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Demystifying Collaboration in BIM Projects under Design-Build Procurement: using Clash Detection as a Use Value

Benjamin Jowett
Northumbria University, United Kingdom

Malak Al Hattab
American University of Beirut, Lebanon

Mohamad Kassem
Northumbria University, United Kingdom

ABSTRACT

Building Information Modelling (BIM) tools and workflows, new procurements methods, and emerging management practices are being adopted on projects to overcome collaboration barriers and improve project performance within the Architecture, Engineering, Construction and Operation (AECO) sector. Academic literature and industry reports recommend the use of collaborative procurement methods such as Design and Build (DB) procurement and Integrated Project Delivery (IPD) when adopting BIM workflows. However, to date there are little operationalization and empirical evidence of the value realization potential when using BIM in conjunction to these procurement methods. This study draws upon five case studies of BIM-based DB projects to analyze and quantify the potential of value realization using Clash Detection as a Use Value. The results reveal potential hurdles inhibiting BIM from reaching its full potential. Accordingly, recommended changes to the current processes are suggested to facilitate BIM in enhancing value on DB projects.

Keywords: Building Information Modelling, Collaboration, Teams Integration, Use Value, Integrated Project Delivery, Design-Bid, Clash Detection

INTRODUCTION

The construction sector of the US, UK, and other countries has been suffering from a constant decline in performance while manufacturing and other industries have been continuously experiencing a boom in productivity (Sveikauskas et al., 2014; Teicholz et al., 2001). The construction sector has consistently been scrutinized for its inefficiency and failure to meet stakeholder expectations and values. The Construction Industry Training Board (CITB) (2016) reveals that both time and cost for design and construction processes are inconsistently predicted and are adversely affecting project stakeholder satisfaction.

The construction sector is built on the interactions and collaboration of multi-disciplinary teams whose processes and information are intertwined. Communication, integration and alignment of values are key success factors given the growing interdependence and complexity of design and construction tasks

(Knotten et al., 2015). Reports spanning across several decades (e.g. Latham, 1994; Egan, 1998; Constructing Excellence, 2009; Cabinet Office, 2011) identified the need for improving project communication and changing adversarial contractual and procurement structures as critical strategies for the construction sector.

One of key process, technology and policy innovations that emerged within the construction sector is Building Information Modeling (BIM). BIM tools and workflows enable project stakeholders to digitally model facility, simulate its performance, and manage information flows across the whole project lifecycle. BIM is increasingly adopted or mandated by central government around the world. For example, the UK government's construction strategy stated that all centrally funded public sector projects needed to achieve Level 2 BIM by April 2016. According to this strategy, the adoption of Level 2 BIM processes is expected to promote the full alignment of supply chains with the people responsible for operating and maintaining the assets (Her Majesty's Government [HMG], 2013). The idealized benefits of BIM in many strategy documents and industry reports (GCCG, 2011) prompted many scholars to investigate the benefits of BIM (Bryde et al., 2013, Love et al., 2014). The collaboration benefits from BIM have been partially operationalised or measured using either quantitative or qualitative key performance indicators (Liu et al., 2016, Oraee et al., 2017, Papadonikolaki et al., 2017, Papadonikolaki and Wamelink, 2017). However, there is still a dearth of studies that investigate collaboration benefits of BIM in conjunction to the procurement framework of projects.

Motivated by Eastman et al. (2008)'s proposition that the use of BIM is clearly advisable in conjunction to Design-Build (DB) procurement, this study aims to address whether the value realization potential of BIM is achieved within DB projects. DB procurement involves a client procuring design and construction services through a single organisation, thereby shifting risk to the supplier whilst also having to only manage a single contract. Under DB delivery, the DB firm subcontracts specific design and construction elements to their suppliers while retaining the single contractual link to the client (Hickethier et al., 2013). The theoretical approach used in this study to link these two strands (i.e. BIM, and DD procurement) adopts some basic Value Management concepts. Value Management is a structured approach to determine what value means to the organization and the project, then delivering to those requirements (Association of Project Management [APM], 2012). The Office of Government Commerce [OGC] (2007) identified that the benefits of having successful value management include more effective team working and the reduction of unnecessary project costs. Both BIM and Value Management are considerably growing within the industry; however, the realisation of their actual benefits remains limited due to the prominence of traditional procurement methods (Eadie et al., 2014; Lindblad, 2013).

While BIM, Value Management, and collaborative procurement strategies concur towards the same outcomes, there is a dearth of studies that combines concepts from across the three subjects. The aim of this chapter is to investigate how DB projects can enhance Value, specifically Use Value, through the utilization of BIM. The specific objectives are:

- Highlight any alignments or misalignments between BIM, Value, and DB/IPD processes by reviewing related literature on these subject areas;
- Determine the effectiveness of BIM processes for enhancing Use Value on DB projects by focusing on the transition from the Preconstruction design phase into the Construction design phase; and
- Identify any necessary improvements or alterations to the design and construction processes to facilitate BIM adoption and its ability to enhance Value on DB projects.

KEY CONCEPTS AND DEFINITIONS

This section introduces the key concepts and definitions from across BIM, DB and Value Management that are relevant to the proposed study. The understanding of these concepts is important to justify the linking proposed across the three subjects (i.e. BIM, DB, and value management), the proposed research methodology, and the empirical analysis of the case studies.

Building Information Modeling

BIM is the current expression of digital innovation in the construction sector (Succar and Kassem, 2015). BIM is a value creating collaboration through the entire lifecycle of an asset, underpinned by the creation, collation and exchange of shared three dimensional (3D) models and intelligent, structured data attached to them (UK BIM Task Group, 2013). It helps stakeholders make educated decisions and execute the project with reduced costs, schedules, rework, and better quality (Azhar, 2011; Eastman et al., 2008; Redmond et al., 2012). The key value proposition of BIM lies in enabling collaboration between participants throughout the project's lifecycle while achieving stakeholder requirements with improved predictability (Demian & Walters, 2013; Eisenmann & Park, 2012).

In BIM workflows there are different levels that determine varying levels of BIM implementation among the project participants and project stages. In industry, four levels are proposed by the UK BIM Task Group: Level 0, Level 1, Level 2, and Level 3 and are summarized in Figure 1 (BIM Industry Working Group, 2011). Level 2 is the mandated level by the UK government. Level 2 BIM is a collaborative way of working, in which 3D models with the required data are created in separate discipline models according to a set of guides, standards and specifications (Kassem et al., 2016). A research-based concept that implicitly embeds the level of implementation among project teams and stages is the BIM capability stages of Succar (2009). The three capability stages are: modelling (BIM Stage 1), collaboration (BIM Stage 2) and integration (BIM Stage 3) and their effect on the project lifecycle phases and corresponding project teams is shown in Figure 2.

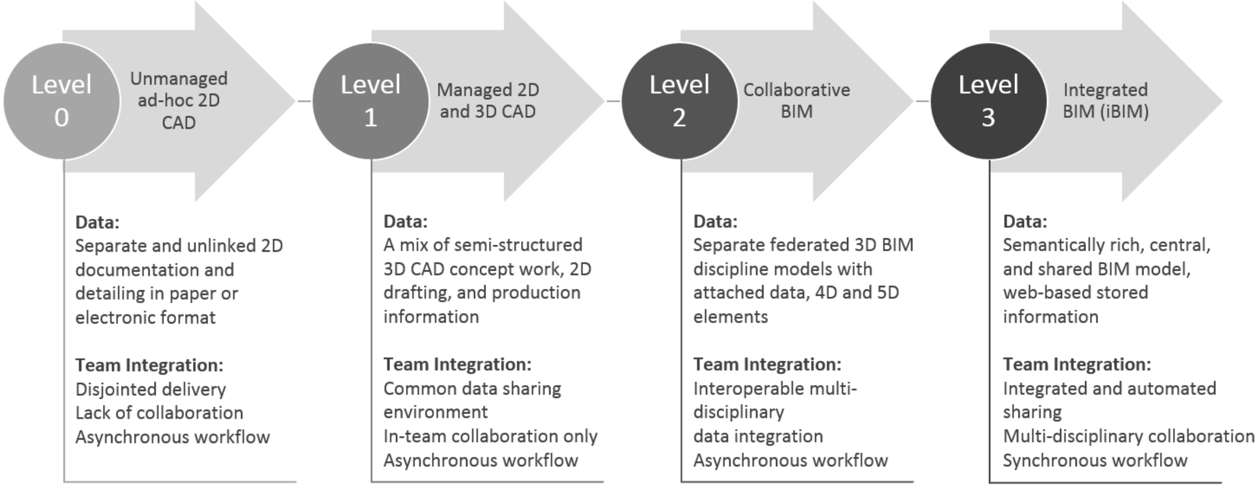


Figure 1. BIM implementation levels (adapted from British Standards Institution [BSi], 2013)

