Jomard Publishing

BIM-BASED DESIGN AND CONSTRUCTION DEPLOYMENT AMONG PROJECT STAKEHOLDERS FROM THE ASPECT OF CONTRACT ADMINISTRATION

Sharifah Nur Aina Syed Alwee[1,2], Hafez Salleh[2*], Umi Kalsum Zolkafli[2], Siti Suhana Judi[1], Ahmad Ridzuan Abu Bakar[3]

[1]College of Built Environment, Universiti Teknologi MARA, Shah Alam, Malaysia
[2]Faculty of Built Environment, Universiti Malaya, Kuala Lumpur, Malaysia
[3]Integrated Asset Planning Branch, Public Works Department, Kuala Lumpur, Malaysia

Abstract. Building information modelling (BIM) can be viewed as a tool that can improve information sharing by allowing various parties to control and collaborate on their design, construction, and operation activities in a different way than the non-BIM approach. However, little is known about how BIM contract administration is currently practised by project stakeholders directly involved in the digital collaborative environment. Hence, this study delves into the extent to which these parties comply with BIM-based contractual requirements. Multiple case studies research design using the qualitative approach involving three BIM-based construction projects in Malaysia was conducted. Semi-structured interviews with project stakeholders and the BIM contractual guidelines referred to in the case studies were used to collect and analyse data. This study concluded by disclosing project stakeholders' contractual compliances during the design and construction phases of BIM deployment, revealing how BIM contract administration is currently practised by construction practitioners in Malaysia.

1.   Introduction

Building information modelling (BIM) is defined by the National Institute of Building Sciences (2007) as "a digital representation of physical and functional characteristics of a facility". The purpose of BIM is to serve as "a shared knowledge resource for information about a facility forming a reliable basis for decisions during its life cycle from inception onwards" (NIBS, 2007). BIM can significantly affect a project's life cycle through improved communication and teamwork to reduce design changes, variation orders, delays in work sequences, and poor-quality performance. Via the BIM process, the management of the operation and maintenance of building assets can be planned with the early involvement of the facilities management team from the planning stage. Current practice has demonstrated the benefit of adopting BIM, whereby 3D visualisation, coordination, and clash detection activities were reported as the main BIM functionalities that had achieved the highest utilisation rates in BIM project

implementation. Framing the right BIM process from the beginning of a construction project is crucial in guiding the project stakeholders to collaborate more efficiently, thus helping them to understand their contractual roles and responsibilities while working in a BIM environment.

Contract administration is the management process requiring contractual parties to fulfil their obligations with due diligence to avoid disputes or conflicts when carrying out their responsibilities. Recently, various BIM contractual guidelines have been established to prescribe the roles and responsibilities in the design and construction activities within the BIM process. These roles and responsibilities are stipulated in the form of contractual requirements and are crucial to safeguard the parties' interests against unforeseen risks and complexities of the project. However, contemporary scholars who are concerned with the liability arising from BIM noncompliance have advocated specific contractual implications, including model management, data exchange procedure, quality control, and data security. Employing the right BIM process at a more advanced maturity level may lead to increased legal and contractual risks due to the increased responsibility to care for other project stakeholders when working in a team that relies heavily on BIM procedures.

The contractual implications demand an in-depth study investigating the current BIM usage in the contract administration of BIM-based construction projects. This study, therefore, aims to explore the levels of compliance among project stakeholders against BIM contractual requirements imposed by the clients. A qualitative approach was deemed most fitting to analyse how construction practitioners such as clients, contractors, design consultants, BIM managers, and quantity surveyors comply with their contractual duties and responsibilities at various BIM-based design and construction phases, particularly in the context of the Malaysian construction industry.

2.   Literature Review

2.1. BIM Contract Administration at Various Design and Construction Phases

Studies on BIM contract administration are meagre in the literature because of the difficulty in allocating risks to the various parties involved, which necessitates fair and just fulfilment when accommodating the duties and obligations required in the contract. In this regard, Pittard and Sell (2016) highlighted the functions of BIM contract administration which require project stakeholders to manage their duties and responsibilities systematically at various design and construction phases. The functions include (1) establishing project requirements and information specifications; (2) quantities extraction; (3) capability assessment; (4) programming and controlling; (5) interim valuations; (6) records and documentation; (7) supervision and site inspections; (8) progress meetings; (9) claims and payments; (10) change orders; (11) client's instructions; (12) contract completion; (13) loss and/or expenses; (14) final accounts; and (15) FM integration. Contract management in BIM-based projects requires the stakeholders to accomplish the goals and objectives of BIM deliverables within a specific time, cost, and quality to ensure that the information managed via the BIM process can be streamlined for future operation and maintenance.

Recently, the British Standards Institution (BSI) proposed eight information management pertaining to the requirements for information that a client must consider when identifying the standardised BIM processes at various project delivery phases (BS EN ISO 19650-2, 2018).

Table 1. Interaction matrix of BIM-based contract administration involving design and construction information management process (Source: Authors, 2023)

Information management Process BS EN ISO 19650-2 (BS EN ISO 19650-2, 2018)		Pre-contract			Post-contract				
		Assessment of need	Invitation to tender	Tender response	Appointment	Mobilisation	Collaborative production of information	Information model delivery	Project close-out
Contract administration functions (Pittard and Sell, 2016)	Explanation	Develop the project and contract requirements, delivery milestones, BIM standards, protocols and other associated tasks	Develop the exchange information requirements, shared resources, tender responses, evaluation criteria and other associated tasks	Develop the assessment for BIM capability, pre-BEP, mobilisation plan, risk register and other associated tasks	Develop contract BEP, responsibility matrix, task information delivery plan (TIDP), master information delivery plan (MIDP), contract documentation and other associated tasks	Mobilise resources in CDE following information production methods and procedures in the responsibility matrix and MIDP	Generate information, share resources, model review, quality checking and other associated tasks	Verification and validation of information model against contract requirements	Archive project information model, gather lessons learned and other associated tasks
Project requirements and information specifications	Details the requirement for contract management and FM uses	/	/	/					
Quantities extraction	Integrates QS software with other project teams to extract quantities from the BIM model		/	/	/	/	/		
Capability assessment	Assessment based on BIM capabilities and competencies		/	/					
Programming and controlling (4D BIM)	Project scheduling incorporates design and model development to reduce clashes and variations	/			/	/	/	/	/
Interim valuations	The BIM model assists the valuation process for the progress of work				/	/	/	/	
Records and documentation	CDE assists in the information exchange and visibility of the information	/	/	/	/	/	/	/	/
Supervision and site inspections	CDE assists with the documentation parts and tracks compliance with the BEP contractual obligations	/	/	/	/	/	/	/	/
Progress meetings	Uses of mobile technology tools (i.e., drones, AR, VR, etc.) to update the progress of works				/	/	/	/	/
Claims and payments (5D BIM)	Assessment of progress payment based on the LOD stages	/			/	/	/	/	/
Change orders	Uses the BIM model to identify variation activities. Changes will be cross-checked with contract requirements to assess the impact against the original scope of work	/			/	/	/	/	
Client's instructions	Uses BIM-enabled software to monitor any changes that affect time and cost management	/			/	/	/	/	
Contract completion	Refers to the contract and schedules produced from the BIM model	/			/			/	/

Loss and/or expenses	Cost schedules integrating the BIM process to manage and assess the loss and/or expense claims	/				/	/	/	/
Final account	Cost schedules integrating the BIM process to manage and assess the final account claims	/						/	/
FM integration	FM integrating the BIM process to monitor asset information requirements and fulfilments	/	/	/	/	/	/	/	/

The eight stages of information management processes include (1) assessment of need; (2) invitation to tender; (3) tender response; (4) appointment; (5) mobilisation; (6) collaborative production of information; (7) information model delivery; and (8) project close-out. These phases can be categorised into pre- and post-contract, which, according to Singh (2002), could differentiate the project administration activities before and after the contract is formalised. In the contract administration of a typical engineering and construction project, the inception and feasibility study, tender documentation, and tendering process are all essential parts of the planning and design phases. The other milestones after the contract between the client and contractor are formalised, including the detailed design stage, construction, handover, and maintenance (Singh, 2002). The contractual responsibilities will end until the key parties conclude the project's final account certificate.

