uptake of BIM in Hong Kong.

2. Development and Implementation of BIM in Developed Regions

The concept of BIM was initiated by Charles M. Eastman in the 1970s and started growing from the 1980s in the European countries [14]. Moreover, in recent years, its implementation and adoption have become widespread in some developed countries such as the United States, the United Kingdom, Norway, Finland, Sweden, Denmark, Singapore and Hong Kong [15]. Bernstein et al. [16] reported that rapid growth in its global appeal and that a

broader set of construction companies have committed resources towards the adoption and implementation of BIM for their construction projects.

To this end, several governments, professional bodies have advocated the use of BIM in the AEC industry to facilitate cooperation and coordination among project stakeholders while ensuring project quality and affordable service [17]. The recent rise in its utilization in countries like the US, the UK, Australia had resulted in more in-depth research into BIM and other knowledge domain areas associated with the construction project processes such as safety management, project management, facility management amongst others [13,18]. Indeed, the development and affordability of ICT services had facilitated in its adoption in several countries, with variants such as mobile BIM and cloud BIM, representing a gradual shift from the desktop-based BIM processes [19]. However, the non-availability of BIM standards in some of these countries is still a disadvantage [20,21].

Meanwhile, the rate of adoption of BIM by various disciplines or professional bodies differs in these countries with more approval by architects, engineers and less by facility managers and quantity surveyors/estimators. Aibinu and Venkatesh [22] and Von Both et al. [23] observed that BIM in Australia and New Zealand focused mostly on 2D and 3D collaboration rather than integration of the whole BIM processes. In New Zealand, cost estimation is carried out based on 2D-drawings [23], while in Australia, Aibinu and Venkatesh [22] reported a low adoption of BIM by Australia's quantity surveyors. One of the factors attributed to the low adoption in Australia was the "lack of trust in the integrity of BIM" and "lack of demand by the clients" among other barriers.

Survey report and studies by Von Both et al. [23] in Germany, Gerrard et al. [24] in Australia, Arayici et al. [25] in the UK and Ku and Taiebat [26] in the US revealed several barriers to adoption of BIM in these countries. These barriers span from lack of BIM expertise, interoperability, resistance to change to the cost of company investment. However, Yan and Damian [27] found out that US firms in the AEC industry utilize more BIM for their projects than other AEC industries elsewhere in the world. In the UK, the government bill on BIM has made it mandatory for public projects from the year 2016 [22].

2.1 BIM Adoption and Implementation in Hong Kong

BIM implementation is still in the primary stage of development in the Hong Kong construction industry. Some companies are fast movers and have adopted this technology; while some are still observing the development and success of BIM [7]. A survey by Tse et al. [12] revealed the lack of demand by project stakeholders and clients as the significant factor hindering implementation of BIM in Hong Kong, and they concluded that the adoption

rate is very low in Hong Kong and that industry professionals still prefer the CAD software. Khodeir et al. [28] discussed the integration of BIM tools for the sustainable retrofitting of heritage buildings. Table 1 and Table 2 shows the barriers and benefits of BIM implementation used in this study based on the review of the extant literature.

In the public sector, the Airport Authority of Hong Kong, Hong Kong Housing Authority, and MTRC have started using BIM system for their projects. The Buildings Department has also launched the consultancy study concerning the feasibility of implementing an electronic system for the approval of drawing submissions [7]. If it is feasible, it will be a revolutionary change of design support in the whole industry [14]. In the private sector, some property developers in Hong Kong have already adopted BIM in their construction projects. Wong et al. [4] observed that these fast movers play a vital role in promoting BIM in Hong Kong because they not only establish their in-house BIM department, they also employ external BIM consultants to provide tailored-made BIM services.

Table 1 - Summary of literature on the barriers to BIM implementation

Barriers to BIM Implementation		Description	References
1.	High initial cost	The cost of procuring the BIM software and licenses, hardware and other associated cost related to BIM start-up usage	[4,22,29–34]
2.	Lack of expertise	The non-existent of competent project staff with previous experience on BIM implementation	[4,21,22,30,31,33,35–40]
3.	Insufficient interoperability of computer software	The loss of data and information in BIM models due to incompatibility among the BIM software and data schema	[6,29–31,33,34,38–41]
4.	Lack of training/course	The non-availability of training programs to facilitate the transfer of knowledge on BIM	[4,21,22,33,36,42]
5.	Cultural barrier (resistance to change)	The apathy of project stakeholders to change from the conventional (2D) ways of managing project and designs.	[31,33,38–40,42–44]
6.	Poor collaboration among participants	The low level of information sharing and coordination among project team members and in the industry.	[31,33,43,44]
7.	An organizational structure that does not support BIM	The non-existent BIM units or department within organizations to support its practice and deployment	[4,31,33,45,46]
8.	Lack of subcontractors who can use BIM technology	Non-existent of BIM-compliance subcontractors to facilitate its use in the industry	[31,34,45,46]
9.	Security risk	Issues arising because of the risk of losing intellectual property right of BIM models	[20,30,31,34,47]
10.	Lack of industry standards	Non-availability of BIM standards, codes and regulation to facilitate BIM implementation	[4,20,21,31,33,34,36,38]
11.	Difficulties in measuring the impacts of BIM	The arduous task involved to independently and exclusively assess the influence of BIM on project success.	[22,26,31,33,34]
12.	Shortage of BIM implementation data in the construction phase	The reduction and insufficient level of detail (LOD) in the BIM model used in the construction stage.	[4,31,48,49]

A communique of the Hong Kong Institute of Building Information Modelling (HKIBIM) and the Hong Kong Construction Industry Council (CIC) announced a new phase in the Hong Kong AEC industry in which automation in construction will be a leading trend in the coming

future of Hong Kong. The communique further attributed it to its endorsement and adoption of BIM as a new approach for facilitating project execution as well as management. Two groups including “the Working Group on Roadmap for BIM Strategic Implementation” and “the Task Group on Establishment of Industry Standards for BIM Implementation” were established by the Hong Kong Construction Industry Council (CIC) to work towards the strategic implementation of BIM in Hong Kong.

Moreover, to keep pace with the global trend in BIM, the Hong Kong SAR government has adopted BIM technology in public sector projects since the year 2006. For instance, the Hong Kong Housing Authority (HKHA) has introduced BIM in its development of public rental housing projects, and it has more than nineteen (19) projects which have already adopted BIM technology [7]. Another example is that the Highways Department has pioneered the application of BIM technology with the Tuen Mun Road Project and the Central-Wan Chai Bypass Project [7]. Meanwhile, based on the literature, key factors that influence the top management of firms to adopt BIM include its ability to enhance the competitiveness in the market and facilitate the business operation [8]. Utilizing the innovative tools can help the firms to maintain their competitiveness within the industry because BIM can improve project quality and minimize the risk as well as the cost of the construction projects [50]. Particularly in Hong Kong, the sustainability issues have become increasingly important [51,52], and building owners can make use of the data generated from BIM to manage their buildings for the optimization of energy consumption [53]. Therefore, it is not difficult to conclude that the use of BIM will be the rising trend in Hong Kong for both public and private sectors.

Although the benefits of BIM is quite evident in the construction industry, the adoption of BIM had not spread as fast as expected because of some barriers [3,54]. For instance, the adoption of technology confronts both technical and non-technical issues. Regarding the technical problems, they lack industry protocols and insufficient interoperability of computer software [3,55]. Regarding the non-technical issues, they include the cultural barrier (resistance to change), the change of practice workflow among others [56]. Therefore, to facilitate the BIM adoption in the Hong Kong (HK) construction industry, it is necessary to understand its benefits, barriers for implementing BIM from the views of different industrial practitioners [4].