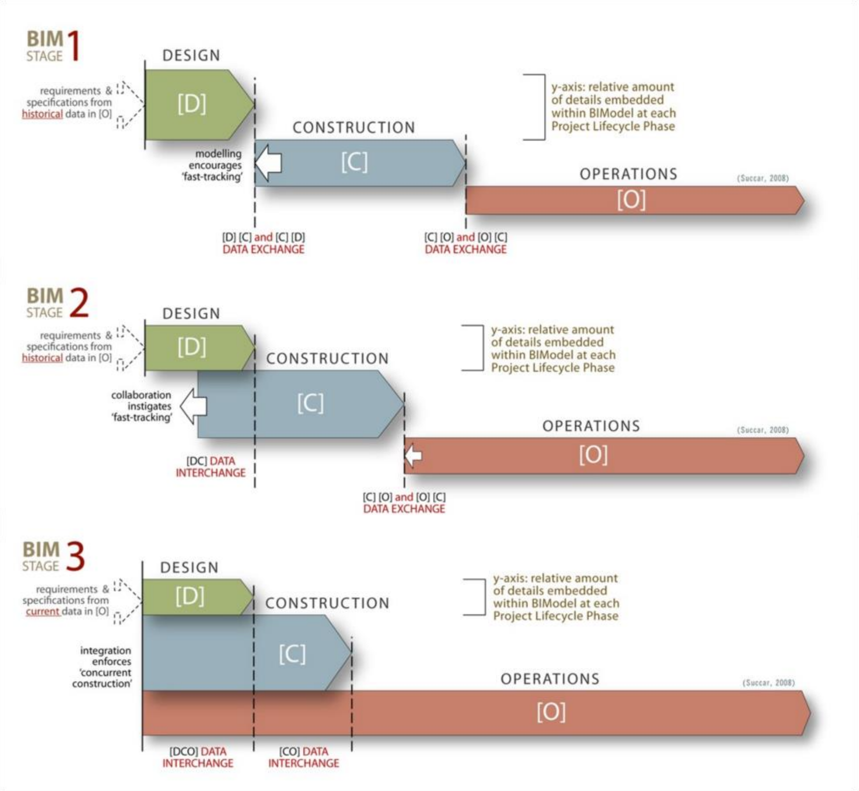


Figure 2. BIM Capability Stages and their effect on project stages and teams (© Copyright 2009, Succar. Used with permission.)

Value Management

Value has varying definitions dependent upon an individual's core beliefs, morals, and ideals (Thyssen et al. 2008; Thomson et al., 2003) and human interest (Korsgaard, 1986; Thomson et al, 2003). Contemporary attempts defining value tend to be increasingly mathematical (Thyssen et al. 2008) and argue that many values are objective and can be quantified (Moore, 1998; Thyssen et al., 2008). The most commonly adopted definition of value in construction is expressed as the ratio between Function and Cost (Park, 1999). Table 1 presents various definitions of value as presented in current literature.

Table 1. Definitions of value

Definitions of Value	Source
Value = Time, Cost, Quality	Best & De Valence (1999)
Value = the relationship between the contribution of the function and the satisfaction of the need and the cost of the function	BSi (1997)
Value = Functionality, Build Quality & Impact (additionally: Finance, Time, Environment & Resources)	Construction Industry Council [CIC] (2006)
Value = Benefits / Price	Fallon (1971)
Value = Capital Cost, Operating Cost, Time, Exchange (earning potential or sale worth of completed project), Environmental Impact, Utility & Esteem	Kelly (2007)
Value = Function / Cost	Park (1999)
Value = Function, Form, Economy & Time	Pena & Parshall (2001)
Value = Use Value, Esteem Value & Exchange Value	Thiry (1997)

Identifying and bringing all key stakeholders together at the correct time in the project is necessary for an effective Value Management process (Male et al., 2007). MacLeamy's curve (2008) states the need for more integration and effort investment at the early design phase to prevent costly and time-consuming changes. Information sharing and communication is key in all proposed Value Management processes. In the construction sector, the traditionally low and ineffective use of information technology contributes to poor communication across construction projects and affects value realisation. Empirical evidence from case studies were found about the positive impact of BIM on communication and consequently on value realisation (Shahrin & Johansen, 2013). Levels of supply chain integration (McCormack & Lockamy III, 2004) within a BIM workflow were also found to be linked with a suppliers' BIM maturity (Papadonikolaki et al., 2015).

Procurement methods: DB and IPD

Traditional construction projects are procured by a client who engages consultants to deliver design work which is then subject to competitive tender by main contractors. The main contractors collate prices from subcontractors and submit a lump sum bid. This traditional procurement structure inhibits cooperation between project teams and diminishes their ability to maximize value on a project (Matthews & Howell, 2005). These limitations of the traditional procurement method called upon more integrated and collaborative forms for procuring assets within the construction sector.

IPD emerged to address the shortcomings of the adversarial relationships associated with traditional procurement. Under IPD, key stakeholders from each discipline are present from project inception to ensure that the project design meets the needs of all stakeholders (American Institute of Architects [AIA], 2007; AIA California Council, 2008). Although several professional organisations have supported the further development of IPD and research has demonstrated its benefits and challenges (Matthews & Howell, 2005; Cohen, 2010), the uptake of this approach by the construction industry remains limited (Becerik-Gerber & Kent, 2010; Looi, 2013).

Design and Build contracts are more popular primarily due to having a longer track-record than IPD (Darrington, 2011). Under DB contracts, the main contractor is responsible for both the design and construction work on a project for an agreed lump-sum price. Being responsible for design, the main contractor can appoint design consultants to carry out this work if they lack this expertise in-house. Furthermore, some designers will become appointed at different stages where, for example, construction designers only become involved until later stages, whereas consultants (e.g. Architect; Mechanical and Electrical (or services) Engineer; Quantity Surveyor or Costs Manager; Structural engineer, and Project manager) may be involved much sooner (Design-Build Institute of America [DBIA], 2017). DB procurement allows for various levels of integration through its different procurement forms, namely, qualifications-only selection, best value selection, and price driven selection.

Although both IPD and DB aim to achieve enhanced integration compared to traditional structures, the underlying concepts and contractual arrangements differ. These differences can be summarized into the following categories: risk allocation, team selection methods, degree of owner involvement, and accountability and risk management. Despite these differences, DB is contractually well-suited for increasing the collaboration among project team members at the project's start, specifically the designers and constructors, which makes the implementation of IPD principles possible. However, a greater level of involvement is required on the client's behalf to achieve IPD's benefits (AIA, 2007).

Under IPD, the stakeholders work collaboratively and make collective decisions while adjusting target cost to achieve the desired value. The wider involvement of the project team on the decision making improves the team's understanding of the project requirements (Ballard et al., 2012) while keeping aligned the interests of stakeholders.

On the other hand, within the DB the client sets the project requirements and then the main contractor determines how to design, build, and manage the construction process to stay within the target price and value (Cohen, 2010; Ballard et al., 2012; Karasulu et al., 2013). This means that DB does not provide the same level of transparency IPD brings and is unable to achieve the alignment of parties' interests achievable within IPD (Ballard et al., 2012; Karasulu, 2013). However, it does offer a project delivery solution for less educated clients (Karasulu et al., 2013).

RELATED LITERATURE

The studies that have addressed the intersections between BIM, Value, DB, and IPD subject areas are listed in Table 2. A few studies have explored the alignment between BIM and DB but they did not address their impact on value realization.

With the absence of any industry standards for the measurement of BIM benefits, it is important to redefine project delivery and management processes to harness the potential of BIM (Ilozor & Kelly, 2011; Bockstael & Issa, 2016; Leite et al., 2010). Reported benefits can be reaped through the alignment between BIM and IPD methods around one integrated model as suggested by Ilozor and Kelly (2011). Mcgraw-Hill Construction (2012) presented the benefit of specifically using Clash Detection and Avoidance as one of the immediate benefits of utilizing BIM on projects. They further noted the value of identifying significant clashes prior to commencing construction work to avoid substantial costs in reworking. The findings of Papadonikolaki et al. (2015) indicated that there are benefits to be derived from the utilization of BIM with an integrated supply chain, which could be applied to the DB scenario.

The utilization of Clash Detection and Avoidance on commercial construction projects was further investigated by Bockstael and Issa (2016). They suggested that the avoidance of design conflicts can result in a reduction of Requests for Information (RFI) and design-related change orders and subsequently in costs and wastes saving. Increasing the Level of Definitions (LOD) within a design model can improve the design accuracy and the ability of BIM tools to detect clashes, and subsequently enhance decision making while reducing conflicts (Leite et al., 2010). Yet, it is necessary to filter irrelevant clashes when investigating and assessing the results of the clash detection process (Leite et al., 2010).

The realignment of business processes with technology use should entail an understanding of the individualities of the construction process (Koskela & Kazi, 2003). For example, the integration of BIM and lean processes requires any process change to be rooted in the conceptual understanding of the theory of production in construction (Koskela et al., 2009). Similarly, much of the literature surrounding Value Management seeks to align with an IPD structure and little considerations is given to DB contracts despite the assertions of Looi (2013) and Darrington (2011) that clients are still more disposed to pass risk down the supply chain in methods such as DB rather than pursuing an IPD structure. Owen et al. (2010) highlighted that IPD, BIM, and Value are commonly developed in isolation from one another and there are limited studies investigating their alignments.

Some market-wide processes proposing some alignment between project delivery processes and BIM workflows have been proposed. For example, the Royal Institute of British Architects (RIBA) updated their standard plan work (i.e. RIBA Plan of Work 2013) to include the alignment with the Information Exchanges that occur within a BIM process. However, there is still a dearth of studies investigating such an alignment and in particular, the transition from one of its stages to the next. Project stakeholders become involved in a project at different phases depending on the procurement method adopted which may also affect value realization. Hence, it is necessary to understand: the interaction between stakeholders across the project lifecycle; how this interaction varies within BIM workflows under different procurement methods, and its effect on value realization. This paper addresses this gap by focusing on the transition from the preconstruction design stages (Stages 0 - 4) to the Construction stage (Stage 5).