As shown in Figure 1, the functions of BIM contract administration (divided into pre- and post-contract stages) present significant interaction with BS EN ISO 19650 standard. The administration emphasises the need to streamline the contractual tasks and responsibilities efficiently to support the standardised BIM-based processes in project implementation (Winfield, 2020). The main aspects of these theoretical models have proved beneficial in showing the relationship between BIM contract administration functions and information management procedures at various pre- and post-contract stages to attain a BIM-coordinated process. This alignment is necessary to solve the various legal and contractual barriers when integrating various stakeholders into a digitalised environment.

2.2. Contractual Requirements Used in BIM Contract Administration

To address the legal and contractual challenges imposed by BIM application in the construction industry, various contractual guidelines and BIM standard forms of contract have been established from an international perspective to guide project stakeholders in implementing the BIM process. Current literature indicates that contractual guidelines such as the UK's CIC BIM Protocol, the US's AIA BIM Docs and exhibits, Singapore's BIM Particular Conditions, and Hong Kong's BIM Conditions of Contract as the explicit BIM contractual requirements that are commonly referred to in BIM-based projects (Alwee et al., 2021; Chong et al., 2017; Mahdian et al., 2023). Other studies have also demonstrated the need for BIM obligations to serve as contract provisions by referring to specific procurement methods, such as Design and Build (DB), Design-Bid-Build (DBB), or others (Abd Jamil & Fathi, 2020; Arshad et al., 2019; Malla et al., 2022). It is believed that identifying BIM contractual requirements or BIM contract provisions could improve the conventional contract forms, which appear to disregard the legal and contractual implications arising from BIM implementation (Almarri et al., 2019; Assaad et al., 2020).

The contract language used when developing BIM requirements should demonstrate the exact intentions that the client wants from the outset. These contractual requirements, as Kumar and Hayne (2017) addressed, should also emphasise the standard format supplied by the assigned parties until the handover stage. This measure is critical to avoid future conflicts or contractual issues when a project team collaborates in a BIM environment.

2.3. Current Issues on the Compliances of BIM Contractual Requirements Among Project Stakeholders

The contractual position on the use of BIM confirms a few factors, including the fact that time and cost management can be managed efficiently using BIM tools, and quality control can be achieved more effectively by integrating coordination processes involving various design and construction disciplines and subcontracting packages. Many scholars have agreed that certain ambiguities that cannot be resolved through conventional practices could be eliminated through this integration. Yet, many scholars from the Eastern and Western contexts have also alluded to several noncompliant cases in BIM projects (as reported in the literature) to demonstrate (i) a lack of contractual compliance by the assigned parties involved in BIM projects or (ii) the vague requirements stipulated in a BIM contract.

Although the BEP is usually bound as one of the contractual documents to support BIM working processes, many people are misled when interpreting the work sequences in a BIM model with on-site progress (Oraee et al., 2021). Some of the processes and procedures designed in the BEP have not been implemented in practice because most of the project actors still do not understand how to incorporate BIM into daily activities (Abd Jamil & Fathi, 2019). Using 2D drawings has become a standard practice in certain development projects, resulting in various design and construction issues such as reworks and modifications because the actual workflow was not properly implemented *(Chong et al.*, 2017; Brahim *et al.*, 2018; Abd Jamil & Fathi, 2020). As a result, correction reports such as the NCR were issued to force the party to repeat the correct process according to the EIR or BEP guidelines (Chen & Luo, 2014).

Table 2. Issues regarding the contractual compliances of BIM requirements among project stakeholders

Key aspects	Sub-aspects	Authors
BIM Execution Plan (BEP)	• Misled interpretation with the work sequences between BIM model and on-site progress	Oraee *et al.* (2021)
	• Processes and procedures not being implemented in the project	Abd Jamil & Fathi (2019)
2D Drawings	• Common reference used in BIM-based projects that lead to reworks and modifications	Chong *et al.* (2017); Brahim *et al.* (2018); Abd Jamil & Fathi (2020)
	• Need to be issued with NCR	Chen & Luo (2014)
Data Transferring Process	• Missing data due to unforeseen circumstances • Inconsistencies and collisions during data transfer • The need for standardising BIM data and information until the FM stage	Arshad *et al.* (2019) Abd Jamil & Fathi (2020) Kamaruzzaman *et al.* (2023); Pishdad-Bozorgi *et al.* (2018)
Vague Contractual Requirements	• Improper processes and procedures to retrieve and reuse data when amending BIM model lead to security issues and impact the project completion	Nilchian et al. (2022); Sardroud et al. (2018)

BIM depends on systematic model management to allow the project team to work effectively via a digitalised system. The data entry process must always be as accurate as

possible by complying with the BIM contract's modelling protocol. Missing data could happen due to unforeseen circumstances, preventing recipients from receiving the correct information (Arshad *et al*., 2019). Such circumstances could lead to inconsistencies and collisions during data transfer (Abd Jamil & Fathi, 2020). Kamaruzzaman et al. (2023) and Pishdad-Bozorgi et al. (2018) further underlined that the consistency in handling BIM model data needs to be standardised until the information is transferred to the FM database for future operation and maintenance.

In other scenarios, BIM noncompliance could transpire due to the vague requirements imposed by a BIM contract. Specific security issues might surface, such as information leakage during data transmission, which Nilchian et al. (2022) and Sardroud et al. (2018) attributed to improper processes and procedures allowing other parties to retrieve or reuse the information when amending the BIM model. The risks associated with project time completion could also happen when large-scale BIM needs to be managed in the right sequences to successfully deliver the BIM workflow. Table 2 summarises the highlighted issues discussed above from the existing literature.

In summary, three key aspects–namely BIM contract administration at various design and construction phases, contractual requirements used in BIM contract administration, and current issues on BIM contractual compliances have been discussed to conceptualise the theoretical lens that requires more in-depth investigation from real case studies. This matter is necessary to explore the actual situation faced by the project stakeholders. Little is known about how BIM compliance with contract administration has been assessed against the contractual guidelines used in BIM-based projects, particularly in the Malaysian construction industry. This gap is the impetus for the current study, in view of the potential of BIM to increase productivity when various working processes are integrated into design and construction management, as documented in the literature.