Table 2 - Summary of literature on the benefits of BIM implementation

Benefits of BIM Implementation	Description	References
1. Improve project quality	BIM implementation improve project quality variables by facilitating the ease of assessment of construction materials and work process	[4,22,27,53,54,57–61]
2. A better understanding of design	The application of n-dimension (3D) could ease the ability of the project team to visualize and understand the design by using some essential functions like “rendering” and “walk-through.	[4,26,39,41,46,53,54,61]
3. Provide life cycle data	The information generated by the BIM system can be utilized in the whole life cycle of the project.	[26,41,53,61,62]
4. Scope Clarification	BIM is an appropriate tool to check clashes and reduce discrepancies among design drawings.	[4,22,54,63–65]
5. Speed up the design process	BIM ease the process of the project design earlier to ensure all stakeholders understand and approve the design earlier.	[4,26,39,41,46,53,62,66]
6. Reduce construction cost	BIM model can facilitate effective site planning to enhance efficiency as well as reduce the rework to save time and money	[4,22,27,41,46,54,57,60,61]
7. Better cost estimates and control	BIM can generate some data including the quantities of materials automatically which can increase the accuracy of the cost estimate and control compared to the manual measurement	[4,26,41,53,54,61,62]
8. Better construction planning and monitoring	BIM system can display a very clear full picture of the project and show the work sequences on a computer before the actual commencement of the project on-site	[4,22,46,53,54,57,61,67–69]
9. More efficient communications	The BIM system facilitates and eases the process of knowledge-sharing and coordination in the industry.	[4,22,41,48,54,61,69,70]
10. Reduce project duration	BIM facilitates the delivery of a construction project on or before schedule.	[4,27,53,54,57,60,69]
11. Improve safety performance	BIM system facilitates the integration of safety precaution and variables which can be simulated to improve safety on site.	[54,58,59,61,71,72]
12. Enhance organizational image	An organization policy or strategy toward integrating and implementing BIM in their work processes can improve their competitive advantage.	[4,53,55,73]

3. Research Methodology

This study evaluated the opinion of core stakeholders in the Hong Kong AEC industry about the barriers to BIM implementation in Hong Kong (HK) and the benefits derivable from BIM implementation. A quantitative research method was employed which involved soliciting the perceptions of key stakeholders in the Hong Kong construction industry via structured questionnaire surveys. The study was conducted via the lens of a post-positivism research paradigm [74], with a mix of deductive and inductive reasoning in arriving at the questionnaire items (benefits and barriers); while a deductive approach was employed for the rest of the study. The study employed a purposive sampling technique [3] in the selection of target survey respondents. Meanwhile, to avoid bias by the survey participants, as also emphasized by Trochim [75] who observed that research measurements are fallible and respondents inherently biased; the study utilizes triangulation technique to achieve some measures of objectivity through the use of multiple statistical measures [75]. The target

respondents for the current study are clients, developers, main contractors and BIM consultants operating within Hong Kong and with practical BIM experience in their construction projects. The identified factors (benefits and barriers) are deduced through the means of a desktop literature review of journal papers, HKIBIM-CIC BIM Conference Proceedings, and web pages. The questionnaire survey forms the basis for assessing the respondents' perceptions. The respondents were obliged to identify and rank the benefits and barriers to BIM implementation in Hong Kong on a five-point Likert-type scale, which was later used to measure their level of agreement.

The questionnaire also solicited background details regarding the survey participants' years of professional working experience in the construction industry and the number of BIM projects they have participated. Since all the survey participants were well-experienced professionals with requisite BIM knowledge in the construction sector, their opinions gathered were considered reliable and representative, and reflected the true perceptions of BIM practices in the construction industry. Other details include the type of organization they are employed and their position within the organization. A total of 62 questionnaire surveys was distributed to the target respondents who engage in BIM projects via a purposive sampling technique. The questionnaire survey was returned with 44 completed and valid questionnaires after a month representing an effective response rate of 71%. The sample size of this study (44 responses) was considered satisfactory and adequate for various type of statistical analysis conducted when compared with other studies which have utilized similar purposive sampling techniques, e.g. Ameyam and Chan [76] with 40 responses; Osei-Kyei and Chan [77] with 42 responses; Chan et al. [78] with 45 responses. So, the chosen sample was regarded as reliable and substantially representative of the survey population.

3.1 *Methods of Data Analysis*

Data analysis is a process of deriving significant facts, details or seek an interpretation of raw statistical data in its vague form [79]. This study employs five statistical analysis tools to analyze the collected data from the questionnaire surveys and to compare the views between groups of respondents. These include Cronbach's alpha reliability test, mean score ranking method, Kendall's concordance analysis, Spearman's rank correlation test, and Mann-Whitney U test.

3.2 *Reliability testing*

Cronbach's alpha reliability test is mainly used to verify the internal consistency or reliability of the construct of the questionnaire item under the adopted Likert scale of measurement

[79–81]. The range of the Cronbach's alpha coefficient is from 0 to 1. The larger the α -value, the higher the reliability of the generated result or scale will be. If the α -value ≥ 0.7 , the measurement scale is reliable [81–83]. Table 3 depicts the alpha values for this study. These alpha values reveal the questionnaire item is closely related, reliable and significant at $< 5\%$; hence further analysis was conducted on the set of data.

Table 3: Reliability analysis for the components of this study.

Questionnaire components	Alpha value
Barriers to BIM implementation in Hong Kong	0.717
Benefits of BIM implementation in Hong Kong	0.771

4. Analysis and Discussion of Survey Findings

This section presents the data collected during the study's questionnaire surveys and discusses the findings of the statistical tools utilized in the study. The characteristics of the respondents' demographics were solicited in section A of the study questionnaire survey and as presented in Table 4. The set of study participants are from diverse organization setup: the majority are from the contractors constituting 41 percent, followed by the client organizations (32%) and the BIM consultants' group (27%). The diversity in the respondents' groups allows for the capturing of the differing viewpoints of the survey participants. Moreover, on the average, the respondents have more than ten years working experience in the construction. However, only 9 percent of the survey participants have less than five years of working experience. The data analysis establishes the fact that the respondents have not just theoretical knowledge of the workings of the AEC industry but have over the years bring such knowledge into practice.

The target respondents for the questionnaire survey were mainly those with at least a year experience in BIM-enabled projects. The majority of them (66%) are involved in more than 5 BIM-enabled projects, 27 percent have direct hands-on experience in 3 – 4 BIM projects, and just 7 percent have managed 1 – 2 BIM projects. In summary, the relative experience and competence of the survey participants is adequate and can be relied upon as a representative of the actual population and give credibility to the survey data collected.

Table 4: Demographics of survey respondents.

Respondent demographics		Percentage (size)
Type of organization		
	Clients	32% (14)
	BIM Consultant	27% (12)
	Contractor	41% (18)
Years of working experience in the AEC industry		
	0 - 5 years	9% (4)
	6 - 10 years	36% (16)
	11 - 15 years	32% (14)
	More than 15 years	23% (10)
Experience with BIM-enabled construction projects		
	1 - 2 projects	7% (3)
	3 - 4 projects	27% (12)
	5 projects or more	66% (29)

4.1 Barriers to BIM Implementation in Hong Kong

4.1.1 Ranking Results

The survey result of the ranking of the barriers to BIM implementation is as presented in Table 5. For the 12 identified barriers, the mean (M) values range from the lowest mean score of M= 2.77 “Poor collaboration among participants” to the highest mean value of M=4.39 “cultural barrier (resistance to change).” The three most significant barriers are related to senior management commitment and technology issues; and these include-cultural barrier (resistance to change) (M=4.39) [42]; an organizational structure that does not support BIM (M=4.27) [33], and insufficient interoperability of computer software (M=4.07) [6,30,38].