Table 2. Literature review interaction matrix

Source	BIM	Value	IPD	DB	Literature Summary
AIA (2007)	x		x		IPD Guide book
Azhar et al. (2011)	x		x		Case study approach to investigate time and cost savings
Bercerik-Gerber & Kensek (2010)	x		x		Survey approach to investigate BIM research trends and directions
Bouazza & Greenwood (2017)	x	x	x		Literature review paper to discuss opportunities linking BIM and Knowledge Management
Bryde et al. (2013)	x		x		Case study approach to investigate benefits of BIM on 35 projects using secondary data
BSi (2013)	x				Level 2 BIM Standard
Darrington (2011)			x	x	Paper discussing possibility of using DB contract in an IPD approach
Eastman et al. (2011)	x		x		Guide book on BIM
Froese (2010)	x		x		Paper discussing integration of ICT & BIM into project management
Ilozor & Kelly (2011)	x		x		Literature review on BIM, IPD & partnering
Shahrin & Johansen (2013)	x	x			Interviews within 2 case study projects investigating meeting client requirements using BIM
Karasulu et al. (2013)	x	x	x		Literature Review and interview to investigate advancement of TVD in IPD using BIM
Kassem et al. (2014)	x		x		Literature Review and design competitions to test adoption of BIM protocols for collaborative work processes
Kelly (2007)		x			Action research in workshops to investigate client values
Matthews & Howell (2005)			x	x	Case study to demonstrate benefits of using IPD
Owen et al. (2010)	x		x		Literature Review and paper discussing challenges for adopting integrated design
Papadonikolaki et al. (2015)	x		x		Case Study research to investigate use of BIM and integrated supply chains
SEC (2007)		x	x		Memorandum by SEC advocating use of IPD
Smith & Tardif (2009)	x				Guide book on implementing BIM
Talebi (2014)	x	x	x		Literature review on benefits and challenges of BIM
Thyssen et al. (2008)		x			Case study and workshop to investigate early engagement for value creation
Aibinu & Papadonikolaki (2016)	x			x	Case study research on the relationship between DB procurement and coordination from BIM

BIM USE TO ENHANCE VALUE ON DB PROJECTS: EVIDENCE FROM PRACTICE

Research Methods

The lack of studies on the use of BIM for enhancing value on DB projects necessitates the collection of relevant data and evidence from practice. Cross-sectional case study research design is used to explore the effect on value when adopting BIM workflows under DB procurement. Quantitative measures were utilized to evaluate specific project data and support themes captured through qualitative data collection. The adopted research methods for fulfilling the posed aim are discussed in this section.

Concepts and Measures

The three concepts underpinning this study are: Value, BIM, and project team integration. It is important to establish a consistent objective view of what Value means within construction projects while also accounting for value's subjective aspects. The definition provided by Kelly (2007) is used in this study and detailed in Table 3. The Utility as a Value Criteria, identified by Thiry (1997) and Kelly (2007) as being a key component of delivering value, was selected for this study as it is a concept that can be transposed and applied across multiple projects compared to other project specific Value Criteria such as Capital Cost, Operational Cost, etc.

Table 3. Value criteria on construction projects (adapted from Kelly, 2007)

Value Criteria	**Measure**
Capital Cost (CAPEX)	All investment costs incurred prior to project completion
Operational Cost (OPEX)	All costs incurred after project completion until the client's time horizon
Time	Time from initial project workshop until completion
Exchange	The earning potential or sale worth of the completed project
Environmental Impact	Impact on Land, Amount of Carbon utilized during project life-cycle
Utility	Use Value
Esteem	Regard/Respect benefits to the client from the world at large due to the project

Defining BIM and clarifying the level of implementation is necessary when evaluating its impact on enhancing value as previous studies (e.g. Papadonikolaki et al; 2015) showed that these can be correlated. This study adopts:

- The definition established by BSi (2013) for the BIM levels (Figure 1) to represent the levels of BIM implementation within the practical context of the selected projects; and
- Succar (2009)'s three BIM capability stages (i.e. Modelling, Collaboration, and Integration) – each inferring a certain level of fast tracking or overlap between project stages/stakeholder – to (1) analyze and visualize the current effect of BIM use and the procurement method (i.e. DB) on value realization (i.e. Use Value), and (2) subsequently visualize the proposed improvement.

The selected case study projects are UK-based and adopted the RIBA Plan of Work 2013 (RIBA, 2013). Table 4 shows the mapping between RIBA Plan of Work stages and the corresponding stages of Succar's framework. The study will focus on investigating the transition from RIBA Stage 4 to RIBA Stage 5 within DB BIM-based projects. The corresponding area of investigation within the Succar's framework is highlighted in Figure 3.

Table 4. Alignment of project stages (Succar, 2009; RIBA, 2013)

Succar (2009) Project Phases	**Equivalent RIBA 2013 Stages**
Design	0, 1, 2, 3, and 4
Construction	5
Operations	6 and 7

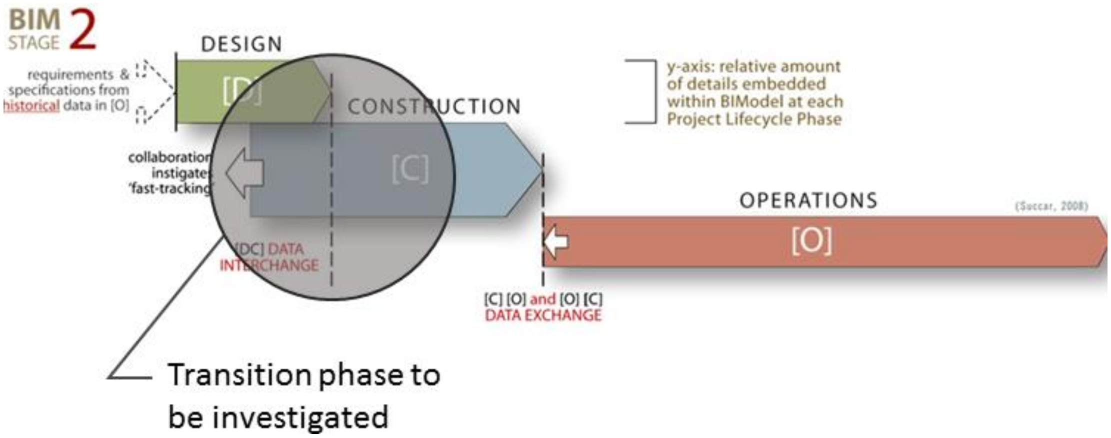


Figure 3. Project transition phase to be investigated (adapted from Succar, 2009)

Data Collection

Primary project data were collected from five construction projects across the UK. This data helps identify both the benefits and challenges encountered when adopting BIM processes in DB projects. Utility will be referred to as the Use Value meaning that the item under investigation must have a specific use or benefit to deliver Utility (Kelly, 2007). The key areas of Use Value that can be realized from a construction project employing BIM are defined by Bryde et al. (2013) as: cost and time reduction or control, communication improvement, coordination enhancement, quality increase or control, risk reduction, and scope clarification.

Building on the findings of the literature review, Clash Detection and Avoidance is identified as one of the main BIM uses that generate cost and time reductions and enhanced coordination (Mcgraw-Hill Construction, 2012; Leite et al., 2010; Bockstael & Issa, 2016). This BIM use, therefore, formed a fundamental data source for measuring the Use Value of BIM across the five selected projects.

One of the objectives of the research is to investigate the transition from the Preconstruction Design (Stage 4) into Construction Design (Stage 5) and the corresponding integration of the supply chain. Hence, collecting data from both phases is necessary to investigate such transition. The cross-sectional nature of this study helped this approach by enabling the collection of such data from across five projects.

The selection of the case studies included a representative sample of Design and Build projects to ensure reliability and generalization of the research. The selection was based on the contract value of the projects ranging between £5m and £25m in value and delivered under DB procurement. An overview of each case study is provided in the following section.

Case Study Overviews

An overview on each case study is presented in Figure 7. Background information about each project includes the contract value, the procurement method, start and end dates, and the project team structure.

Case Study A comprises 7600m^2 of teaching and workshop space including specialist rail equipment such as 150m of external track and catenary. The completed building is intended to train engineers to meet the future needs of the wider HS2 project as well as those in the rail sector. The project was procured via the Scape Framework which supports the DB procurement structure. The direct client for the project was a representative of the end user which added a further line of communication to an otherwise conventional DB team structure as shown in Figure 4.

Case Study B involves the new build construction of a Swimming Pool with associated changing rooms, gymnasium and fitness studio area. The completed building is intended to replace a similar facility that existed on the same site due to the previous building deteriorating beyond repair. It was procured via the Scape Framework, aligning with the DB procurement structure. The client for the project was also the end user, thus simplifying project communications in terms of project requirements.

Case Study C involves the new build construction of a Leisure Centre consisting of a learner and main pool, gymnasium, changing areas, fitness studios, and sports courts. The building will replace an equivalent building on an adjacent site which had become costly to maintain and run whilst deteriorating in condition. It was also procured via the Scape Framework and has the same project team structure as Case Study B.

Case Study D consists of a 5000m^2, three-storey building which is being constructed to BREEAM Excellence standards. The building will comprise of office, laboratory, and workshop space for up to 700 people. It is designed to be a central hub for the science park that it is located on and will become an important regional center for a range of businesses from start-ups to large corporate companies. Case Study D was procured via the North Wales Construction Framework, which also coincides with the DB structure and has the same project team structure as Case Study B and C.