3.   Research Methodology

A qualitative method was adopted by means of a multiple case study design to assess the compliance of BIM contractual requirements by project stakeholders when managing construction contracts in the Malaysian construction industry. Following Creswell and Poth (2018), the themes were analysed across cases to find similarities and differences to demonstrate the patterns reflected in the current situations, as derived from the in-depth process of the real context under investigation.

As shown in Figure 1, the study was divided into three stages. The first stage involved problem identification, where past studies were reviewed to understand BIM contract administration, contractual requirements in BIM contract administration, and the current issues on compliance with BIM contractual requirements among project stakeholders. References were taken directly from academic journals and other scholarly sources to set the context for what will be learned inductively in the case studies. The second stage was data collection, in which three case studies were identified, and their BIM contractual requirements (also known as the Employer's Information Requirements – EIR) were assessed through cross-case analysis based on the actual practices complied by the project participants. Thus, two research techniques–semi-structured interview and document analysis were employed to elicit data directly from the project participants. The third stage was a cross-case analysis of the multiple case studies to disclose the patterns and relationships in the current contractual practices upheld by the project stakeholders.
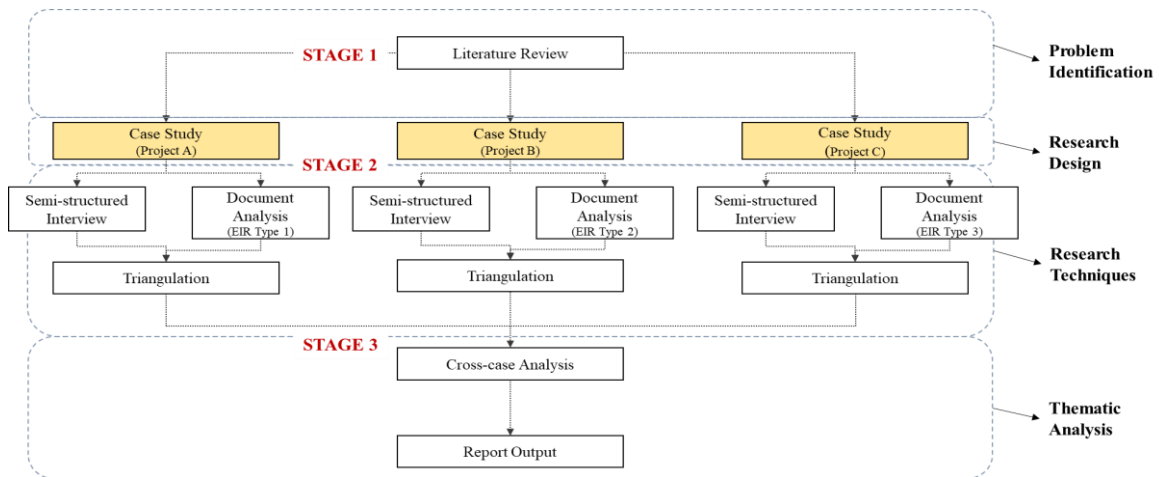
Figure 1. Research stages (Source: Authors, 2023)

Table 3. Background of projects and BIM stakeholders (Source: Authors, 2023)

Information	Project A	Project B	Project C
Background	Description: Complex development project comprised of functional blocks, carparks and MEP facilities Estimated contract value (USD): 83 million Current stage: 81 % completion (during data collection)	Description: Complex development project comprised of functional blocks, carparks and MEP facilities Estimated contract value (USD): 108 million Current stage: 95% completion (during data collection)	Description: Complex development project comprised of functional blocks, carparks and MEP facilities Estimated contract value (USD): 63 million Current stage: 65% completion (during data collection)
BIM utilisation	Until LOD 500	Until LOD 500	Until LOD 500
BIM contractual guideline	EIR (Type 1)	EIR (Type 2)	EIR (Type 3)
BIM coordination	Decentralised D&B	Decentralised D&B	Decentralised D&B
Project participants	Informant / Background / Experience A — C&S engineering — 11 years B — C&S engineering — 13 years C — Construction management — 9 years D — Construction management — 9 years E — Quantity surveying — 19 years F — Mechanical engineering — 13 years G — Construction management — 12 years	Informant / Background / Experience H — Construction management — 21 years I — Architecture — 11 years J — Quantity surveying — 13 years K — Construction management — 9 years L — Quantity surveying — 26 years M — Architecture — 6 years	Informant / Background / Experience N — C& engineering — 10 years O — Architecture — 28 years P — Mechanical engineering — 12 years Q — Quantity Surveying — 6 years R — Construction management — 19 years S — Mechanical engineering — 25 years T — Quantity Surveying — 12 years
Range of years working in BIM-based projects	5 to 10 years	5 to 9 years	5 to 12 years
Compliance status of BIM contractual requirements (during Pre-construction)	Need to remedy all comments as provided in the Non-Conformance Report (NCR) issued during the project award: • Submission of BIM models & clash report in the Contractor's Proposal • Details of the BIM processes and workflow in the proposed BEP	Need to remedy all comments as listed in the NCR during the project award: • Roles and responsibilities for BIM staff • Milestones of submittal of BIM deliverables	Need to remedy all comments as listed in the NCR during the project award: • Details of the BIM processes and workflow in the proposed BEP • Submission of BIM models & clash report in the Contractor's Proposal
Implications to the contract management (during Post-construction)	Some delays during the construction stage were contributed by poor design integration during the detailed design stage. Most of the project actors are still on the learning curve	The contractor's team did not wait for the BIM models to be fully coordinated before beginning construction. The client is also not rigid in terms of BIM contractual compliances	Massive variation activities due to the end-user's new requirements, which have impacted the BIM processes and integration of sub-package works during the construction stage

This study employed purposeful and snowball sampling techniques to identify the construction sites and project stakeholders for data collection. The selection criteria included the need to find BIM-based construction projects using Design and Build as the procurement method (early involvement of the contractor's team starting from the designing stage), construction projects that have achieved 50 percent completion and the projects must be executed with BIM-based processes until the LOD 500 (close-out). The same principles were also applied when identifying the project stakeholders; 20 participants from three case studies (Project A, B, and C) were employed as the client or contractor's team members with various backgrounds, i.e., BIM management, design

consultants, quantity surveyors, and client's representatives. The participants must know about current practices of BIM contract administration for them to elicit responses towards the research findings. The profiles of the case studies and brief information about the project stakeholders are shown in Table 3.

The validity of this study was increased by triangulating the findings from the two methods of data collection (interviews and document analysis) to gather new information gleaned from the exploratory study (Creswell & Creswell, 2018). Member checks were conducted after the initial codes, categories, and themes were discovered to validate the interpretations made before the reporting stage. Some literature relevant to the study was interpreted collectively in the discussion to comprehend the findings. The next section reports the analysis and findings from the overall cross-case analysis, particularly the extent to which the stakeholders comply with the BIM-based contract requirements imposed on the project.

