



The Potential of Building Information Modeling in the Project Lifecycle – Reflection Against Iceberg Model

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Purpose: The implementation of building information modelling (BIM) has been previously approached from various perspectives, but confusion remains regarding BIM's full potential throughout the lifecycle (planning, design, construction, and maintenance). The whole is viewed from distinct perspectives to reflect the full potential and explain the tentatively unused potential.

Study design/methodology/approach: The study follows a conceptual research approach in conjunction with a single case study. The BIM iceberg model is utilised as an explanatory synthesis frame to reflect perspectives describing BIM utilisation.

Findings: A BIM implementation status framework is developed to describe the BIM utilisation maturity in a typical case company. The framework is tested, and indications of support for the logic of the BIM iceberg model are gained. BIM has been used successfully in the early construction project stages (tip of the iceberg, initial BIM). However, the below-sea-level parts, the collaborative and integrative BIM - the full potential - are rarely recognised.

Originality/value: The presented BIM implementation status shows a gap between the full potential of BIM and the level of BIM utilisation in practice.

Keywords: Building Information Modeling, BIM Mature Implementation, BIM Iceberg

Introduction

The integration of information and communication technologies into construction has revolutionised the way projects are delivered and is denoted by a recent trend towards automation and data exchange through Building information modelling (BIM). The general advantages of BIM are well known. BIM is interpreted as a catalyst for change and a solution to inefficiencies in the construction industry (Hardin & McCool, 2015; Haron et al., 2009). BIM can integrate and strengthen the quality of design and building processes (Antwi-Afari et al., 2018; Bryde et al., 2013), facilitate integration and information flow (Azhar, 2011; Eadie et al., 2013; Eastman et al., 2018), enhance predictability and executive efficiency (Merschbrock & Munkvold, 2012) in less time (Autodesk, 2002) and at a lower cost (McGraw-Hill Construction, 2012).

However, the rate of implementation and use of BIM systems drags behind the possibilities (Arayici & Aouad, 2010; Halttula et al., 2015) and simultaneously create new opportunities and pose challenges (Tsai et al., 2014). The challenges against BIM implementation, such as lack of competence (Ghaffarianhoseini et al., 2017), resistance to change (Eadie et al., 2013), legal and technical barriers (Eastman et al., 2018; Merschbrock & Munkvold, 2012), and lack of willingness to share information with project participants (Siebelink et al., 2021) have been studied extensively. From a building project lifecycle perspective, BIM implementation is slow

and limited to design and construction phases (European Construction Sector Observatory, 2021; Gholizadeh et al., 2018; Olanrewaju et al., 2022), and BIM's full potential is yet to be realised (Hull & Ewart, 2020; Sacks et al., 2020). Furthermore, the ambiguity surrounding BIM's meaning, business value, and objective, embedded in the diverse approaches by individuals from different disciplines, hinders establishing a common understanding among stakeholders and makes BIM challenging to implement (Zuppa et al., 2009).

BIM implementation has been investigated from a variety of perspectives (Gu & London, 2010), by individuals from distinct disciplines, including architects (Son et al., 2015), facility owners (Love et al., 2013), contractor suppliers (Korpela et al., 2015), and engineers (Aranda et al., 2020) with a focus limited to their specific area. The challenge is that the approaches in BIM implementation are presented in isolation, ignoring the expectations and limitations of other disciplines. As a result, the distinct approaches cannot contribute towards collaborative BIM implementation. Hence the major benefits remain undiscovered, even though BIM's value lies in collaboration and integrating stakeholders and systems throughout project lifecycles.

Most BIM-related studies have been conducted by isolated actors, focusing on distinct groups of participants, including designers, contractors, and owners, while neglecting second-level actors such as suppliers (Papadonikolaki et al., 2017). Despite wide evidence that BIM enables a high level of collaboration and integration, the use of BIM beyond the project boundaries by structured, multi-disciplinary teams such as contractually bound supply-chain partnerships is still not completely understood (Papadonikolaki et al., 2016). Even though both BIM and supply chain management have been demonstrated to aim towards integration. Kuiper and Holzer (2013) agree that all collaborative procurement methods support BIM. Meanwhile, integrative capacity could induce collaboration and integration across the supply chain (Papadonikolaki & Wamelink, 2017).