Case Study E involves the construction of a 450-place secondary school including class rooms, sports hall, conferencing facility, as well as public arts space and gallery. The project has been constructed adjacent to an existing sister Primary School facility and designed to offer open and flexible learning spaces. It was procured via the EFA Framework, complementing the DB procurement structure. The client was a representative of the end user while also involving the use of a Project Management consultant which added further lines of communication to the team structure shown in Figure 4.

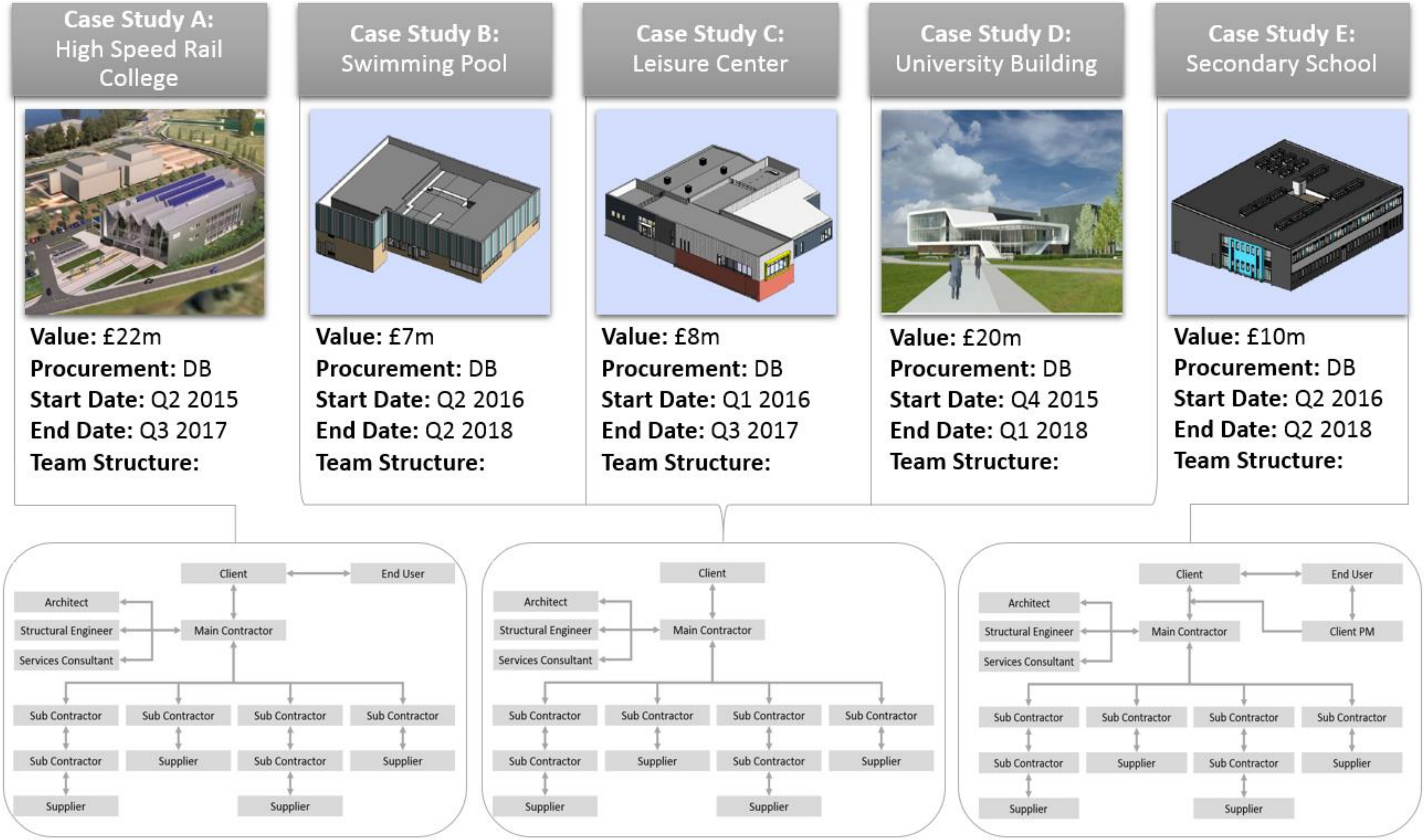


Figure 4. Case study projects background information

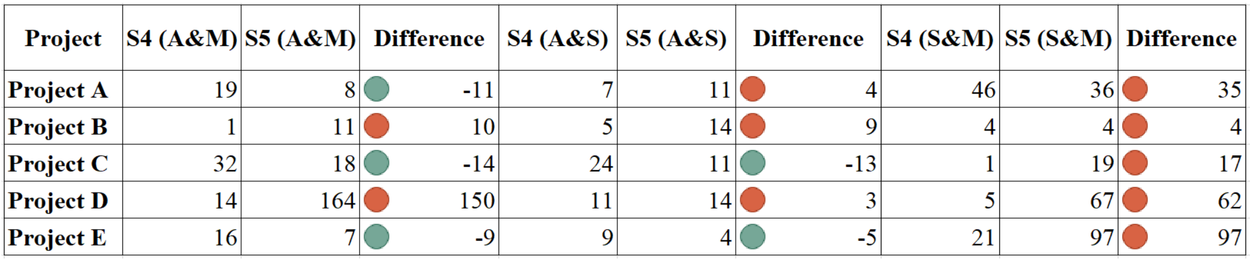
ANALYSIS OF CASE STUDY DATA

Data pertaining to the two Use Value items, (1) clash detection and avoidance and (2) project team integration, has been collected on each project and aggregated across the five case studies to facilitate the analysis. Such data will be presented in this section for each project and will be analyzed across all projects in the next section.

Clash Detection and Avoidance

The number of clashes from the federated BIM models is recorded at the end of Stage 4 (Design) and at the onset of Stage 5 (Construction). Clashes are investigated between each pair of disciplines: architectural (denoted by A) and MEP (denoted by M); architectural and structural (denoted by S) packages, and structural and MEP packages. It is also necessary to filter the clashes for actual and irrelevant/non-clashes as suggested by Leite et al. (2010). These values are summarized in Table 5 for the five case studies for each pair of trades which also shows differences in the number of clashes during the transition from Stage 4 and Stage 5. All projects had an increase in the number of clashes between at least one pair of trades during the transition from Stage 4 to Stage 5. In particular, clashes between Structural and MEP increased in four of the case studies during the transition from Stage 4 to Stage 5.

Table 5. Actual clashes at Stages 4 and 5 for the five case studies



Project	S4 (A&M)	S5 (A&M)	Difference	S4 (A&S)	S5 (A&S)	Difference	S4 (S&M)	S5 (S&M)	Difference
Project A	19	8	🟢 -11	7	11	🔴 4	46	36	🔴 35
Project B	1	11	🔴 10	5	14	🔴 9	4	4	🔴 4
Project C	32	18	🟢 -14	24	11	🟢 -13	1	19	🔴 17
Project D	14	164	🔴 150	11	14	🔴 3	5	67	🔴 62
Project E	16	7	🟢 -9	9	4	🟢 -5	21	97	🔴 97

The number of model components for each case study at Stage 4 and Stage 5 are summarized in Table 6. The table also shows whether there has an increase or decrease in the number of model components for each discipline during the transition from preconstruction to construction. The number of model components increased for all trades across all projects when passing from Stage 4 to Stage 5 with the exception of the Architectural disciplines in Projects B and C.

The BIM authoring tools of each design package are listed in Table 7. For the structural trade, the data shows that there has been a change in the adopted design package across all projects when transitioning from Stage 4 to Stage 5.

Table 6. Disciplines showing increase in number of model components between Stage 4 and Stage 5

Case Study	**Increase in number of model components from Stage 4 to Stage 5**				
	Architectural	**Structural**	**MEP**	**Total Component count Stage 4**	**Total Component count Stage 5**
A	Yes	Yes	Yes	17085	24699
B	No	Yes	Yes	5339	16938
C	No	Yes	Yes	23725	49405
D	Yes	Yes	Yes	17398	34914
E	Yes	Yes	Yes	14717	18704

Table 7. **C***ase studies entailing a change in the type of authoring tools used* **between Stages 4 and 5**

Case Study	**Native Authoring Tool**					
	Stage 4 Architecture Format	**Stage 5 Architecture Format**	**Stage 4 Structure Format**	**Stage 5 Structure Format**	**Stage 4 MEP Format**	**Stage 5 MEP Format**
A	Archicad	Archicad	Revit	Tekla	Revit	Revit
B	Revit	Revit	Revit	Strucad	Revit	Revit
C	Revit	Revit	Revit	Strucad	Revit	Revit
D	Revit	Revit	Revit	StruMIS	Revit	Revit
E	Revit	Revit	Revit	Strucad	Revit	Revit

Project Team Integration

The stage at which teams get involved on the project and the level of team integration depends on the procurement structure and contractual arrangements. However, the level of BIM implementation may either induce different engagement dynamics or be distorted by default engagement structure of such procurement methods. Exploring the involvement of project teams can help determine the differences in the input of organizations between the Preconstruction and Construction stages of a project. It can also provide insights to enhance integration and the Use Value of the implemented BIM capability stage.

The level of organizational integration and involvement at Stages 4 and 5 is summarized in Table 8. The data shows that across all projects there has been at least one specialist trade who get involved prior to being awarded a contact.