Most of the respondents aligned to the fact that the slow adoption of this innovative approach [3] has affected the incorporation of construction management techniques which increases the current workload of workers. Also, most of the respondents perceived that the development of BIM without changing some aspects of the organizational structures and strategies [4,33] might not motivate the staff to learn and apply this technology for their work. Furthermore, the survey participants believed that it might increase the time and cost of information exchange and communications among project stakeholders if there is an insufficient interoperable environment. Overall speaking, the level of consensus between these three groups is very high because the three most significant barriers are both included in the top 3 items in these three groups.

Table 5: Barriers to BIM implementation in Hong Kong

Barriers to BIM Implementation	All Respondents		Client Group		Consultant Group		Contractor Group	
	Mean	Rank	Mean	Rank	Mean	Rank	Mean	Rank
Cultural barrier (resistance to change)	4.39	1	4.29	2	4.33	1	4.50	2
Organizational structure that does not support BIM	4.27	2	4.00	3	4.17	2	4.56	1
Insufficient interoperability of computer software	4.07	3	4.43	1	3.67	3	4.06	3
Lack of industry standards	3.61	4	3.50	4	3.42	4	3.83	4
Difficulties in measuring impacts of BIM	3.48	5	3.50	4	3.42	4	3.50	5
Shortage of BIM implementation data in construction phase	3.39	6	3.36	8	3.33	6	3.44	6
Security risk	3.30	7	3.07	10	3.33	6	3.44	6
Lack of expertise	3.23	8	3.50	4	2.92	10	3.22	9
Lack of training / course	3.20	9	3.21	9	2.83	11	3.44	6
High initial cost	3.18	10	3.43	7	3.08	8	3.06	11
Lack of subcontractors who can use BIM technology	2.98	11	2.64	12	3.08	8	3.17	10
Poor collaboration among participants	2.77	12	2.93	11	2.58	12	2.78	12

4.1.2 Ranking Agreement within Each Respondent Group

The Kendall's coefficient of concordance (W) was employed to measure the agreement of different respondents on their rankings regarding barriers to BIM implementation based on mean values within a group [3,17]. The Kendall's coefficient of concordance measures the agreement of the various respondents based on mean values within a group [84]. The range of the value of Kendall's coefficient of concordance (W) is from 0 to 1. The higher the value of W , the higher the level of consensus among the survey respondents within the group [85,86]. If the number of variables to be ranked is larger than 7, chi-square analysis should be applied instead [87].

The null hypothesis (H_a) states that *"the survey respondents' sets of rankings are unrelated or independent to each other within a study group."* The rule is that if the calculated chi-square value equals or is greater than the critical value from the table showing a particular level of significance and value of degrees of freedom, H_a will be rejected. In other words, there is a significant degree of agreement on the rankings of the items among the survey respondents within the group.

The value of W is as follows:

$$W = \frac{\sum_{i=1}^n (\bar{R}_i - \bar{R})^2}{n(n^2 - 1)/12}$$

Where n = Number of items ranked; R_i = Average of the ranks assigned to the i th item;

R = Average of the ranks assigned to all items

The calculated chi-square value with (N-1) degrees of freedom is as follows: (Siegel & Castellan, 1988)

$$\psi^2 = k(N - 1)W$$

Where k = number of respondents ranking the items; N = number of items ranked

The value of W of all respondents, client group, consultant group, and contractor group is 0.289, 0.281, 0.329 and 0.350, respectively. The levels of significance of all groups are 0.000 which are less than the allowable level of significance (5%), so the null hypothesis should be rejected. The Chi-square test was carried out because there were 12 items involved (more than seven variables). The calculated Chi-square values of the client group, consultant group, and contractor group are 43.247, 43.406 and 69.318 which all of them are higher than the critical value of 19.675 (df=11, p<0.005) so the null hypothesis should be rejected as well. From the results of the analysis, there is adequate evidence to conclude that the respondent's sets of rankings regarding the barriers to BIM implementation are dependent on each other with a significant degree of consensus within each group.

4.1.3 Ranking Agreement between the Respondent Groups

The Spearman's rank correlation coefficient was adopted to test the strength of a relationship amongst two sets of rankings [88]. The range of the Spearman's rank correlation coefficient (r_s) is from -1 to +1. The higher the positive/negative value of r_s , the stronger positive/negative linear correlation [3,80]. If $r_s = 0$, there is no linear correlation at all [80,86]. If r_s is statistically significant at a predetermined significance level (e.g., 5%), the null hypothesis (H_0) which states that "no significant correlation between the two groups on rankings" can be rejected. In other words, there is no significant disagreement between the two groups on the ranking exercise. The r_s is calculated by the following equation:

$$r_s = 1 - \frac{6 \sum d^2}{N(N^2 - 1)}$$

Where d = difference in rank of the two groups for the same item;

N = total number of responses regarding that item.

The r_s for the barriers to BIM implementation in Hong Kong (1) between the client group and consultant group, (2) between client group and contractor group, and (3) between consultant group and contractor group are 0.678, 0.748 and 0.930. More so, the calculated significance levels are 0.015, 0.005 and 0.000, respectively which are lower than the allowable level of

significance (5%). Therefore, the null hypothesis (H_0) should be rejected. In other words, there is a significant correlation between the client group and consultant group, between client group and contractor group, and between consultant group and contractor group on the rankings of the barriers to BIM implementation.

4.1.4 Statistical Differences among the Respondents' Groups

The Mann-Whitney U test was adopted to determine any divergences in the median values of the same item among two selected respondent groups [3,80]. The Mann-Whitney U test is used to determine any statistically significant differences or divergences in the median values of the same item between any two selected respondent groups [89]. The rule is that if the calculated p-value is less than the allowable significance level (e.g., 1%), the null hypothesis (H_0) which states that "*there are no significant differences in the median values of the same item between the two survey groups*" can be rejected [85,86].

The first pair is (1) the client group versus the consultant group, the second pair is the client group versus the contractor group, and the third pair is the *consultant group versus contractor group*. For the first pair (client group versus consultant group), only one discriminating item is identified which is item 3 – "insufficient interoperability of computer software" [30,38]. Interoperability is the ability to exchange information between different types of computer software to facilitate automation and presentation [13,42]. The description above of interoperability best describes "technological interoperability" which refers to the exchange of information between different software. With good interoperability of BIM, the client can make use of data to facilitate the schedule in the construction stage and extract the data from the BIM model to other software for the future use such as for the facility management phase and periodic maintenance. On the other hand, it enables BIM consultants to provide efficient BIM services and enable them in understanding related technical issues which they can tackle. Based on the analysis of the data, the BIM consultants identified the factor to be of less significant as a barrier to BIM adoption in Hong Kong.

Therefore, it is reasonable that the clients emphasize that insufficient interoperability of computer software may obstruct the implementation of BIM in Hong Kong. The details of the analysis are shown in Table 6. For the (2) second pair (client group versus contractor group) and (3) the third pair (consultant group versus contractor group), all the calculated p-values are larger than 0.01; the null hypothesis (H_0) should not be rejected. Therefore, there is no discriminating item identified in the second pair and third pair.