4. Findings and Discussion

The data analysis for the case studies began concurrently with the data collection, which took nearly a year to complete. This study utilised the ATLAS. ti (Version 9) software as the main tool for analysing the interview transcripts and project documents. Thematic analysis, which entails a few series of interpretations, was conducted to derive the patterns and relationships. This study adopted the following six considerations in a thematic analysis as proposed by Braun and Clarke (2006): (1) familiarising data, (2) generating initial codes, (3) searching for themes, (4) reviewing themes, (5) defining and naming themes, and (6) producing a report. Based on 20 semi-structured interviews with the project participants from the three case studies and triangulation with the contractual guidelines used in the projects, the study revealed three levels of compliance in regard to the current usage of BIM contract administration among the project stakeholders, namely:

(1) '**Level 1 – Not adopting the right concept of BIM'**: representing the level of compliance on BIM contract administration during the pre- and post-contract phases in which the project stakeholders do not carry out the works following the specified BIM contractual requirements
(2) '**Level 2 – Partially adopting BIM'**: highlighting the level of compliance on BIM contract administration during the pre- and post-contract phases, which the project stakeholders partially carry out and comply with the BIM contractual requirements
(3) '**Level 3 – Fully adopting BIM'**: referring the level of compliance on BIM contract administration during the pre- and post-contract phases, which the project stakeholders fully carry out and comply with the BIM contractual requirements

Most of the interpretations were triangulated by the projects' contractual requirements to disclose the similarities and differences, which then led to the development of the key themes, as defined above. Findings from the semi-structured interviews and document analysis are presented in the following themes.

4.1. Level 1 - Not adopting the right concept of BIM

This theme denotes the contractual implications arising from BIM implementation, which demonstrate that certain BIM-based processes were not accomplished in accordance with the contract requirements. The elaborations were divided into (1) pre-

contract (tendering stage) and (2) post-contract phases (detailed design, construction, and handover stage) to show the implications regarding the contract compliances (refer to Table 4).

Table 4. Codes and categories for 'Level 1 - Not adopting the right concept of BIM'
(Source: Authors, 2023)

Level 1 - Not adopting the right concept of BIM

Code Frequencies

Category		Project A	Project B	Project C	Total	Code
1) Tendering stage	PRE	11	2	6	19	- Reliance on third-party consultants
		2	4	4	10	- Non-conformance record (NCR)
2) Detailed-design stage	POST	6	4	4	14	- BIM models based on 2D drawings
3) Construction stage		5	3	7	17	- Lack of 5D BIM integration
		9	5	3	15	- Lack of updates of the BIM Execution Plan (BEP)
		3	3	3	9	- Construction sequences not referring to BIM models
4) Toward handover stage		6	1	2	9	- Lack of accuracy of Asset Information Requirements (AIR)

4.1.1. Level 1- Not adopting the right concept of BIM (_Tendering stage_)

As a critical stage that influenced the client to select the best potential contractor to complete a project, Level 1 indicates that all of the main contractors in the case studies have hired third-party BIM consultants to design the tender proposals when submitting their proposals (Interviewee I until T). They claimed that issues on professional liabilities arose due to the employment of third parties, some of whom do not have professional backgrounds related to the design and construction fields. The client representatives also criticised the nonconformance report (NCR) that had to be issued to the winning contractors to remedy any nonconformances and design inconsistencies discovered during the tender evaluation. Half of the interviewees admitted that no other methods were used as a punitive measure to penalise nonconformities. These findings are consistent with Brahim et al. (2018) and Abd Jamil and Fathi (2020), who found that the employment of BIM consultants has increased in the current context to meet the needs of producing BIM models, which are still poorly practised by design consultants. Some designers still lack any mastery of BIM software and do understand the workflows integrated within the BIM ecosystem.

4.1.2. Level 1 - Not adopting the right concept of BIM (_Detailed-design stage_)

Most of the projects relied on two-dimensional CAD drawings for the detailed design, although part of the EIR had emphasised the need to use more user-friendly BIM-enable software for BIM integration. The designers who produced the 2D drawings would pass the drawings to the engaged third-party(s) consultants to develop 3D models for clash analysis and design review. The existing practice did not comply with the express requirement stated in the EIR, which emphasised the need to extract drawings, schedules, and other outputs from the model, not vice versa (Clause 2.3.2 of the Project C' EIR). The contract principle and policy governing BIM projects must always reflect the drawings generated from the fully developed BIM model (Chong _et al._, 2017). This matter is imperative as the basis for solving any conflicting issues or disputes arising from the discrepancies between contracting documents.

4.1.3. Level 1 - Not adopting the right concept of BIM (Construction stage)

The cross-case analysis found that the project participants incurred some coordination issues as the execution plan, processes, and procedures were not followed. The BEP looked beautiful on paper, but in actual execution, most parties failed to comply with the established procedures, and so on. Another result that emerged from this category was that the 5D BIM, which focuses on cost management based on the BIM model, was not integrated into the actual implementation since most of the project actors preferred to monitor the time and cost progress via the physical site evaluation. A few participants claimed that 5D integration could expose their cash flow to the client, which is one of the main reasons they opposed using 5D BIM in the project. Another challenge associated with the construction stage was the massive amount of repair work required after the works have been constructed on-site, which did not tally with the model progress.

When comparing the above situation with the document analysis, it was found that the root cause of these failures was noncompliance with the right sequences of the BIM process from the beginning. Clause 3.3.7 (Project A's EIR) and Clause 3.4.4 (Project C's EIR) expressly required that the submission of construction drawings be derived solely from the BIM model as part of fulfilment for embarking on the works on site. Moreover, if the BEP is treated as a 'living document', the parties will be able to engage in collaborative working practices (Nor *et al*., 2021). The present study raises the possibility that the failure to meet the contract requirements may affect changes in the scope of work compared to the original proposal (Abd Jamil & Fathi, 2020). Some changes made by the client can also be the factors contributing to the double-handling, which is also due to the lack of coordination during the modelling process.

4.1.4. Level 1 - Not adopting the right concept of BIM (toward Handover stage)

Tasks referred to as-built models' production are closely linked to updating construction and asset information in the BIM models since the three case studies which had not yet reached the close-out stage during data collection. Some of the interviewees accorded that the asset requirements that they had to rely on were provided in a brief format, leading to some uncertainties about the kind of information the clients wish to focus upon for the operation stage. Nevertheless, the completeness of information must adhere to the client's requirements, which necessitate the contractor to acquire and integrate the data in BIM models before handing it over to the client once the project is completed (Clause 3.5.1 of Project B' EIR). The findings concluded that a lack of well-defined asset requirements as part of the contractual framework could be a major hindrance to implementing BIM for FM usage (Becerik-Gerber et al., 2012; Okwe et al., 2022). Proactive participation by clients and end-users should be considered part of the project administration process, which should begin with the planning stage and continue until the final as-built model is handed over to the project owner.

Several interesting concerns arise during the tendering stage, including whether the third party(s) who modelled the design elements should be responsible for any inconsistencies and liabilities resulting from the BIM-based processes at the outset. A note of caution is due here since the observations from the case studies revealed the isolation of the modelling process performed among the project team from the design tasks that should be carried out simultaneously during the detailed design stage. The implication could be seen during post-construction; although the parties constructed the works and did not wait for the construction models to be fully developed, some challenges

in meeting the quality standard occurred due to the massive repairing works caused by the noncompliance of work sequences as planned in the BIM models.