Table 9 presents the level of details (LOD) [the geometric part of the Level of Definitions] of each BIM model element at Stages 4 and 5. The data shows that (1) different LODs co-exist at the same stage to reflect the actual decision making and the client requirements, and (2) across all projects there has been an increase in the LOD for LOD4 to LOD5 for several work packages.

Table 10 shows the responsibility for the design of different elements at Stage 4. At this stage the responsibility for all components, with the exception of filtration systems, reside with the consultant.

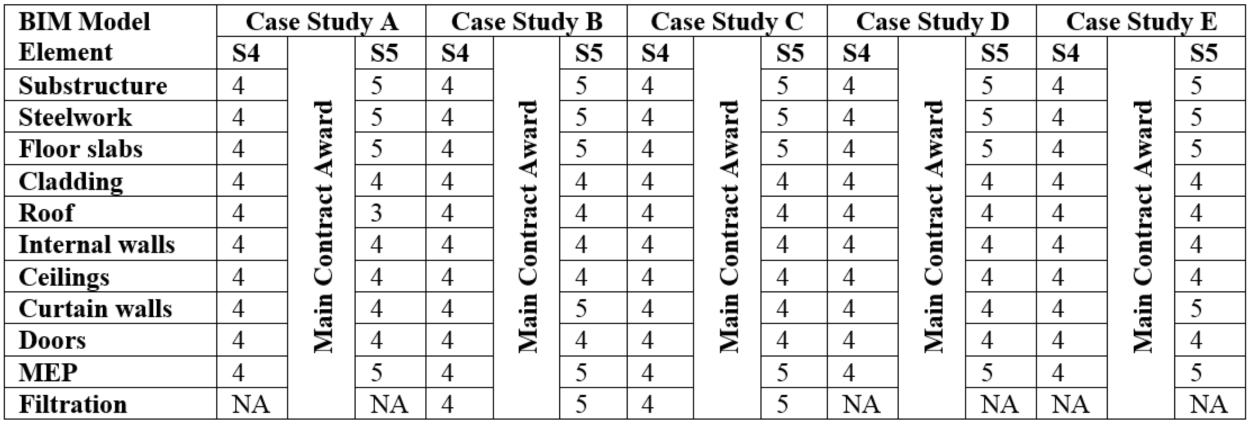
Table 11 shows the responsibilities for the design of different elements and their corresponding BIMs (models). From this data, there appears to be a shift between the BIMs (models) authoring responsibility and the corresponding design responsibility between stages 4 and 5. In other words, the player responsible for the design is not responsible for authoring the corresponding BIM (model) which is ultimately used in clash detection for coordination purpose. All the data about team integration from across the five case studies is aggregated in Table 12 to provide a clearer analysis of the changes occurring between Preconstruction and Construction.

Table 8. Organizations involvement at Stages 4 and 5

Organization	Case Study A			Case Study B			Case Study C			Case Study D			Case Study E		
	S4		**S5**	**S4**		**S5**	**S4**		**S5**	**S4**		**S5**	**S4**		**S5**
Main Contractor	2	**Main Contract Award**	2	2	**Main Contract Award**	2	2	**Main Contract Award**	2	2	**Main Contract Award**	2	2	**Main Contract Award**	2
Architectural Engineer	2		2	2		2	2		2	2		2	2		2
Structural Engineer	2		2	2		2	2		2	2		2	2		2
Steelwork Consultant	2			2			2			2			2		
MEP Consultant	2			2			2			2			2		
Steelwork Supply/Design	2*		2	2*		2			2	2*		2	2*		2
MEP Supply/Design	2*		2			2			2	2*		2			2
Cladding and Roofing	2*		2			2			2	2*		2			2
Curtain Walling			2			2			2	2*		2			2
Filtration	NA		NA	2		2	2*		2*	NA		NA	NA		NA

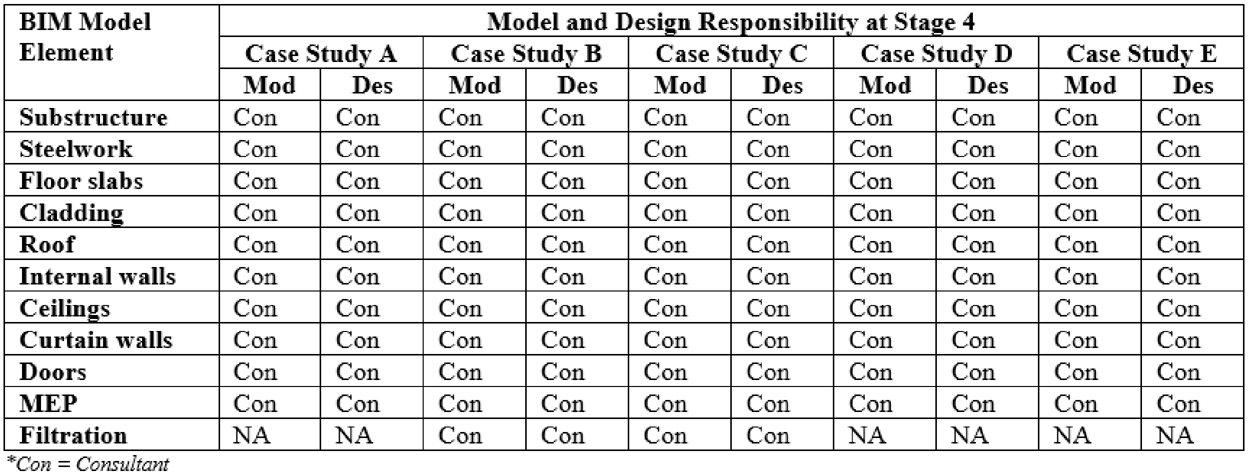
X denotes that an organization was involved prior to being awarded a subcontract*
S4=Stage 4, S5=Stage 5

TABLE 9. LOD FOR EACH BIM MODEL ELEMENT AT STAGES 4 AND 5



BIM Model Element	Case Study A			Case Study B			Case Study C			Case Study D			Case Study E		
	S4		**S5**	**S4**		**S5**	**S4**		**S5**	**S4**		**S5**	**S4**		**S5**
Substructure	4	**Main Contract Award**	5	4	**Main Contract Award**	5	4	**Main Contract Award**	5	4	**Main Contract Award**	5	4	**Main Contract Award**	5
Steelwork	4		5	4		5	4		5	4		5	4		5
Floor slabs	4		5	4		5	4		5	4		5	4		5
Cladding	4		4	4		4	4		4	4		4	4		4
Roof	4		3	4		4	4		4	4		4	4		4
Internal walls	4		4	4		4	4		4	4		4	4		4
Ceilings	4		4	4		4	4		4	4		4	4		4
Curtain walls	4		4	4		5	4		4	4		4	4		5
Doors	4		4	4		4	4		4	4		4	4		4
MEP	4		5	4		5	4		5	4		5	4		5
Filtration	NA		NA	4		5	4		5	NA		NA	NA		NA

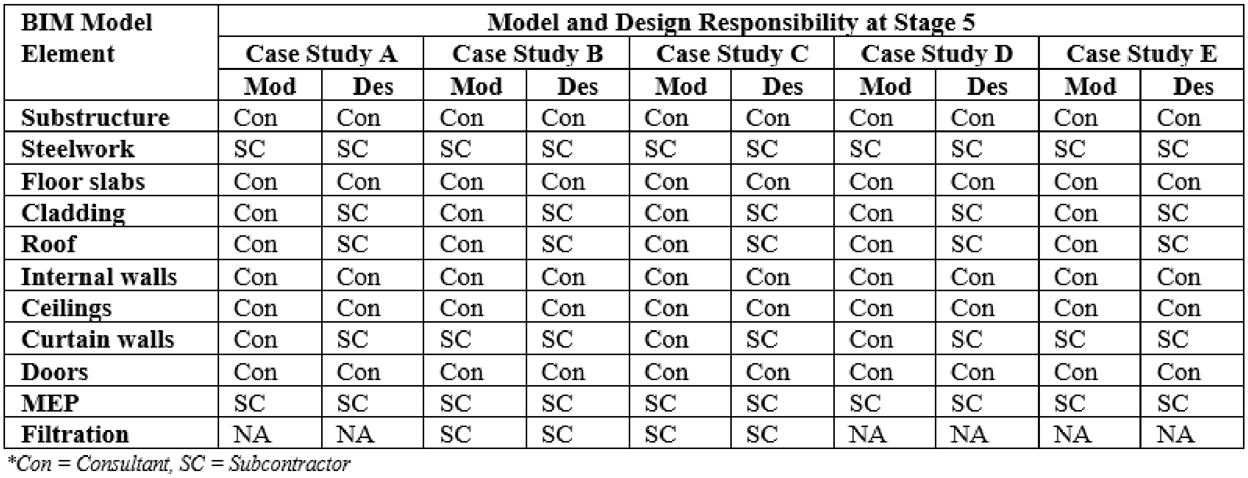
Table 10. Model and design responsibility at stage 4