Table 6: Results of Mann-Whitney U test for the barriers to BIM implementation (client group versus consultant group)

Item	Barriers to BIM Implementation	Mean Rank		Mann-Whitney U	Z-value	p-value	Conclusion to H ₀
		Client Group	Consultant Group				
1	High initial cost	15.04	11.71	62.500	-1.166	.243	Accept
2	Lack of expertise	15.54	11.13	55.500	-1.552	.121	Accept
3	Insufficient interoperability of computer software	17.21	9.17	32.000	-3.084	.002	Reject
4	Lack of training / course	14.64	12.17	68.000	-.862	.389	Accept
5	Cultural barrier (resistance to change)	13.21	13.83	80.000	-.257	.797	Accept
6	Poor collaboration among participants	14.79	12.00	66.000	-.983	.325	Accept
7	Organizational structure that does not support BIM	12.79	14.33	74.000	-.547	.584	Accept
8	Lack of subcontractors who can use BIM technology	11.61	15.71	57.500	-1.530	.126	Accept
9	Security risk	12.64	14.50	72.000	-.671	.502	Accept
10	Lack of industry standards	13.54	13.46	83.500	-.027	.978	Accept
11	Difficulties in measuring impacts of BIM	14.29	12.58	73.000	-.646	.518	Accept
12	Shortage of BIM implementation data in construction phase	13.29	13.75	81.000	-.164	.869	Accept

4.2 Benefits of BIM Implementation in Hong Kong

4.2.1 Ranking Results

The survey result of the ranking of the benefits of BIM implementation is as presented in Table 7. For the 12 benefits identified, the mean (M) values range from the lowest mean score of M= 2.70 “Scope clarification” to the highest mean value of M=4.45 “Better cost estimates and control.” The three most significant benefits of BIM implementation include: better cost estimates and control (M=4.45) [41,54,61]; better understanding of design (M=4.39) [46,53], and reduce construction cost (M=4.09) [22,60].

Most respondents agreed that the database and the auto-quantification function of BIM could enhance their accuracies and efficiencies for the cost valuation and audit. Furthermore, the majority of the survey participants opined that the application of n-dimension could make the participants easier to visualize and understand the design by using some essential functions like “rendering” and “walk-through” [13]. Moreover, they reckoned that the construction cost could be minimized because the BIM model can demonstrate the whole project procedures and address the potential risks before the commencement of the construction phase.

For the contractor group, these three most significant benefits are included in its top 3 items. However, the client and consultant groups considered that another item “better construction planning and monitoring” [67,68] is also essential, hence, the two respondents’ groups considered in their top-three most significant factors. The findings are consistent with the fact that cost and time are always regarded as the prime concerns to the clients, and the respondents perceive that BIM model facilitates effective site planning as well as reduce the rework to save time and money. Therefore, the rankings of item 6 and item 8 are closely ranked in the client group and consultant group.

Table 7: Benefits of BIM implementation

Benefits of BIM Implementation	All Respondents		Client Group		Consultant Group		Contractor Group	
	Mean	Rank	Mean	Rank	Mean	Rank	Mean	Rank
Better cost estimates and control	4.45	1	4.50	1	4.33	1	4.50	2
Better understanding of design	4.39	2	4.36	2	4.17	2	4.56	1
Reduce construction cost	4.09	3	3.93	5	3.92	4	4.33	3
Better construction planning and monitoring	4.07	4	4.14	3	4.17	2	3.94	5
Improve project quality	3.91	5	4.07	4	3.42	5	4.11	4
Provide life cycle data	3.39	6	3.29	9	3.17	6	3.61	6
Improve safety performance	3.36	7	3.43	7	3.08	8	3.50	8
Speed up the design process	3.27	8	3.36	8	2.75	11	3.56	7
More efficient communications	3.23	9	3.50	6	3.08	8	3.11	10
Reduce project duration	3.23	9	3.29	9	3.17	6	3.22	9
Enhance organizational image	2.98	11	2.86	11	3.00	10	3.06	11
Scope clarification	2.70	12	2.79	12	2.67	12	2.67	12

4.2.2 Ranking Agreement within Each Respondent Group

The Kendall's coefficient of concordance (W) was applied to measure the agreement of different respondents on their rankings regarding the benefits of BIM implementation based on mean values within a group. The value of W of all respondents, client group, consultant group, and contractor group are 0.382, 0.337, 0.422 and 0.486 respectively. The levels of significance of all groups are 0.000 which are less than the allowable level of significance (5%), so the null hypothesis (H_a) should be rejected. The Chi-square test was also employed because there are 12 items involved (more than seven variables). The calculated Chi-square values of the client group, consultant group, and contractor group are 51.869, 55.690 and 96.275 which all of them are higher than the critical value of 19.675 so the null hypothesis should be rejected as well.

From the results of these two tests, there is adequate evidence to conclude that the respondent's sets of rankings regarding the benefits of BIM implementation are dependent on each other with a significant degree of consensus within each group. This concordance

test enables the data and opinions collected from the questionnaire survey to be valid and consistent for further statistical analysis.

4.2.3 Ranking Agreement between the Respondent Groups

The Spearman's rank correlation coefficient was adopted to test the strength of a relationship amongst two sets of rankings [17]. The Spearman's rank correlation coefficient (r_s) of rankings of the benefits of BIM implementation (1) between the client group and consultant group, (2) between client group and contractor group, and (3) between consultant group and contractor group are 0.860, 0.867 and 0.818. The calculated significance levels are 0.000, 0.000 and 0.001 respectively which are lower than the allowable level of significance (5%). Therefore, the null hypothesis (H_0) should be rejected. In other words, there is a significant correlation between the client group and consultant group, between client group and contractor group, and between consultant group and contractor group, on the rankings of the benefits of BIM implementation.

4.2.4 Statistical Differences among the Respondents' Groups

The first groups of respondents for comparative analysis are (1) the client group versus the consultant group, the second pair is (2) the client group versus the contractor group, and (3) the third pair is the consultant group versus contractor group. The rule is that if the calculated p-value is less than the allowable significance level (1%), the null hypothesis (H_0) which states that *"there are no significant differences in the median values of the same item between any two survey groups"* can be rejected [80].

For the first pair (client group versus consultant group) and the second pair (client group versus contractor group), all the calculated p-values are larger than 0.01; the null hypothesis should not be rejected. Therefore, there is no discriminating item identified in the first pair and second pair. For the third pair in Table 8 (consultant group versus contractor group), there is only one discriminating item identified which is item 5 – "speed up the design process" [26,53]. The design process is a very engaging phase of project development as it involves several stakeholders [90–92] who contributes their ideas to the development of the building model. For the BIM consultants, they tend to spend more time collaborating with the various stakeholders [93] to produce the buildings' building model. This process may increase the workload required for the design stage. Therefore, the consultants believed using BIM early in the project will help speed up the design process. On the other hand, the contractors are usually not involved in the design stage.

Table 8: Results of Mann-Whitney U test for the benefits of BIM (consultant group versus contractor group)

Item	Benefits of BIM Implementation	Mean Rank		Mann-Whitney U	Z-value	p-value	Conclusion to H ₀
		Consultant Group	Contractor Group				
1	Improve project quality	12.50	17.50	72.000	-1.590	.112	Accept
2	Better understanding of design	13.08	17.11	79.000	-1.377	.169	Accept
3	Provide life cycle data	13.33	16.94	82.000	-1.191	.234	Accept
4	Scope clarification	15.33	15.61	106.000	-.091	.927	Accept
5	Speed up the design process	10.63	18.75	49.500	-2.683	.007	Reject
6	Reduce construction cost	12.50	17.50	72.000	-1.788	.074	Accept
7	Better cost estimates and control	14.00	16.50	90.000	-.887	.375	Accept
8	Better construction planning and monitoring	17.17	14.39	88.000	-1.050	.294	Accept
9	More efficient communications	15.38	15.58	106.500	-.068	.946	Accept
10	Reduce project duration	16.08	15.11	101.000	-.326	.744	Accept
11	Improve safety performance	13.42	16.89	83.000	-1.190	.234	Accept
12	Enhance organizational image	15.42	15.56	107.000	-.047	.963	Accept

5. Practical Implications of Research Findings

The study examined the barriers and benefits of BIM implementation in the Hong Kong construction industry. The survey participants identified cultural barriers (resistant to change) [42], an organizational structure that does not support BIM [31], and insufficient interoperability of BIM software [34] as the most significant barriers to BIM implementation in Hong Kong. A closer look at these barriers reveals that it falls within the purview of project stakeholders, firms, and BIM technology. Stakeholders resistant to change from the industry's traditional 2D approach to 3D is still prevalent [3], and a change in perspective is needed to improve the uptake of BIM in construction projects in Hong Kong both by the private developers and the Hong Kong Housing Authority. Also, for constructions firms and property developers in Hong Kong, it is recommended for them to set up specific BIM department to handle or facilitate BIM implementation in their construction projects.