4.2. Level 2 – Partially adopting BIM

This second theme evidenced the contractual implications of BIM implementation when the project stakeholders adopted the BIM work processes partly from the overall contract administration activities that should follow the contract requirements (see Table 5). The same categories as in the previous themes were used because the cross-case analysis of this second theme also impacted the same project stages as previously discussed.

Table 5. Codes and categories for 'Level 2 – Partially adopting BIM'
(Source: Authors, 2023)

Level 2 - Partially adopting BIM

Category		Project A	Project B	Project C	Total	Code
		Code Frequencies				
1) Tendering stage	PRE	4	6	7	17	- BIM competency for capability assessment
		-	3	1	4	- Tender estimate based on conventional practice
2) Detailed-design stage	POST	-	1	4	5	- Resolution for clash analysis
		2	1	2	5	- Integrity of data and information in BIM models
3) Construction stage		6	3	4	13	- Site progress against 4D construction simulation model
		-	-	12	12	- Variations caused by end-users
		-	1	7	8	- Coordination for sub-contract packages
4) Toward handover stage		9	3	1	13	- BIM in FM applications
		2	2	1	5	- Registration of asset information

4.2.1. Level 2 - Partially adopting BIM (Tendering stage)

Most of the interviewees believed that one of the major barriers to BIM implementation was the lack of BIM knowledge, skills, and competencies among professionals. This phenomenon was also evident in the case studies. All the contractors involved in the case studies were evaluated using a specific weightage and scoring matrix to assess their BIM capabilities. Some of the interviewees revealed that only architects and BIM managers had prior experience with BIM-based projects compared to other designers. In reality, many project actors had to engage a third party(s) to design the models and execute the BIM processes. This result is consistent with empirical research done by Olatunji (2014) and Mahamadu et al. (2019), who emphasised that professional skills development for BIM competencies is one of the crucial aspects that must be assessed accurately by the client. The findings indicate that a BIM capability imbalance among the project stakeholders could lead to efficiency in collaboration while contributing to some associated risks during the BIM implementation (Gao et al., 2022).

The interviewees also mentioned that the BIM models and other deliverables for tender submission were provided with minimal capacity due to the time constraint when fulfilling the pre-bid requirements. Only three months were allocated to the contractors to furnish their tender proposals. The conventional process of deriving the project estimate was adopted to determine the overall tender cost when bidding on the project. Although it is stipulated in the EIR that the cost estimate should be made using information obtained from BIM software (Clause 3.1.4 of Project A' EIR), the actual

practice from case studies revealed that most of the project actors still used the conventional method to derive the cost estimate due to the limited time incurred to complete the models. One explanation for this finding is that the cost estimation to be prepared by the QS during the pre-contract stage is usually determined based on certain formulae or cost per square foot before the actual detailed design is made (Sacks et al., 2018). This finding also implies that the accuracy and reliability of the tender cost estimate are heavily reliant on the experience and capability of designers and QS consultants to produce a proper design integrating the cost breakdown when producing technical and financial proposals for evaluation purposes.

4.2.2. Level 2 - Partially adopting BIM (Detailed-design stage)

One of the critical elements for the detailed-design stage is to ensure that the modelling process integrates all graphic design elements, including the size, shape, orientation, location, and works associated with subcontract packages. Therefore, the clash analysis must be finalised by resolving all clashes detected during the design review, which involves the respective designers and subcontractors attending the coordination workshops periodically. From the case studies, it can be seen that some of the project stakeholders preferred to solve the clashes in isolation way since they had difficulties collaborating and sharing the design progress during the design development stage. The EIR has stipulated that the duty to solve all clashes must be performed upfront before construction works begin on site (Clause 3.3.1 of Project C's EIR).

It is critical to note that the lack of coordination has resulted in integrity concerns after some issues, such as misplacing certain data and information in the models, particularly during the actual project execution. Past studies have confirmed the identification of poor coordination via BIM-based processes as one of the barriers impeding BIM collaboration (Ahmadi & Arashpour, 2020; Khosrowshahi, 2017; Oraee *et al.*, 2019). Responsible parties must ensure that all data updated in the BIM model are managed accurately and that no substantial doubt exists while exchanging BIM information. Designers must be well-versed and experienced to understand the true design intentions that must satisfy the client's needs and all the requirements imposed by local authorities.

4.2.3. Level 2 - Partially adopting BIM (Construction stage)

It is worth mentioning that project actors have only used the 4D construction simulation model a few times to monitor the work sequences at the respective construction site. This situation happens during the initial construction stage, although one of the BIM objectives required in the EIR has highlighted the necessity to carry out site audits using the 4D simulation model on a monthly basis. The model development must also adhere to the technical requirements approved by the client (Clause 3.4.1 of Project C's EIR). This study confirms that some project stakeholders still lack 4D BIM knowledge, which directly contributes to the lack of 4D simulation in the actual practice (Charlesraj & Dinesh, 2020). Information in the BIM model must be assured and verified following the EIR and BEP to support the precision of the decision-making process.

As the interviewees mentioned, some of the end-users contributed to variation works, resulting in many deviations from the original scope of works after the federated model was completed. Some of the construction processes also became counterproductive since their tasks doubled the actual working process. In addition, the work sequences which involved various subcontractors have been impacted by such changes since the

coordination, including the reviewing process and the clash analysis, had to be done multiple times, which then contributed to the delay in meeting the progress on time. A comparison of findings from the interviews with those from the document analysis indicates that the client gave no guarantee of any accuracy and sufficiency of the information provided to the contractor. Therefore, the contractor must fulfil any obligations imposed on them to complete the project (Clause 1.12 of Project C's EIR). Any unexpected events that at times led to variation while working in a BIM environment could not be prevented (Mustaffa *et al*., 2021). The possible explanation for this discovery is the late involvement of all parties (including the end-users and subcontractors), thus increasing the risks of achieving high efficiency in BIM coordination (Lee et al., 2020). There is still a lack of cooperation when integrating various service works involving various subcontractors and sub-trades who are still not proficient in using BIM tools and software. Nevertheless, the main contractor must ensure that the BIM workflow at each LOD stage is carried out as per the BEP and consistently supervised by the client or end-user when delivering the project.

4.2.4. Level 2 - Partially adopting BIM (toward Handover stage)

Analysis from the interviews disclosed that most projects have started to insert the asset registration for as-built model production after the projects reached more than 50% completion, although they were still unsure whether the final product would be used for FM implementation. The client representatives have provided guidelines and templates for asset coding and registration to accomplish this task. The activities related to the asset tagging are explicitly stated in the EIR, in which the contractor must fulfil the final BIM deliverables for the close-out phase, such as the as-built models and as-built drawings before the projects are handed over to the client for future operation (Clause 3.5 of Project C's EIR). Accuracy in asset registration is critical for smoothing out the process during the handover phase (Dixit *et al*., 2019; Khosrowshahi, 2017).