BIM Model Element	Model and Design Responsibility at Stage 4									
	Case Study A		Case Study B		Case Study C		Case Study D		Case Study E	
	Mod	Des	Mod	Des	Mod	Des	Mod	Des	Mod	Des
Substructure	Con	Con	Con	Con	Con	Con	Con	Con	Con	Con
Steelwork	Con	Con	Con	Con	Con	Con	Con	Con	Con	Con
Floor slabs	Con	Con	Con	Con	Con	Con	Con	Con	Con	Con
Cladding	Con	Con	Con	Con	Con	Con	Con	Con	Con	Con
Roof	Con	Con	Con	Con	Con	Con	Con	Con	Con	Con
Internal walls	Con	Con	Con	Con	Con	Con	Con	Con	Con	Con
Ceilings	Con	Con	Con	Con	Con	Con	Con	Con	Con	Con
Curtain walls	Con	Con	Con	Con	Con	Con	Con	Con	Con	Con
Doors	Con	Con	Con	Con	Con	Con	Con	Con	Con	Con
MEP	Con	Con	Con	Con	Con	Con	Con	Con	Con	Con
Filtration	NA	NA	Con	Con	Con	Con	NA	NA	NA	NA

**Con = Consultant*

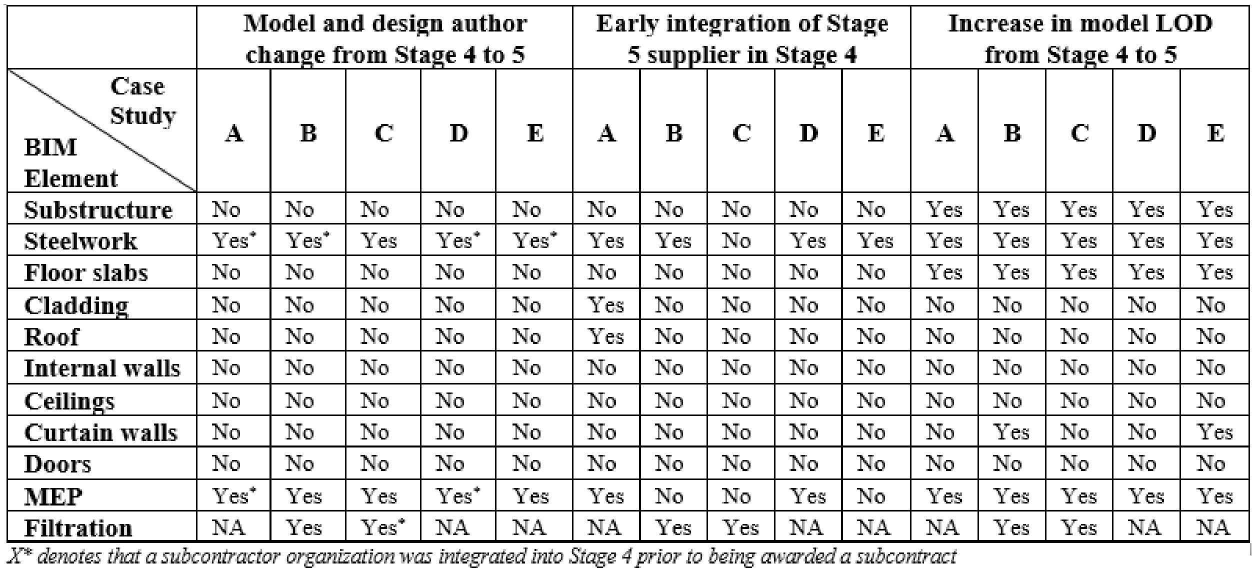
Table 11. Model and design responsibility at stage 5



BIM Model Element	Model and Design Responsibility at Stage 5									
	Case Study A		Case Study B		Case Study C		Case Study D		Case Study E	
	Mod	Des	Mod	Des	Mod	Des	Mod	Des	Mod	Des
Substructure	Con	Con	Con	Con	Con	Con	Con	Con	Con	Con
Steelwork	SC	SC	SC	SC	SC	SC	SC	SC	SC	SC
Floor slabs	Con	Con	Con	Con	Con	Con	Con	Con	Con	Con
Cladding	Con	SC	Con	SC	Con	SC	Con	SC	Con	SC
Roof	Con	SC	Con	SC	Con	SC	Con	SC	Con	SC
Internal walls	Con	Con	Con	Con	Con	Con	Con	Con	Con	Con
Ceilings	Con	Con	Con	Con	Con	Con	Con	Con	Con	Con
Curtain walls	Con	SC	SC	SC	Con	SC	Con	SC	SC	SC
Doors	Con	Con	Con	Con	Con	Con	Con	Con	Con	Con
MEP	SC	SC	SC	SC	SC	SC	SC	SC	SC	SC
Filtration	NA	NA	SC	SC	SC	SC	NA	NA	NA	NA

**Con = Consultant, SC = Subcontractor*

Table 12. Summary analysis of case studies for team integration use value area



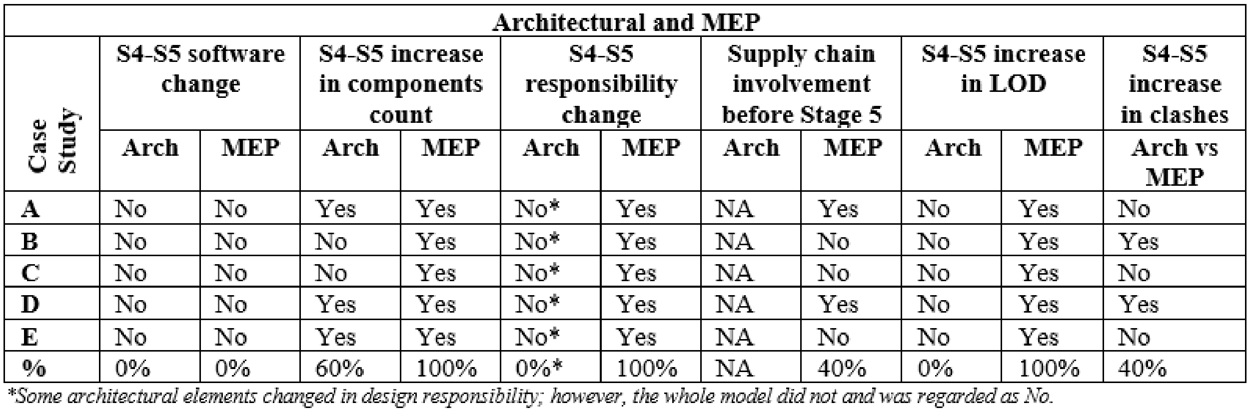
	Model and design author change from Stage 4 to 5					Early integration of Stage 5 supplier in Stage 4					Increase in model LOD from Stage 4 to 5				
Case Study / BIM Element	A	B	C	D	E	A	B	C	D	E	A	B	C	D	E
Substructure	No	No	No	No	No	No	No	No	No	No	Yes	Yes	Yes	Yes	Yes
Steelwork	Yes*	Yes*	Yes	Yes*	Yes*	Yes	Yes	No	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Floor slabs	No	No	No	No	No	No	No	No	No	No	Yes	Yes	Yes	Yes	Yes
Cladding	No	No	No	No	No	Yes	No	No	No	No	No	No	No	No	No
Roof	No	No	No	No	No	Yes	No	No	No	No	No	No	No	No	No
Internal walls	No	No	No	No	No	No	No	No	No	No	No	No	No	No	No
Ceilings	No	No	No	No	No	No	No	No	No	No	No	No	No	No	No
Curtain walls	No	No	No	No	No	No	No	No	No	No	No	Yes	No	No	Yes
Doors	No	No	No	No	No	No	No	No	No	No	No	No	No	No	No
MEP	Yes*	Yes	Yes	Yes*	Yes	Yes	No	No	Yes	No	Yes	Yes	Yes	Yes	Yes
Filtration	NA	Yes	Yes*	NA	NA	NA	Yes	Yes	NA	NA	NA	Yes	Yes	NA	NA

X denotes that a subcontractor organization was integrated into Stage 4 prior to being awarded a subcontract*

DISCUSSION OF FINDINGS: CROSS-PROJECT ANALYSIS

To enable a cross-project analysis, the data is aggregated for each pair of disciplines from across all the five studies. Tables 13, 14 and 15 show the aggregated data for ‘Architecture and MEP’, ‘Architectural and Structural’, and ‘MEP and Structural’ respectively. This cross-project analysis aims to improve the understanding of potential associations between these factors or independent variables and value realization when transitioning from Stage 4 to 5.