Moreover, construction firms' management is encouraged to address the deficiency in their personnels' skill sets by sponsoring them to relevant BIM seminar, workshops or conferences to enhance their BIM capacity and development. Also, the establishment of in-house BIM department in firms and developers' organization will reduce among other things the cost of outsourcing BIM services to freelance specialists and increase the technical competence of their staff. Interoperability or incompatibility of major BIM software is still a significant barrier in the global AEC industry. Hence, the study encourages partnerships among these software vendors and construction firms. It is expected that the collaboration will help ensure a higher level of compatibility and reduce the incidence of loss of data during data migration between software. Also, full migration to cloud BIM by firms and developers

alike could minimize the severity of this factor. The issue of interoperability is more hyped in this study by the client group and the consultant's group of respondents.

Moreover, factors such as- better cost estimates and control [61], a better understanding of design [53], and reduction in construction cost [27] are the most significant benefits of implementation of BIM in Hong Kong. The three most beneficial factors can be regrouped into cost-control related benefits and design benefits. Proper implementation of BIM in Hong Kong will ensure project cost are better estimated as well as minimizes the incidence of under-budget or over-budget; this will help eradicate the prevalence of cost overrun in construction projects. Previous research studies [3,94] have revealed cost savings as one of the key benefits gained in deploying BIM in a project. However, Fazli [94] argued further that the gains made by the construction firms are consumed by the time, cost, and other resources needed to train staff needed to use BIM effectively. The issue above according to Fazli [94] had deterred some firms and made them less interested in adopting BIM. Olawumi and Chan [95] recommended the establishment of a startup funding scheme for construction firms, especially for smaller companies. Hence, clients who demand the use of BIM in their projects are most time in an advantageous position to benefits more from projects' cost savings that the construction firms involved; in the form of less cost to complete such projects which will free up funds for the client for other projects.

It is observed from the results of the Mann-Whitney U test for the barriers and benefits to BIM implementation that only one item each among the pairs showed a statistically significant difference. The findings are consistent with the nature and structure of the Hong Kong construction industry in which a significant portion of the market share is controlled by developers who sometimes functions as a client, consultant or contractor depending on the level of their involvement in the project. More so, as argued by Olatunji et al. [79] that a situation whereby construction stakeholders have practiced their profession in more than one of these organization setups, it might influence their perceptions and leads to little or no difference in their opinions on a set of observed items.

Some BIM software has advanced to the 5D-BIM development phase [19], hence ensuring proper accounting and estimate of all project activities and processes from inception to completion. Furthermore, BIM software facilitates changes in one view to be observed in other views, and its intelligence at the object level has facilitated a better understanding of project designs and drawings. This benefit is of great value to project stakeholders as it allows them to have a grasp of the design and allows the clients to appreciate the works of the project team in facilitating its use for their projects. It also, facilitate the ease of producing 2D drawings for reference use on the project site, walk-through visualizations and, the use of

augmented reality to detect errors on site and clash detection among others. Roberts et al. [96] highlighted issues such as property rights (such as virtual property [VP] & intellectual property [IP]) as a critical barrier to collaborative working among stakeholders as each construction organization works toward protecting their designs or company's data. Although the issue was not part of the barrier factors, it can be classified under the factor – “poor collaboration among participants” as a causative factor. Essentially, several other factors can be deduced as causal factors influencing some of the factors (barriers and benefits) identified in this paper.

A Delphi survey conducted by Olawumi et al. [3] in eight countries which included the United States, the United Kingdom, Australia among others also reinforced the barrier factor “cultural barrier (resistance to change) as a key barrier to the implementation of BIM in the construction as the factor was ranked as first among other set of factors. More so, in the survey above [3], the lack of commitment by construction firms' top management also featured as a top-five ranked factor which is closely similar to barrier factor such as “organizational structure that does not support BIM” in this study. More so, a study by Olawumi and Chan [17] highlighted the benefit factors- “better construction planning and monitoring,” “better understanding of design,” and “improve project quality” as key benefits derivable by the construction industry when BIM is implemented. Li [97] affirmed that the use of BIM could help quantity surveyors ensure better estimates, reduce overall project schedule, facilitate project coordination and collaboration, reduce lifecycle project cost, and avoid design errors and risks.

The Hong Kong Construction Industry Council (CIC) and the Hong Kong Institute of Building Information Modelling (HKBIM) recently commissioned a team to develop a BIM standard for Hong Kong, which is a good step towards enhancing the implementation and development of BIM in Hong Kong. The BIM standard is expected to establish a process for adopting BIM in building, civil and other infrastructural projects. Parts of the commissioned team's objective is to enable a client to specify, manage and assess BIM deliverables by architects, engineers, surveyors, and contractors. It will also ensure that project deliverables produced using the BIM processes achieve an agreed level of quality. The principle for its development is the planning, implementation, management, and checking of the use of BIM on a project and to ensure the delivery of the BIM process meet the established targets.

6. Conclusions

The study assessed issues affecting the implementation of BIM in Hong Kong and carried out a review of BIM implementation in the leading economies of the world such as the US and the UK. Moreover, several factors were identified as benefits and barriers to BIM

implementation in Hong Kong by respondents from the consultant, contracting and clients' organization in Hong Kong. More so, a comparative analysis of the perceptions of the three main respondents' groups was analyzed, and the discussion of the findings presented.

The five most significant barriers are- cultural barriers (resistance to change), an organizational structure that does not support BIM, insufficient interoperability of computer software, lack of industry standards and difficulties in measuring impacts of BIM. Moreover, the five most significant benefits are better cost estimates and control, a better understanding of design, reduce construction cost, better construction planning and monitoring and improvement of project quality. The BIM consultants and contractors underscore the importance of BIM to speed up the design process. Also, there was a relatively good level of consensus among the respondents' groups on the identified barriers and benefits. More so, as highlighted in section 5, some studies corroborated the findings of this study as prevalent in other climes.

In most developed economies, the role of the government in the advocacy and implementation of innovative technology is highly integral to BIM's successful adoption in the AEC industry. Therefore, the study recommends for the local authorities to consider establishing a start-up funding for the construction companies to enable them to adopt BIM in their firms and projects. Especially for small-sized and median-sized firms, the financial support from the government can form a strong incentive for them to launch BIM in construction projects. Furthermore, some relevant bodies like HKIBIM and CIC should strengthen professional activities such as BIM workshops, seminars, technical forums and induction of BIM experts to improve their members BIM skills and knowledge. Moreover, these professional bodies can coordinate with other technical professionals to develop some useful and helpful software to facilitate the data interoperability between BIM and other software.

Section 5 discussed the practical implications of the research findings to knowledge and the industry. The findings revealed that most of the barriers to BIM implementation relate to the project stakeholders and use of technology. Hence, a dynamic change in attitude, working, and policies of construction firms and the project team will reduce the effect of some of these barriers on BIM implementation. More so, the benefits that the key construction project stakeholders can gain from BIM adoption is mostly related to the efficient delivery of project objectives regarding cost, time, and quality. The highlighted benefits can be enhanced when there is the current collaborative environment in the construction industry is improved as well as addressing the issues of interoperability.