Most of the interviewees agreed that they were preparing the as-built models to fulfil the final BIM deliverable before the projects achieved the close-out stage. Nonetheless, many of the participants expressed their doubts about using the federated as-built model for FM because some uncertainties remained, such as concerns about the model's accuracy for future asset management. The document analysis explicitly highlighted that the as-built model must be documented as actual as-built conditions that hyperlink to related documents, such as the specifications and services manual for FM usage (Clause 1.2.3 of Project B's EIR). This finding also agrees with the results of Pishdad-Bozorgi et al. (2018) and Dixit et al. (2019), who highlighted that the systematic process for capturing FM information for the BIM model must be determined at the outset to streamline future FM activities. To guide this process, templates, notes, or guidelines must be created and implemented by the project. To maintain model integrity, all data, including asset registrations, must be validated and verified simultaneously during the contract period.

From the above findings, it can be inferred that delivering and producing BIM submissions starting from the tendering stage could be done successfully only if the people behind the process are capable and competent in their scope of work. As indicated from the cross-case analysis, a lack of initiative to verify the data inserted in the models was also encountered during the detailed design stage, despite the need for all parties to collaborate during the coordination meetings and review process to ensure that design clashes can be solved in a single platform. Also important to note is that the monitoring

and supervision during the construction stage could be done efficiently only if all parties can provide a huge commitment with the best endeavours to ensure that all work programmed earlier could meet the targeted BIM project milestones. Standardised procedures to manage asset data and information must be developed sufficiently to improve BIM usage for later maintenance and operation stages.

4.3. Level 3 -Fully adopting BIM

The final theme of this study revealed the contractual implications of BIM implementation when the project stakeholders fully implemented BIM in accordance with the contract requirements, as defined by the client (see Table 6). Findings for this final theme also employed the same project stages described in the previous analysis.

Table 6. Codes and categories for 'Level 3 – Fully adopting BIM'
(Source: Authors, 2023)

Level 3 - Fully adopting BIM

Category		Project A	Project B	Project C	Total	Code
		Code Frequencies				
1) Tendering stage	PRE	1	-	7	8	- Provision of BIM expenses
2) Detailed-design stage		2	4	6	12	- Four-wall interaction for 3D visualisation
	POST	3	2	4	9	- Contract documentation
3) Construction stage		4	-	5	9	- Common Data Environment (CDE) as collaborative platform
		1	5	2	8	- BIM progress inspection
4) Toward handover stage		12	4	8	24	- Federating as-built model production

4.3.1. Level 3 - Fully adopting BIM (Tendering stage)

Interviewees discussed that most of the provisions for BIM expenses were priced and included as the preliminary costs in the tender document to cover the supervision fees to pay the BIM manager and allocations for the BIM workstation, including the software and hardware to be used by the contractors and client's representatives. These costs would usually be allocated as part of contractual requirements, with most contractors referring to the instructions given to tenderers when purchasing the tender documents. However, additional costs may still arise when managing BIM data during project administration (Azhar *et al*., 2012). To avoid additional costs that could reduce profit margins and budgets, it is critical to identify the breakdown expenses arising from BIM implementation, including costs for supervision and purchasing BIM-enabled tools starting from the tender stage.

4.3.2. Level 3 - Fully adopting BIM (Detailed-design stage)

One of the interesting findings during the LOD 300 stage was that all interviewees were satisfied with the BIM presentation using four walls, which helped the client and end-user to improve their 3D visualisation to see where the building components and their exact locations compared to the layout plans. During the room data interaction, direct instructions were issued to change or modify the layout design by altering the 3D model, which became more practical for all the parties to conclude their decision before the final version of the detailed drawings was prepared. This finding is supported by previous research, which found that visualisation via the BIM model could assist many project

stakeholders in confirming the design options via 3D simulations for the detailed design process (Azizi *et al*., 2021). A few interviewees across the cases also agreed that the contract documentation process was carried out soon after all NCR comments were rectified accordingly by the contractors' team. In Clause 1 of the EIR (Project C), the General Principles regarding the BIM requirements explained the duties on BIM contract documentation that all the parties must fulfil. This finding is consistent with Hardin and McCool (2015), who emphasised the need for BIM contractual documents to serve as a "charter document" that reflects the intent of the stakeholders to accomplish BIM deliverables at specified project milestones.

4.3.3. Level 3 - Fully adopting BIM (<u>Construction stage</u>)

The CDE was used to enhance collaboration whereby the project information was integrated into a platform so that all project actors could share their data and works via a digital process. The key person in charge of monitoring the overall activities was the BIM manager. The respective members were allowed to edit and modify their works via the CDE. High-specification hardware was used to enable BIM to work efficiently by using the platform, and, usually, the client's representatives would inspect and check BIM progress quarterly to ensure that the workflows defined in the BEP were complied with when executing the construction progress. Any variances during the construction stage must also adhere to the EIR procedures, which require all discrepancies to be resolved, analysed, and coordinated in accordance with Clause 3.3.2 of the EIR (Project C). Pishdad-Bozorgi et al. (2018) emphasised the need for all parties to perform their duties by complying with the contract requirements throughout the project lifespan to sustain quality performance when executing BIM-based processes. It is believed that the extensive use of CDE could improve BIM user communication and integration via a virtual environment.

4.3.4. Level 3 - Fully adopting BIM (<u>toward Handover stage</u>)

All the interviewees believed they could produce and come out with the federated as-built model once the associated works related to asset tagging and registration are completed before the handover stage. Many workshops were carried out to facilitate the construction team, including the subcontractors, to finalise the modelling tasks in which they must adhere to all asset registration guidelines and templates. Ample time will have to be considered to validate and verify the completeness of information integrated into the final model to enhance the model's integrity for future reference. These findings corroborate those of Azizi et al. (2021), who suggested further checking to validate any differences between the final as-built model and the tender submission by considering any remeasurement works that occurred after the overall construction is completed.