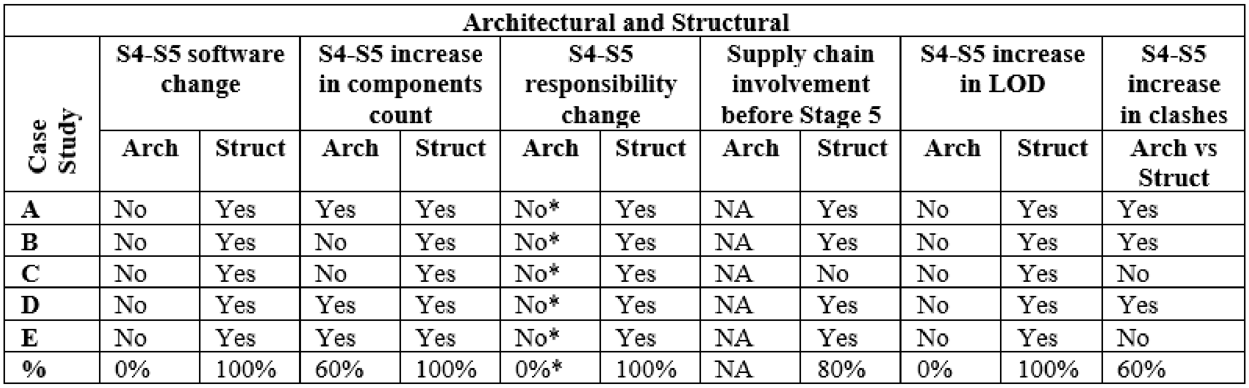
Table 13. Architecture and MEP grouping data



Architectural and MEP											
Case Study	**S4-S5 software change**		**S4-S5 increase in components count**		**S4-S5 responsibility change**		**Supply chain involvement before Stage 5**		**S4-S5 increase in LOD**		**S4-S5 increase in clashes**
	Arch	**MEP**	**Arch**	**MEP**	**Arch**	**MEP**	**Arch**	**MEP**	**Arch**	**MEP**	**Arch vs MEP**
A	No	No	Yes	Yes	No*	Yes	NA	Yes	No	Yes	No
B	No	No	No	Yes	No*	Yes	NA	No	No	Yes	Yes
C	No	No	No	Yes	No*	Yes	NA	No	No	Yes	No
D	No	No	Yes	Yes	No*	Yes	NA	Yes	No	Yes	Yes
E	No	No	Yes	Yes	No*	Yes	NA	No	No	Yes	No
%	0%	0%	60%	100%	0%*	100%	NA	40%	0%	100%	40%

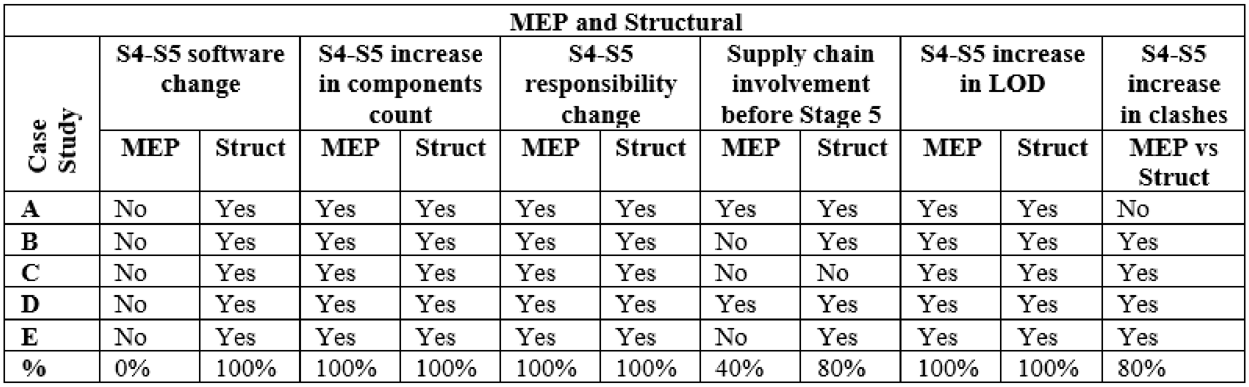
**Some architectural elements changed in design responsibility; however, the whole model did not and was regarded as No.*

Table 14. Architecture and structural grouping data



Architectural and Structural											
Case Study	**S4-S5 software change**		**S4-S5 increase in components count**		**S4-S5 responsibility change**		**Supply chain involvement before Stage 5**		**S4-S5 increase in LOD**		**S4-S5 increase in clashes**
	Arch	**Struct**	**Arch**	**Struct**	**Arch**	**Struct**	**Arch**	**Struct**	**Arch**	**Struct**	**Arch vs Struct**
A	No	Yes	Yes	Yes	No*	Yes	NA	Yes	No	Yes	Yes
B	No	Yes	No	Yes	No*	Yes	NA	Yes	No	Yes	Yes
C	No	Yes	No	Yes	No*	Yes	NA	No	No	Yes	No
D	No	Yes	Yes	Yes	No*	Yes	NA	Yes	No	Yes	Yes
E	No	Yes	Yes	Yes	No*	Yes	NA	Yes	No	Yes	No
%	0%	100%	60%	100%	0%*	100%	NA	80%	0%	100%	60%

Table 15. MEP and structural grouping data



MEP and Structural											
Case Study	**S4-S5 software change**		**S4-S5 increase in components count**		**S4-S5 responsibility change**		**Supply chain involvement before Stage 5**		**S4-S5 increase in LOD**		**S4-S5 increase in clashes**
	MEP	**Struct**	**MEP**	**Struct**	**MEP**	**Struct**	**MEP**	**Struct**	**MEP**	**Struct**	**MEP vs Struct**
A	No	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	No
B	No	Yes	Yes	Yes	Yes	Yes	No	Yes	Yes	Yes	Yes
C	No	Yes	Yes	Yes	Yes	Yes	No	No	Yes	Yes	Yes
D	No	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
E	No	Yes	Yes	Yes	Yes	Yes	No	Yes	Yes	Yes	Yes
%	0%	100%	100%	100%	100%	100%	40%	80%	100%	100%	80%

The clash detection and avoidance was identified through the literature as an important Use Value due to its potential contribution to time and cost savings. Research work discussed earlier identified that a reduction in the number of clashes can result in both a reduction in RFI's and change orders, subsequently reducing delays and costs (Bockstael & Issa, 2016; Mcgraw-Hill Construction, 2012).

The data analysis pertaining to this use value area revealed that the most significant changes during the transition from Preconstruction to the Construction phase occurred within the Structural and MEP grouping. Four of the case studies showed an increase in the number of detected clashes in this grouping compared to the other two groupings involving the Architectural model. In conjunction with these findings, both the Structural and MEP disciplines demonstrated an increase in the number of model components when comparing the preconstruction and construction model. This observation suggests that more information was being added to a model after a contract has been awarded rather than prior to it. The noted findings provide a balanced view about the idealized impact associated with combining DB and BIM in terms of anticipating the effort and investing more knowledge into the upstream phases of a project's life cycle (AIA, 2007; Macleamy, 2008). Clashes still either persist or grow in number at construction phase (i.e. Stage 5).

However, there are some independent variables in these case studies that may be associated with this increase in clash number. One of such variables is the increase in the level of information and the number of components when transitioning from Stage 4 to Stage 5. In addition to the increase the number of components, most disciplines consistently showed an increase in LOD from Preconstruction to Construction across all five case study projects, aligning with the suggestions of Leite et al. (2010). The latter study indicates that the LOD influences the accuracy of design elements and subsequently the volume of identified clashes.

Four of the five case studies revealed an association between the increase in LOD, the increase in the number of model components, and the increase in the number of detected clashes. When adding the supply chain involvement variable, it is evident that there are varying levels of organizational involvement at different stages: only in a few instances the MEP and structural consultants were involved at Stage 4 (Tables 14 and 15); the majority of subcontractors / work packages do not get involved in Stage 4 but only in Stage 5 after a contract award (Table 12). In fact, the formal contractual stance states that any use of digital information prior to a formal contract is completely at the risk of the supply chain organization until such a subcontract and supporting BIM protocol is formally established (AIA, 2013). However, despite the established contractual risks that face the supply chain under a traditional DB structure, some packages – MEP and Steelwork mainly – showed early supply chain involvement in Stage 4.

In the unique instance where the Structural and MEP disciplines did not show an increase in clashes (Table 15, Case Study A), both disciplines were involved on the project at Stage 4 prior to being awarded a contract. This project did not show an increase in the number of clashes despite most of the other independent variables were present (i.e. increase in components count; change of responsibility for design and modelling; increase in LOD). This is in line with the ideas presented by Macleamy (2009) that earlier involvement of key project stakeholder and integration of knowledge can decrease the changes needed at later stages by detecting any clashes earlier in the project. This also provides empirical evidence about a theoretical notion proposed in Succar (2009) who inferred the potential occurrence of increased fast tracking between stages/stakeholders in transitioning across the BIM capability stages (i.e. modelling, collaboration, and integration)

Considering the design and model responsibility during the transition from Preconstruction to Construction, both the Structural and MEP disciplines experienced a change in responsibility where different organizations handled the design of these disciplines at different stages. This shift in responsibility is primarily due to the team integration structure dictated by the DB procurement method. The initial analysis of the project team during Stage 5 showed a disconnection between the responsibility of organizations for the construction design and BIM representation of certain design elements, in addition to a change in the authoring tool used. For example, all five case studies showed a change in the assigned organization responsible for designing and 3D modeling for the Cladding and Roofing elements within the Architecture discipline. It is suggested that levels of BIM collaboration on projects depends upon the level of supply chain maturity (Papadonikolaki et al., 2015). This is consistent with the observations from the presented case studies where some of the supply chain organizations responsible for Stage 5 design were collaborating using 2D design only. This shift in modeling and designing responsibility and the discrepancy in maturity levels yield inconsistencies in the produced components and a distortion of transferred knowledge, thus can be also associated the observed increase in detected conflicts.

Despite the capabilities of automating the detection of clashes with BIM, the persistence of conflicts between different design disciplines and their increase during the later stages of a project are a sign of underlying issues within the project delivery process itself. The findings reveal potential associations between project team structure and the amount of detected conflicts. Although the DB procurement structure integrates the design and construction processes under the responsibility of a single entity, the fragmentation of the involved supply chain and its varying maturity levels inhibit the realization of BIM's potential in enhancing value for the project stakeholders. Traditional management strategies, isolated team work, and risk adverse mentalities pose great challenges for harnessing the continuously claimed BIM merits. Delaying knowledge integration till later project stages and varying the assignment of responsibility to different organizations (i.e. model responsibility vs. design responsibility) can not only result in more conflicts and inconsistencies, but also delay their detection beyond the point of effective resolution.