There is a need to look at BIM implementation from a holistic perspective, considering alternative approaches to realising BIM's full potential in the construction lifecycle. Therefore, it is desirable to investigate the BIM utilisation maturity with a holistic perspective throughout the project lifecycle and consider intra- and beyond project activities. This study aims to synthesise distinct previous approaches to BIM implementation and supply chain integration. A conceptual approach is followed to present an explanatory synthesis of approaches describing BIM utilisation maturity. First, related concepts to BIM implementation are grouped and offered through avenues. The term avenue refers to possible ways of presenting the approaches.

It is worth noting that the aim here is not to compare, sort, or equalise the avenues. Instead, the aim is to develop a whole from distinct perspectives to reflect BIM's full potential and explain the tentatively unused potential of BIM. Based on the synthesis, a BIM implementation status framework is developed using the BIM Iceberg analogy. Since the focus is to reflect BIM's full potential, the BIM implementation status framework will help pinpoint the used and hidden potential of BIM in practice. The following research questions (RQ) are aimed to answer:

RQ1: What approaches/avenues can describe BIM utilisation within a project life cycle – levels of BIM iceberg?

RQ2: How do typical case company projects realise and represent the maturity of BIM utilisation?

The practical applicability of the developed framework is tested through case analysis. It is argued that construction projects can utilise the framework to assess their progress toward mature BIM implementation. The framework reveals the BIM implementation status in construction projects and indicates steps required to realise BIM's full potential.

This paper is structured as follows: The following section presents the research process and applies methodology under the heading materials and methods, describing the process of conceptual research and the case study approach. The literature review section introduces a brief outline of avenues of describing BIM utilisation maturity, including the purpose and evolutionary logic, BIM implementation across a project lifecycle, BIM maturity, and how supply chain integration and supplier coordination studies are framed. This section concludes with a synthesis of the reviewed literature and offers linkages to the BIM iceberg and foundations for the developed BIM implementation status framework. The data analyses and findings from the conceptual research and case study analysis follow. This section begins with a presentation of the BIM iceberg and then analyses the BIM implementation status framework in a case study. A traffic light indicator is used to interpret the status of BIM implementation. Next, the BIM implementation status framework with case company indications is presented. In the last two sections, a discussion and conclusions suggest the theoretical and managerial implications and limitations and future directions.

Materials and methods

This study is mainly based on a conceptual research approach combined with a qualitative case study. The conceptual research is carried out through literature reviews on relevant concepts to explain different approaches to BIM utilisation maturity. In addition, an integrative literature review (Torraco, 2005) is used to cover both academic and practical studies and generate new frameworks and perspectives on the topic. A procedure for identifying, selecting, assessing, and synthesising literature was followed in this study. As a result, the first step was to search for relevant studies in line with the research objectives, which included journal articles, conference papers, and books written in English. The key parameters (Wilson, 2014) in RQ1 were used to set study boundaries to focus on the study's objectives and narrow down what was intended to be searched. BIM implementation and lifecycle approach are defined as the key parameters in this study. Therefore, the scope of the study is limited to papers that focus on BIM implementation through the entire construction cycle.

After the first search phase, all discovered publications' abstracts, key results, and conclusions were assessed to see if they were relevant to the study topics. For this purpose, the following exclusion criteria were used: articles that did not refer to the research topic or were duplicated. The remaining identified publications were reviewed in-depth to see how BIM implementation is discussed throughout the project lifecycle. The search goes beyond academic databases, as publications by relevant stakeholders, such as standard committees and software-solution providers, are reviewed. The most frequently used concepts of mature BIM implementation are selected, and avenues are formed from categorised concepts based on similarities.

A synthesis of the key concepts is drawn, as illustrated in the last part of the literature review section. The synthesis forms the theoretical foundation of this research and represents avenues about BIM utilisation maturity throughout the project lifecycle. The synthesis serves two purposes: first, the synthesis supports the BIM iceberg perception by allowing side-by-side comparisons of different stages of avenues in the synthesis to explain the full potential of BIM compared to its realised application. Secondly, it is used to develop a framework to examine the status of BIM implementation in practice.