More so, the Hong Kong CIC and HKBIM are coordinating steps to develop a BIM standing for the Hong Kong construction industry which ameliorates the effect of the lack of uniform BIM standard in the industry. Implementing innovative technologies in the construction industry is a lengthy process. Therefore, the construction firms, government departments, and key stakeholders should lead the process of ensuring BIM uptake and implementation takes a continuous increase in the Hong Kong construction industry. For future research studies, case study investigations can be explored to supplement the contents and findings of the current research study including the benefits, barriers, and drivers for BIM implementation in Hong Kong.

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References

- [1] H. Salleh, W.P. Fung, Building information modeling application: focus-group discussion, *Journal of the Croatian Association of Civil Engineers*. 66 (2014) 705–714. doi:10.14256/JCE.1007.2014.
- [2] T.O. Olawumi, D.W.M. Chan, Beneficial Factors of Integrating Building Information Modelling (BIM) and Sustainability Practices in Construction Projects, in: *Hong Kong International Conference on Engineering and Applied Science (HKICEAS), Higher Education Forum, Hong Kong, 2018*: pp. 141–152.
- [3] T.O. Olawumi, D.W.M. Chan, J.K.W. Wong, A.P.C. Chan, Barriers to the Integration of BIM and Sustainability Practices in Construction Projects: A Delphi Survey of International Experts, *Journal of Building Engineering*. 20 (2018) 60–71. doi:10.1016/j.jobbe.2018.06.017.
- [4] A.K.D. Wong, F.K.W. Wong, A. Nadeem, Attributes of Building Information Modelling and its Development in Hong Kong, *HKIE Transactions*. 16 (2009) 1–8.
- [5] R. Takim, M. Harris, A.H. Nawawi, Building Information Modeling(BIM): A new paradigm for quality of life within Architectural, Engineering, and Construction (AEC) industry, *Procedia - Social and Behavioral Sciences*. 101 (2013) 23–32.
- [6] F.H. Abanda, C. Vidalakis, A.H. Oti, J.H.M. Tah, A critical analysis of Building Information Modelling systems used in construction projects, *Advances in Engineering Software*. 90 (2015) 183–201. doi:10.1016/j.advengsoft.2015.08.009.
- [7] “The Hong Kong Construction Industry Council” CIC, Final Draft Report of the Roadmap for BIM Strategic Implementation in Hong Kong’s Construction Industry, 2013.
- [8] D.K. Smith, M. Tardif, Building Information Modeling: A Strategic Implementation Guide for Architects, Engineers, Constructors, and Real Estate Asset Managers, John Wiley & Sons, Inc, Canada, 2009.
- [9] “The Hong Kong Institute of Building Information Modeling” HKIBIM, Definitions, 2009. http://www.hkibim.org/?page_id=31.

- [10] D. Cao, H. Li, G. Wang, X. Luo, X. Yang, D. Tan, Dynamics of Project-Based Collaborative Networks for BIM Implementation: Analysis Based on Stochastic Actor-Oriented Models, *Journal of Management in Engineering*. 33 (2015) 1–12. doi:10.1061/(ASCE)ME.1943-5479.0000503.
- [11] S.A. Kori, A. Kiviniemi, Toward Adoption of BIM in the Nigeria AEC Industry: Context Framing, Data Collecting and Paradigm for Interpretation, in: 9th BIM Academic Symposium & Job Task Analysis Review, NIBS-Washington DC, USA, 2015: pp. 1–8.
- [12] T.K. Tse, K.A. Wong, K.F. Wong, The utilisation of building information models in Nd modelling: A study of data interfacing and adoption barriers, *Journal of Information Technology in Construction*. 10 (2005) 85–110.
- [13] T.O. Olawumi, D.W.M. Chan, J.K.W. Wong, Evolution in the Intellectual Structure of BIM Research: A Bibliometric Analysis, *Journal of Civil Engineering and Management*. 23 (2017) 1060–1081. doi:10.3846/13923730.2017.1374301.
- [14] A.K.D. Wong, F.K.W. Wong, A. Nadeem, Government roles in implementing building information modelling systems: Comparison between Hong Kong and the United States, *Construction Innovation: Information, Process, Management*. 11 (2011) 61–76. doi:10.1108/147141711111104637.
- [15] L. Khemlani, Around the World with BIM, 2012. <http://www.aecbytes.com/feature/2012/Global-BIM.html>.
- [16] H.M. Bernstein, S. Jones, M. Russo, The business value of BIM in North America: multi-year trend analysis and user rating (2007–2012), 2012.
- [17] T.O. Olawumi, D.W.M. Chan, Identifying and prioritizing the benefits of integrating BIM and sustainability practices in construction projects: A Delphi survey of international experts, *Sustainable Cities and Society*. 40 (2018) 16–27. doi:10.1016/j.scs.2018.03.033.
- [18] J.K.W. Wong, J. Zhou, Enhancing environmental sustainability over building life cycles through green BIM: A review, *Automation in Construction*. 57 (2015) 156–165. doi:10.1016/j.autcon.2015.06.003.
- [19] T.O. Olawumi, D.W.M. Chan, Development of a Benchmarking Model for BIM Implementation in Developing Countries, *Benchmarking: An International Journal*. (2019). doi:10.1108/BIJ-05-2018-0138 (*in press*).
- [20] A. Redmond, A. Hore, M. Alshawi, R. West, Exploring how information exchanges can be enhanced through Cloud BIM, *Automation in Construction*. 24 (2012) 175–183. doi:10.1016/j.autcon.2012.02.003.
- [21] C.T.W. Chan, Barriers of Implementing BIM in Construction Industry from the Designers' Perspective: A Hong Kong Experience, *Journal of System and Management Sciences*. 4 (2014) 24–40.
- [22] A. Aibinu, S. Venkatesh, Status of BIM Adoption and the BIM Experience of Cost Consultants in Australia, *Journal of Professional Issues in Engineering Education Practice*. 140 (2014) 1–10. doi:10.1061/(ASCE)EI.1943-5541.0000193.
- [23] P. Von Both, V. Koch, A. Kindsvater, Potential and barriers for implementing BIM in the German AEC market, in: 14th International Conference on Computing in Civil and Building Engineering, Moscow, Russia, 2012.
- [24] A. Gerrard, J. Zuo, G. Zillante, M. Skitmore, Building information modelling in the Australian Architecture Engineering and Construction Industry: Handbook of research on building information modelling and construction informatics: concepts and

technologies, Information Science Reference, Hershey, PA, 2010.