The findings also reveal that where early full integration of the supply chain occurred prior to contract award, the organizations were required to operate at risk until a formal subcontract has been awarded by the main DB firm. This affects the willingness of the supply chain to participate in a more integrated process given that they would not be covered under any insurances should any errors occur (Looi, 2013). In conclusions, the five case studies provided empirical evidence that value realization cannot be fully attained through combining BIM and DB procurement methods unless the entire supply chain is integrated earlier and unified towards common project goals under contractual arrangements that cater for these needs.

SOLUTIONS AND RECOMMENDATIONS

To represent the current actual level of attainable collaboration in BIM-based projects under DB procurement, the model depicted in Figure 5 is proposed.

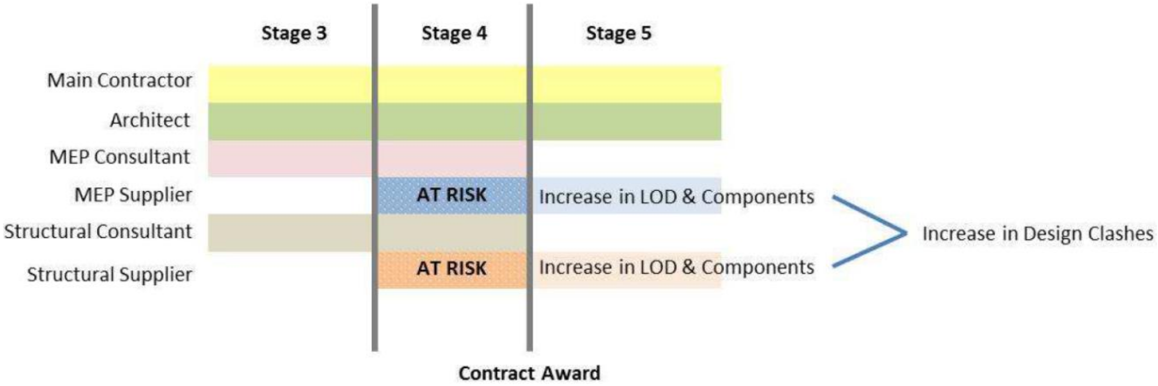


Figure 5. Current state of BIM Stage 2 in DB projects

Clash Detection and Avoidance was identified to be one of the key areas that could generate cost and time reduction whilst improving coordination (Mcgraw-Hill Construction, 2012; Leite et al, 2010; Bockstael &

Issa, 2016). When this potential value enhancing area is placed in tandem with the principles of Macleamy (2008) and AIA (2007), detecting clashes later in the project stages entails detrimental impact on time and cost during the construction stage. In alignment with the objectives of this chapter, it is necessary to identify any alterations that are required to the DB process to facilitate BIM and its influence on delivering enhanced value. In this regard, a proposed BIM Stage 2 model is provided in Figure 6. The model proposes that the appointment of key construction design packages of Structural and MEP be procured in preconstruction prior to construction contract award. Supply chain selection can be based upon success criteria rather than a lump sum cost which would then place more emphasis on generating valuable outcomes (SEC, 2007; Integrated Project Initiatives [IPI], 2014). This process could also be applied to the DB structure for construction design critical packages, such as Structural and MEP. In engaging with the supply chain sooner during preconstruction while also having a contractual agreement in place to support this involvement and protect organizations against unnecessary risk, the anticipated increase in the number of components, LOD, and consequently the potential increase in clashes could be identified and addressed much sooner in the DB process (AIA, 2007; Macleamy, 2008).

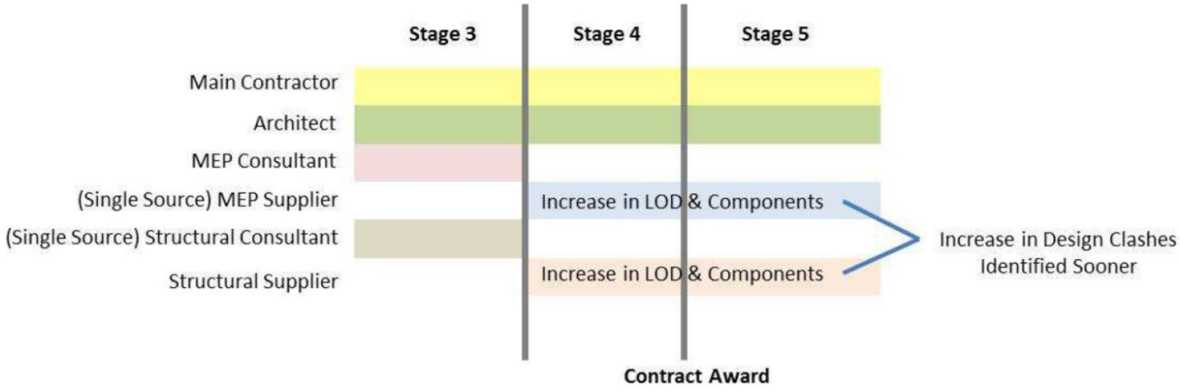


Figure 6. Proposed changes for BIM Stage 2 in DB projects

FUTURE RESEARCH DIRECTIONS

The limited literature works surrounding the use of BIM on DB projects necessitates further research to be conducted on this topic to expand the existing body of knowledge and enhance the performance of BIM-based DB projects. The following are suggested areas that are worthy of exploration:

- Increasing the number of case studies and explore potential statistical correlations between the identified independent variables affecting value realization;
- Investigating the maturity capability of the supply chain organization and its effect on collaboration and value realization;
- The development of metrics for the Utility Value of BIM for main contractors that consider the subjective nature of value; and
- The investigation of contractual structures and BIM protocols for DB projects that eliminate the requirement for supply chain members to operate at risk prior to a subcontract agreement.

CONCLUSION

Prior studies suggest that the realization of value in BIM-based projects depends on the integration and maturity of the involved supply chain as well as the contractual arrangements that accommodate this integration. While existing research constantly regards the virtues of BIM in achieving enhanced value for stakeholders through its collaborative approach, little evidence and relevant data is available in the literature, in particular on BIM-based project using DB procurement. This chapter therefore explored the opportunities and challenges facing value realisation in BIM-based projects procured through Design and Build method. Two utility criteria (i.e. Clash Detection and Avoidance, and Project Team Integration), deemed useful in enhancing use value on projects, were investigated. Analyzing the transition from the preconstruction to the construction stage of five BIM-based DB projects revealed a disconnection between the two stages. Much of the detailed construction design and the appointment of construction designers still occur at the construction stage which is in contradiction to the early engagement and integration principles that are idealized in the literature. The element of risk attached to the current state of the supply chain's early involvement in DB projects is worthy of note. The case studies showed that as the LOD and number of components increased in supply chain packages, the number of clashes followed suit in most of the case study projects. Additionally, the results showed a change in the organizations responsible for the design and the corresponding 3D BIMs (models) and an incomplete integration of organizations in the preconstruction stage before the contract award.

Accordingly, an early involvement of the supply chain within preconstruction whilst eliminating the need for consultancy cost in the same stage has the potential to provide a structure that can deliver an enhanced value. However, two other factors need to be considered when adopting this approach: (1) the willingness of employers to invest more in the upfront design to accrue potential benefits during construction is still not widely proven; and (2) the earlier selection of supply chain members in preconstruction has the potential to compromise commercial competitiveness, therefore selection of such subcontractors need ensure that both value and commercial competitiveness are achieved.

Based on the findings from the five case studies and notions within the literature review, a model was proposed to address the identified challenges affecting the value realization in BIM-based DB projects. The proposed model suggests anticipating the appointment of key construction designers from current stage 5 (construction) to the earlier design phases (stage 4) in DB projects. This will eliminate the current at-risk-operation for the concerned stakeholders; increase their contribution to collaborative workings, and enhance value realization. However, challenges related to the BIM maturity of these stakeholders and the commercial competitiveness of procurement remain to be addressed.

ACKNOWLEDGMENT

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KEY TERMS AND DEFINITIONS

Building Information Modeling: is a set of technologies, processes and policies enabling multiple stakeholders to collaboratively design, construct and operate a Facility in virtual space. As a term, BIM has grown tremendously over the years and is now the 'current expression of digital innovation' across the construction industry [source: https://bimdictionary.com/].

Clash Detection: A process of digitally identifying, inspecting and reporting conflicts between disciplines' models through the use of BIM technologies and workflows.

Collaboration: A process of jointly working with others towards a common vision or goal.

Design-Build: A project delivery method whereby design and construction are performed by one entity.

Integrated Project Delivery: A collaborative approach for delivering a project where all team members work as one entity to deliver value.

Level of Definitions: A BIM metric encapsulating the Levels of Detail (LOD) (graphical content of models) and the Levels of Information (non-graphical content of models).

LOD 300: The Model Element is graphically represented within the Model as a specific system, object, or assembly in terms of quantity, size, shape, location, and orientation. Non-graphic information may also be attached to the Model Element.

LOD 400: The Model Element is graphically represented within the Model as a specific system, object or assembly in terms of size, shape, location, quantity, and orientation with detailing, fabrication, assembly, and installation information. Non-graphic information may also be attached to the Model Element.

LOD 500: The Model Element is a field verified representation in terms of size, shape, location, quantity, and orientation. Non-graphic information may also be attached to the Model Elements.

Value Management: A management approach for satisfying stakeholders' requirements and achieving their perceived values.