It can be summarised that the project team understood that the drawings generated from the 3D models need to be bound in the contract documents so that if any contractual issues arise due to design and construction inconsistencies, the drawings could serve as the basis on which the concerned parties could refer. Additionally, collaboration via CDE could be seen as a safety measure to protect all parties, specifically during the data transmission when exchanging digital information. Findings from the cross-case analysis also indicate that any issues arising from the final as-built model must still be monitored during the defects liability period, as the contractor is still liable and obligated to remedy any outstanding or defective works.
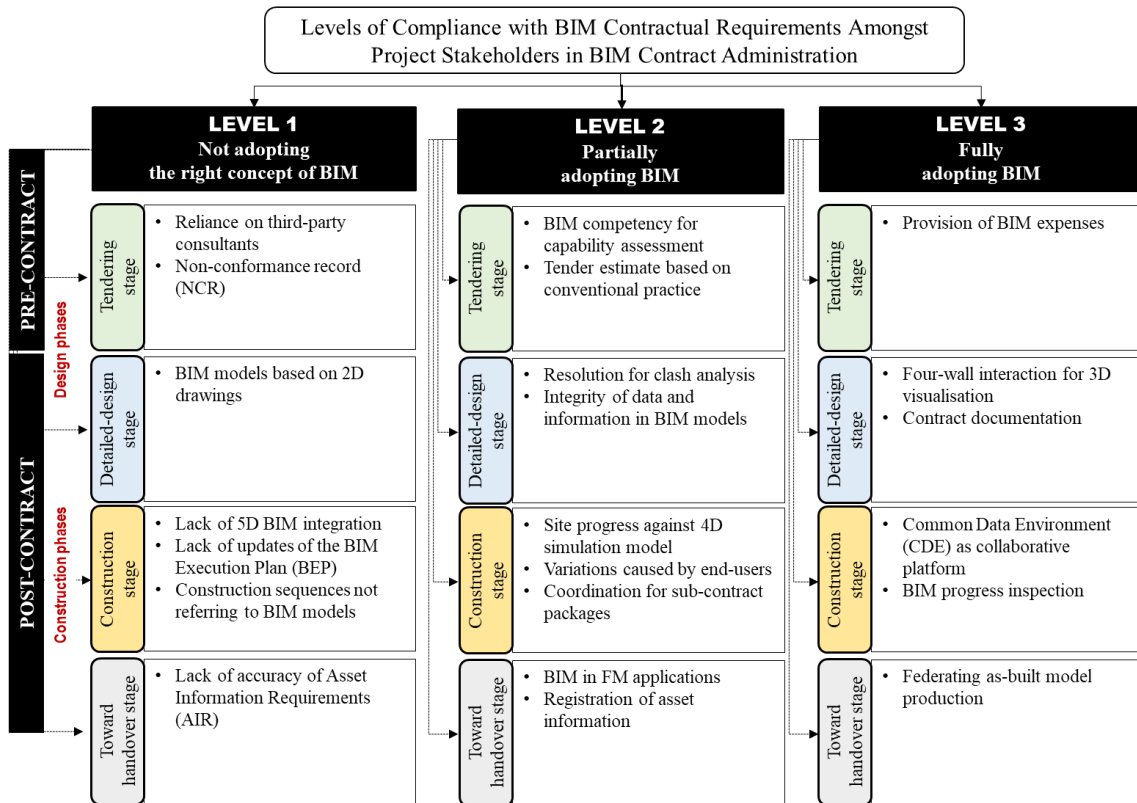
Figure 2. Framework that demonstrates the extent of BIM usage that affects the contract administration of BIM-based construction projects (Source: Authors, 2023)

5. Conclusion

As discussed in the literature, the functions of BIM contract administration have enormous potential to overcome contractual impediments in the conventional project delivery process. The explicit roles and responsibilities, when responded to by complying with contract requirements, could improve many loopholes associated with time management, cost, and quality control. The multiple case studies showed that BIM contract administration was deployed throughout the projects' life cycle, including the tendering phase, since BIM integration requires the various stakeholders to collaborate starting from the early stages. The extent of compliance with the BIM contractual requirements emerged into three main levels ('Level 1 - Not adopting the right concept of BIM', 'Level 2 - Partially adopting BIM', and 'Level 3 - Fully adopting BIM'), as indicated by the semi-structured interviews with the project participants. The findings were then corroborated with the projects' contractual guidelines (EIRs). As contextualised in Figure 3, the framework demonstrates the major themes, categories, and codes that demonstrate the extent of BIM usage that affects the contract administration of BIM-based construction projects.

The preliminary framework reveals some insights from the in-depth process. However, the framework requires validation from industry experts. In addition, the various levels of BIM knowledge, skills, and competencies are some of the study's limitations that could influence the interpretation of the findings. Hence, it is high time to integrate the information management system using the BS EN ISO 19650 standards, which is believed to be able to improve the quality measures until the FM stage for the

operation of the building assets. The explicit contractual requirements integrated with the BS EN ISO 19650 standard should be developed into the client's working manuals and contractor's ISO protocols for BIM implementation. All the required forms and standardised checklists must be provided to improve the validation procedures during the BIM reviewing process at each LOD stage.

The centralised data management system that could integrate with the CDE must also be considered and streamlined with BIM-based contract administration. Future studies may highlight the various punitive measures that align with BIM contractual needs, which must be understood by all project actors, particularly when signing the main contract document, subcontract agreements, or deed of assignments for contracts involving design consultancies and services. This mechanism is crucial to safeguard all liabilities concerning BIM-based processes due to the multiparty involvements.

It can be concluded that an effective contract administration process can be achieved via BIM integration if all parties are willing to become the change agents for digital construction. This practice could provide a better understanding of how existing BIM contractual requirements should be refined and redefined by considering emerging contractual considerations for BIM and other technological advancements. This measure could improve the design and delivery process of construction projects for the future Malaysian construction industry.

Acknowledgement

References

Abd Jamil, A.H., Fathi, M.S. (2019). Contractual issues for Building Information Modelling (BIM)-based construction projects: An exploratory case study. *IOP Conference Series: Materials Science and Engineering*, *513*(1). https://doi.org/10.1088/1757-899X/513/1/012035

Abd Jamil, A.H., Fathi, M.S. (2020). Enhancing bim-based information interoperability: Dispute resolution from legal and contractual perspectives. *Journal of Construction Engineering and Management*, *146*(7), 1–12. https://doi.org/10.1061/(asce)co.1943-7862.0001868

Ahmadi, P.F., Arashpour, M. (2020). An analysis of 4D-BIM construction planning: Advantages, risks and challenges. *Proceedings of the 37th International Symposium on Automation and Robotics in Construction, ISARC 2020: From Demonstration to Practical Use - To New Stage of Construction Robot*, *October*, 163–170. https://doi.org/10.22260/isarc2020/0025

Almarri, K., Aljarman, M., & Boussabaine, H. (2019). Emerging contractual and legal risks from the application of building information modelling. *Engineering, Construction and Architectural Management*, *26*(10). https://doi.org/10.1108/ECAM-06-2018-0224

Alwee, S.N.A.S., Salleh, H., & Zulkifli, U. K. (2021). Strategic process protocol for building information modelling (BIM) contract administration in Malaysia – A concept paper. *Malaysian Construction Research Journal*, *12*(1), 37–52.

Arshad, M.F., Thaheem, M.J., Nasir, A.R., & Malik, M.S.A. (2019). Contractual risks of building information modelling: Toward a standardized legal framework for design-bid-build projects. *Journal of Construction Engineering and Management*, *145*(4), 04019010. https://doi.org/10.1061/(asce)co.1943-7862.0001617

Assaad, R., El-adaway, I.H., El Hakea, A.H., Parker, M.J., Henderson, T.I., Salvo, C.R., & Ahmed, M.O. (2020). Contractual perspective for BIM utilization in US construction

projects. *Journal of Construction Engineering and Management*, *146*(12), 04020128. https://doi.org/10.1061/(asce)co.1943-7862.0001927

Azhar, S., Khalfan, M., & Maqsood, T. (2012). Building information modelling (BIM): Now and beyond. *Australasian Journal of Construction Economics and Building*, *12*(4), 15–28. https://doi.org/10.5130/ajceb.v12i4.3032

Azizi, N.S.M., Yu, T.Z., & Azizi, Z. (2021). Preliminary study of changes in work practices of quantity surveyors in building information modelling (BIM) projects. *International Journal of Sustainable Construction Engineering and Technology*, *12*(1), 140–152. https://doi.org/10.30880/ijscet.2021.12.01.014

Becerik-Gerber, B., Jazizadeh, F., Li, N., & Calis, G. (2012). Application areas and data requirements for BIM-enabled facilities management. *Journal of Construction Engineering and Management*, *138*(3), 431–442. https://doi.org/10.1061/(asce)co.1943-7862.0000433

Brahim, J., Ahmad Latiffi, A., & Fathi, M.S. (2018). Application of building information modelling (BIM) in design and build projects in Malaysia. *Malaysian Construction Research Journal*, *25*(No.2), 29–41.