- [25] Y. Arayici, F. Khorowshahi, A. Marshall-Ponting, S. Mihindu, Towards implementation of Building Information Modelling in the construction industry, in: *Construction in the 21st Century Collaboration and Integration in Engineering, Management and Technology (CITC-V)*, Miami, Florida, USA, 2009.
- [26] K. Ku, M. Taiebat, BIM Experiences and Expectations: The Constructors' Perspective, *International Journal of Construction Education and Research*. 7 (2011) 175–197. doi:10.1080/15578771.2010.544155.
- [27] H. Yan, P. Damian, Benefits and barriers of building information modelling, in: *Proceedings of the 12th International Conference on Computing in Civil and Building Engineering*, Tsinghua University, Beijing, China, 2008.
- [28] L.M. Khodeir, D. Aly, S. Tarek, Integrating HBIM (Heritage Building Information Modeling) Tools in the Application of Sustainable Retrofitting of Heritage Buildings in Egypt, *Procedia Environmental Sciences*. 34 (2016) 258–270. doi:10.1016/j.proenv.2016.04.024.
- [29] A. Nanajkar, Z. Gao, BIM Implementation Practices at India's AEC Firms, in: *International Conference on Construction and Real Estate Management*, Kunming, China, 2014.
- [30] R.A. Kivits, C. Furneaux, BIM: Enabling sustainability and asset management through knowledge management, *The Scientific World Journal*. 2013 (2013). doi:10.1155/2013/983721.
- [31] J. Won, G. Lee, Identifying the consideration factors for successful BIM projects Critical success factors in BIM adoption, *Construction*. (2010) 1–6. <http://www.engineering.nottingham.ac.uk/iccbe/proceedings/pdf/pf72.pdf>.
- [32] NBS, NBS national BIM survey [Online], 2014. <http://www.thenbs.com/pdfs/NBS-NationalBIM-Report-2014.pdf>.
- [33] I. Czmocho, A. Pękala, Traditional Design versus BIM Based Design, *Procedia Engineering*. 91 (2014) 210–215.
- [34] S. Azhar, M. Khalfan, T. Maqsood, Building Information Modelling (BIM): now and beyond, *Australasian Journal of Construction Economics and Building*. 12 (2012) 15–28.
- [35] C. Cook, Scaling the building information mountain, *Architectural, Engineering, Construction and Management*. 17 (2004).
- [36] BuildingSMART, BIM in the Middle East 2011, 2011.
- [37] M. Kassem, T. Brogden, N. Dawood, BIM and 4D planning: a holistic study of the barriers and drivers to widespread adoption, *Journal of Construction Engineering and Project Management*. 2 (2012) 1–10.
- [38] J. Rogers, H.-Y. Chong, C. Preece, Adoption of Building Information Modelling technology (BIM) Perspectives from Malaysian engineering consulting services firms, *Engineering, Construction and Architectural Management*. 22 (2015) 424–445. doi:10.1108/ECAM-05-2014-0067.
- [39] G. Aranda-Mena, J. Crawford, A. Chevez, T. Froese, Building Information Modelling Demystified: Does it make business sense to adopt BIM, *International Journal of Managing Projects in Business*. 2 (2009) 419–434.
- [40] B. Becerik-gerber, K. Kensek, Building Information Modeling in Architecture,

- Engineering, and Construction: Emerging Research Directions and Trends, *Journal of Professional Issues in Engineering Education and Practice*. 136 (2010) 139–147. doi:10.1061/(ASCE)EI.1943-5541.0000023.
- [41] S. Azhar, Building Information Modeling (BIM): Trends, Benefits, Risks, and Challenges for the AEC Industry, *Leadership and Management in Engineering*. 11 (2011) 241–252.
 - [42] N. Gu, K. London, Understanding and facilitating BIM adoption in the AEC industry, *Automation in Construction*. 19 (2010) 988–999. doi:10.1016/j.autcon.2010.09.002.
 - [43] J. Harding, S. Suresh, S. Renukappa, S. Mushatat, Design Teams in Achieving BREEAM Accreditation ?, *Journal of Construction Engineering*. (2014). doi:http://dx.doi.org/10.1155/2014/390158.
 - [44] A. Hope, Z. Alwan, Building the Future : Integrating Building Information Modelling and Environmental Assessment Methodologies, Northumbria Research Link. (2012). <https://core.ac.uk/download/pdf/8790178.pdf>.
 - [45] C.S. Dossick, G. Neff, Organizational Divisions in BIM-Enabled Commercial Construction, *Journal of Construction Engineering and Management - ASCE*. 136 (2010) 459–467. doi:10.1061/(ASCE)CO.1943-7862.0000109.
 - [46] R.G. Saxon, Growth through BIM, Construction Industry Council. (2013).
 - [47] N.H. Philip, Building Information Modeling (BIM) and the consultant: Managing roles and risk in an evolving design and construction process, *Proceedings of Meetings on Acoustics*. 19 (2013) 1–5. doi:10.1121/1.4800320.
 - [48] K. Ahn, Y. Kim, C. Park, I. Kim, K. Lee, BIM interface for full vs . semi-automated building energy simulation, *Energy & Buildings*. 68 (2014) 671–678. doi:10.1016/j.enbuild.2013.08.063.
 - [49] S. Zhang, T. Xiao, Building Information Modeling and Sustainable Architecture Design Analysis, in: *Proceedings of the 2013 International Conference on Advanced ICT*, 2013: pp. 758–62.
 - [50] E. Epstein, Implementing Successful Building Information Modeling, Artech House, Norwood, MA, USA, 2012.
 - [51] T.O. Olawumi, D.W.M. Chan, A Scientometric Review of Global Research on Sustainability and Sustainable Development, *Journal of Cleaner Production*. 183 (2018) 231–250. doi:10.1016/j.jclepro.2018.02.162.
 - [52] T.O. Olawumi, D.W.M. Chan, Geospatial Map of the Global Research on Sustainability and Sustainable Development: Generating and converting KML files to Map, Mendeley Data. 1 (2017). doi:10.17632/sv23pvr252.1.
 - [53] M. Alshawi, A. Dakhil, Client's Role in Building Disaster Management through Building Information Modelling, *Procedia Economics and Finance*. 18 (2014) 47–54.
 - [54] R. Masood, K.M. Kharal, A.R. Nasir, Is BIM Adoption Advantageous for Construction Industry of Pakistan?, *Procedia Engineering*. 77 (2014) 229–238.
 - [55] L.Á. Antón, J. Díaz, Integration of LCA and BIM for Sustainable Construction, *International Journal of Social, Behavioral, Educational, Economic, Business and Industrial Engineering*. 8 (2014) 1378–1382.
 - [56] M. Mom, M.-H. Tsai, S.-H. Hsieh, Developing critical success factors for the assessment of BIM technology adoption: Part II. Analysis and results, *Journal of the Chinese Institute of Engineers*. 37 (2014) 859–868.

doi:10.1080/02533839.2014.888798.

- [57] N.W. Young, S.A. Jones, H.M. Bernstein, Building Information Modeling (BIM) - Transforming Design and Construction to Achieve Greater Industry Productivity, in: SmartMarket Report, New York, 2008: p. 48.
- [58] O.O. Akinade, L.O. Oyedele, M. Bilal, S.O. Ajayi, H.A. Owolabi, H.A. Alaka, S.A. Bello, Waste minimisation through deconstruction: A BIM based Deconstructability Assessment Score (BIM-DAS), *Resources, Conservation and Recycling*. 105 (2015) 167–176. doi:10.1016/j.resconrec.2015.10.018.
- [59] M. Akula, R.R. Lipman, M. Franaszek, K.S. Saidi, G.S. Cheok, V.R. Kamat, Real-time drill monitoring and control using building information models augmented with 3D imaging data, *Automation in Construction*. 36 (2013) 1–15. doi:10.1016/j.autcon.2013.08.010.
- [60] M. Al Hattab, F. Hamzeh, Using social network theory and simulation to compare traditional versus BIM-lean practice for design error management, *Automation in Construction*. 52 (2015) 59–69. doi:10.1016/j.autcon.2015.02.014.
- [61] M.H. Enferadi, A. Fazli, S. Fathi, M. Fazli, B. Fathi, Appraising effectiveness of Building Information Management (BIM) in project management, *Procedia Technology*. 16 (2014) 1116–1125.
- [62] G. Lee, H.K. Park, J. Won, D-3 City project - Economic impact of BIM-assisted design validation, *Automation in Construction*. 22 (2012) 577–586. doi:10.1016/j.autcon.2011.12.003.
- [63] A. Akintoye, J. Goulding, G. Zawdie, *Construction Innovation and Process Improvement*, Wiley-Blackwell, Hoboken, 2012.
- [64] G.B. Hua, *Implementing IT Business Strategy in the Construction Industry*, IGI Publishing, Hershey, 2013.
- [65] C. Eastman, P. Teicholz, R. Sacks, K. Liston, *BIM Handbook: A Guide to Building Information Modeling for Owners, Managers, Designers, Engineers and Contractors*, 2nd ed., Wiley, Hoboken, 2011.
- [66] R. Sacks, L. Koskela, B.A. Dave, R. Owen, Interaction of Lean and Building Information Modeling in Construction, *Journal of Construction Engineering and Management-ASCE*. 136 (2010) 968–980. doi:10.1061/(ASCE)CO.1943-7862.0000203.
- [67] J.E. Taylor, P.G. Bernstein, Paradigm Trajectories of Building Information Modeling Practice in Project Networks, *Journal of Management in Engineering*. 25 (2009) 69–76. doi:10.1061/(ASCE)0742-597X(2009)25:2(69).
- [68] W. Wu, R.R.A. Issa, BIM Execution Planning in Green Building Projects: LEED as a Use Case, *Journal of Management in Engineering*. 31 (2015) 1–18. doi:10.1061/(ASCE)ME.1943-5479.0000314.
- [69] M. Ajam, M. Alshawi, T. Mezher, Augmented process model for e-tendering: Towards integrating object models with document management systems, *Automation in Construction*. 19 (2010) 762–778. doi:10.1016/j.autcon.2010.04.001.
- [70] A. Aksamija, BIM-Based Building Performance Analysis : Evaluation and Simulation of Design Decisions Integration of BIM-Based Performance Analysis with Design, in: *ACEEE Summer Study on Energy Efficiency in Buildings*, 2012: pp. 1–12.
- [71] B. Vacharapoom, B. Sdhabhon, An integrated safety management with construction

- management using 4D CAD model, *Safety Science*. 48 (2010) 395–403.
- [72] S. Zhang, J. Lee, M. Venugopal, J. Teizer, C. Eastman, A framework for automatic safety checking of building information models, in: *Construction Research Congress*, ASCE, Reston, VA, 2012: pp. 574–581.
 - [73] Autodesk, The Advantages of BIM-Enabled Sustainable Design for Improving Commercial Building Performance, Autodesk Whitepaper. (2010). http://images.autodesk.com/adsk/files/advantages_of_bim_enabled_sustainable_design.pdf.
 - [74] B. Chilisa, B.B. Kawulich, Selecting a research approach: paradigm, methodology and methods. *Doing Social Research, A Global Context*, McGraw Hill, London, 2012.
 - [75] W.M.K. Trochim, Positivism & Post-Positivism, *Philosophy of Research*. (2006). <https://socialresearchmethods.net/kb/positivism.php> (accessed January 8, 2019).
 - [76] E.E. Ameyaw, A.P.C. Chan, Evaluation and ranking of risk factors in public-private partnership water supply projects in developing countries using fuzzy synthetic evaluation approach, *Expert Systems with Applications*. 42 (2015) 5102–5116.
 - [77] R. Osei-Kyei, A.P.C. Chan, Perceptions of stakeholders on the critical success factors for operational management of public-private partnership projects, *Facilities*. 35 (2017) 21–38.
 - [78] D.W.M. Chan, A.P.C. Chan, P.T.I. Lam, J.M.W. Wong, An empirical survey of the motives and benefits of adopting guaranteed maximum price and target cost contracts in construction, *International Journal of Project Management*. 29 (2011) 577–590.
 - [79] S.O. Olatunji, T.O. Olawumi, I.O. Aje, Rethinking Partnering among Quantity-Surveying Firms in Nigeria, *Journal of Construction Engineering and Management*. 143 (2017) 1–12. doi:10.1061/(ASCE)CO.1943-7862.0001394.
 - [80] D.W.M. Chan, A.P.C. Chan, T.N.Y. Choi, An empirical survey of the benefits of implementing pay for safety scheme (PFSS) in the Hong Kong construction industry, *Journal of Safety Research*. 41 (2010) 433–443. doi:10.1016/j.jsr.2010.07.001.
 - [81] O.O. Akinade, L.O. Oyedele, S.O. Ajayi, M. Bilal, H.A. Alaka, H.A. Owolabi, S.A. Bello, B.E. Jaiyeoba, K.O. Kadiri, Design for Deconstruction (DfD): Critical success factors for diverting end-of-life waste from landfills, *Waste Management*. 60 (2017) 3–13. doi:10.1016/j.wasman.2016.08.017.
 - [82] A. Field, *Discovering Statistics Using SPSS*, 2009. doi:10.1234/12345678.
 - [83] J.R.A. Santos, Cronbach's Alpha: A Tool for Assessing the Reliability of Scales, *Journal of Extension*. 37 (1999) 1–5.
 - [84] P. Legendre, *Species Associations: The Kendall Coefficient of Concordance Revisited*, 2004.
 - [85] D.W.M. Chan, T.N.Y. Choi, Difficulties in executing the Mandatory Building Inspection Scheme (MBIS) for existing private buildings in Hong Kong, *Habitat International*. 48 (2015) 97–105. doi:10.1016/j.habitatint.2015.03.015.
 - [86] D.W.M. Chan, H.T.W. Hung, An empirical survey of the perceived benefits of implementing the Mandatory Building Inspection Scheme (MBIS) in Hong Kong, *Facilities*. 33 (2015) 337–366. doi:10.1108/F-09-2013-0066.
 - [87] C.K.H. Hon, A.P.C. Chan, D.W.M. Chan, Strategies for improving safety performance of repair, maintenance, minor alteration and addition (RMAA) works, *Facilities*. 29 (2011) 591–610. doi:10.1108/02632771111178391.

- [88] P.Y. Chen, P.M. Popovich, Correlation: Parametric and nonparametric measures., Sage Publications, California, 2002.
- [89] E. Kasuya, Mann-Whitney U test when variances are unequal, *Animal Behaviour*. 61 (2001) 1247–1249.
- [90] S.O. Olatunji, T.O. Olawumi, O.A. Awodele, Achieving Value for Money (VFM) in Construction Projects, *Journal of Civil and Environmental Research- The International Institute for Science, Technology and Education (IISTE)*. 9 (2017) 54–64.
- [91] S.O. Olatunji, T.O. Olawumi, D.R. Ogunsemi, Demystifying Issues Regarding Public Private Partnerships (PPP), *Journal of Economics and Sustainable Development- The International Institute for Science, Technology and Education (IISTE)*. 7 (2016) 1–22.
- [92] T.O. Olawumi, O.A. Ayegun, Are Quantity Surveyors competent to value for Civil Engineering Works? Evaluating QSs' competencies and militating factors, *Journal of Education and Practice- The International Institute for Science, Technology and Education (IISTE)*. 7 (2016) 1–16.
- [93] X. Ma, F. Xiong, T.O. Olawumi, N. Dong, A.P.C. Chan, Conceptual Framework and Roadmap Approach for Integrating BIM into Lifecycle Project Management, *Journal of Management in Engineering*. 34 (2018) 1–10. doi:10.1061/(ASCE)ME.1943-5479.0000647.
- [94] A. Fazli, S. Fathi, M. Hadi, M. Fazli, B. Fathi, Appraising effectiveness of Building Information Management (BIM) in project management, *Procedia Technology*. 16 (2014) 1116–1125. doi:10.1016/j.protcy.2014.10.126.
- [95] T.O. Olawumi, D.W.M. Chan, Critical Success Factors of Implementing Building Information Modelling (BIM) and Sustainability Practices in Construction Projects: A Delphi Survey, *Sustainable Development*. (2019) 1–16. doi:10.1002/sd.1925 (*in press*).
- [96] C.J. Roberts, E.A. Pärn, D.J. Edwards, C. Aigbavboa, Digitalising asset management: concomitant benefits and persistent challenges, *International Journal of Building Pathology and Adaptation*. 36 (2018) 152–173. doi:10.1108/IJBPA-09-2017-0036.
- [97] J. Li, L. Hou, X. Wang, J. Wang, J. Guo, S. Zhang, Y. Jiao, A Project-Based Quantification of BIM Benefits, *International Journal of Advanced Robotic Systems*. 11 (2014) 123. doi:10.5772/58448.