Braun, V., Clarke, V. (2006). Using thematic analysis in psychology. *Qualitative Research in Psychology*, *3*(2), 77–101. https://doi.org/10.1191/1478088706qp063oa

BS EN ISO 19650-2. (2018). *BS EN ISO 19650-2:2018 - Organization and digitization of information about buildings and civil engineering works, including building information modelling (BIM) - information management using building information modelling Part 2: delivery phase of the*.

Charlesraj, V.P.C., Dinesh, T. (2020). Status of 4D BIM implementation in Indian construction. *Proceedings of the 37th International Symposium on Automation and Robotics in Construction, ISARC 2020: From Demonstration to Practical Use - To New Stage of Construction Robot*, *December*, 199–206. https://doi.org/10.22260/isarc2020/0030

Chen, L., Luo, H. (2014). A BIM-based construction quality management model and its applications. *Automation in Construction*, *46*, 64–73. https://doi.org/10.1016/j.autcon.2014.05.009

Chong, H.Y., Fan, S.L., Sutrisna, M., Hsieh, S.H., & Tsai, C.M. (2017). Preliminary contractual framework for BIM-enabled projects. *Journal of Construction Engineering and Management*, *143*(7), 04017025-1–8. https://doi.org/10.1061/(asce)co.1943-7862.0001278

Creswell, J.W., Creswell, J.D. (2018). Research design - Qualitative, quantitative, and mixed methods approaches. In *Sage* (Fifth edit). SAGE Publications, Inc.

Creswell, J.W., Poth, C.N. (2018). Qualitative inquiry & research design: Choosing among five approaches. In *Sage Publication* (Forth Edit). SAGE Publications, Inc.

Dixit, M. K., Venkatraj, V., Ostadalimakhmalbaf, M., Pariafsai, F., & Lavy, S. (2019). Integration of facility management and building information modelling (BIM): A review of key issues and challenges. *Facilities*, *37*(7–8), 455–483. https://doi.org/10.1108/F-03-2018-0043

Gao, Y., Guo, Q., Zhang, S., & Zhang, J. (2022). Understanding the effect of BIM capability imbalance on opportunistic behaviour: The case of the Chinese construction market. *Journal of Management in Engineering*, *38*(3), 1–12. https://doi.org/10.1061/(asce)me.1943-5479.0001028

Hardin, B., McCool, D. (2015). *BIM and construction management: proven tools, methods, and workflow* (Second Edi). John Wiley & Sons, Inc.

Kamaruzzaman, S.N., Suznan, S.N., & Myeda, N.E. (2023). Building information modelling facilities management (BIMFM) coordination for digital construction projects. *Journal of Facilities Management*, 1–21. https://doi.org/10.1108/JFM-10-2021-0127

Khosrowshahi, F. (2017). Building information modelling (BIM) a paradigm shift in construction. In *Building Information Modelling, Building Performance, Design and Smart Construction* (pp. 47–64). Springer. https://doi.org/10.1007/978-3-319-50346-2

Kumar, B., Hayne, G. (2017). Implementation of level 2 building information modelling strategy for asset procurement. *Management, Procurement and Law*, *170*(5), 190–206.

Lee, Z.P., Rahman, R.A., & Doh, S.I. (2020). Key drivers for adopting design-build: A comparative study between project stakeholders. *Physics and Chemistry of the Earth*, *120*(October), 102945. https://doi.org/10.1016/j.pce.2020.102945

Mahamadu, A.M., Manu, P., Mahdjoubi, L., Booth, C., Aigbavboa, C., & Abanda, F.H. (2019). The importance of BIM capability assessment: An evaluation of post-selection performance of organisations on construction projects. *Engineering, Construction and Architectural Management*, *27*(1), 24–48. https://doi.org/10.1108/ECAM-09-2018-0357

Mahdian, A., Parchami Jalal, M., & Yavari Roushan, T. (2023). Contractual risks of BIM implementation and the proposed contract form for DBB and DB projects. *Journal of Legal Affairs and Dispute Resolution in Engineering and Construction*, *15*(1), 1–19. https://doi.org/10.1061/(asce)la.1943-4170.0000561

Malla, V., Jagannathan, M., & Kumar Delhi, V.S. (2022). Identification of BIM dimension-specific contract clauses in EPC Turnkey projects. *Journal of Legal Affairs and Dispute Resolution in Engineering and Construction*, *14*(1), 04521040-1–13. https://doi.org/10.1061/(asce)la.1943-4170.0000512

Mustaffa, N.E., Xiong, S.K.Z., Mustapa, M., Ariffin, H.L.T., & Ismail, F. (2021). Management of contractual risks in a BIM-enabled project. *AIP Conference Proceedings*, *2428*(November), 060004-1–10. https://doi.org/10.1063/5.0071177

NIBS. (2007). National building information modelling standard version 1 part 1: overview, principles and methodologies. In *National Institute of Building Sciences*. https://doi.org/10.1017/CBO9781107415324.004

Nor, R., Raja, H., Noor, M., Khairil, C., & Che, I. (2021). *Making sense of multi-actor social collaboration in building information modelling level 2 projects : a case in Malaysia*. *21*(4), 89–114.

Okwe, E.I., Olanrewaju, O.I., Heckman, M., & Chileshe, N. (2022). Barriers to building information modelling and facility management practices integration in Nigeria. *Journal of Facilities Management*, *1472–5967*. https://doi.org/10.1108/JFM-12-2021-0153

Olatunji, O.A. (2014). Views on building information modelling, procurement and contract management. *Management, Procurement and Law*, *167*(3), 117–126. https://doi.org/10.1680/mpal.13.00011

Oraee, M., Hosseini, M.R., Edwards, D.J., Li, H., Papadonikolaki, E., & Cao, D. (2019). Collaboration barriers in BIM-based construction networks: a conceptual model. *International Journal of Project Management*, *37*(6), 839–854. https://doi.org/10.1016/j.ijproman.2019.05.004

Pishdad-Bozorgi, P., Gao, X., Eastman, C., & Self, A. P. (2018). Planning and developing facility management-enabled building information model (FM-enabled BIM). *Automation in Construction*, *87*(December 2017), 22–38. https://doi.org/10.1016/j.autcon.2017.12.004

Pittard, S., Sell, P. (2016). *BIM and quantity surveying*. In Routledge.

Sacks, R., Eastman, C., Lee, G., & Teicholz, P. (2018). *A guide to building information modelling for owners, designers, engineers, contractors, and facility managers*. (Third Edit). John Wiley & Sons, Inc.

Singh, H.K.S. (2002) *Engineering and construction contracts management*. *Pre-contract award practice*. LexisNexis.

Winfield, M. (2020). Construction 4.0 and ISO 19650: A panacea for the digital revolution? *Proceedings of Institution of Civil Engineers: Management, Procurement and Law*, *173*(4), 1–23.