The single case study examines the findings of the conceptual research. Yin (2009) defines case study research as “an empirical inquiry that investigates a contemporary phenomenon (the case) in depth and within its real-world context, especially when the boundaries between phenomenon and context may not be evident” (Yin, 2009, p. 18). Accordingly, the initial focus of the data collection and analysis will be on the case company. The single study aims to undertake a modest test of the proposed framework to demonstrate how it can be used in

practice. The role of empirical data then is to explain and evaluate the applicability of BIM implementation and pinpoint how the framework represents the level of BIM implementation. The company was chosen based on purposive sampling (Marshall, 1996), as the case was rich with information about the substantive research problem. A traffic light indicator is used to interpret the status of BIM implementation: green means the avenue steps are successfully utilised, yellow means they are partially used, red means they are recognised but not used. The diagonal stripes show the steps that are not recognised at all. Findings from the literature review and the company interviews are discussed in the data analysis and findings section. This section begins with a presentation of the BIM iceberg and then analyses the BIM implementation status framework by a case study. Figure 1 illustrates the research process.

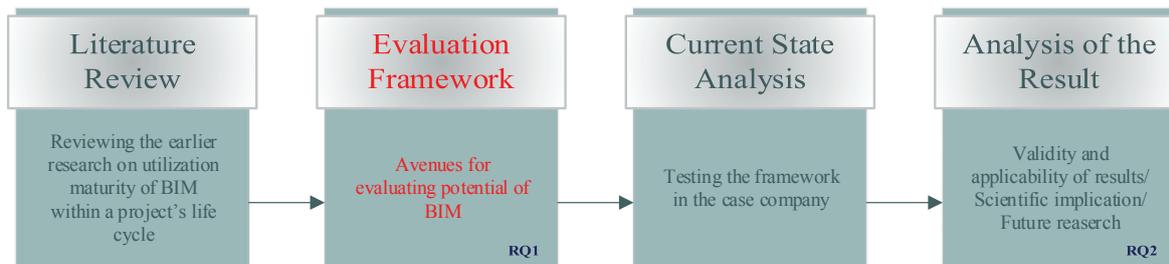


Figure 1: Research process

Literature Review: different avenues of describing the maturity of BIM utilisation

The following avenues for describing the maturity of BIM implementation (referring to readiness, the capability to perform, and performance maturity) and utilisation are outlined: *'purpose and evolutionary logic of BIM utilisation'*, *'BIM implementation across project lifecycle'*, *'BIM maturity'* and *'supply chain integration and supplier coordination'*. The purpose of BIM and the evolutionary logic of BIM utilisation provide insights into the projects' readiness to implement BIM. This paper reviews the steps towards mature BIM implementation to demonstrate how it can benefit from BIM capacities in stages over a project's lifecycle. In addition, the literature on supply-chain integration, and development of supplier coordination, are reviewed since the mature implementation of BIM requires people and systems integration aside from communication, including that with supply-chain members. Finally, a synthesis of the above avenues is presented at the end of this section to give a fresh perspective by considering different streams of research to focus on the core aspects of BIM implementation.

Purpose and evolutionary logic of BIM utilisation

BIM is usable as a multidimensional concept (Succar, 2009) for different purposes within the construction phases. Along with the growth in BIM acceptance, the industry has transitioned from merely adopting BIM to successfully implementing it. Ahmed and Kassem (2018) propose a BIM adoption taxonomy including innovation characteristics, external environment, and internal environment as the main drivers of successful BIM implementation. The term implementation differs from adoption and refers to a "three-phased approach, combining organisational readiness to adopt, capability to perform, and performance maturity." (Kassem & Succar, 2017, p. 288). Studies on the purpose of BIM utilisation show how BIM utilisation has mainly focused on the initial BIM capabilities. BIM is primarily utilised as a tool in the early stages of building projects, such as preconstruction and design, with a limited aim of visualisation and error detection, rather than facility lifecycle management (Zuppa et al., 2009). Technological advances in construction have resulted in the increasing adoption of BIM as a

new system (Gledson & Greenwood, 2016) to improve construction projects' current drawing-based performance. BIM utilised 3D-graphic data initially, and the more comprehensive BIM usage expanded to an nD environment (Jung & Joo, 2011).

An evolutionary logic and a paradigm shift are visible in the literature regarding the purpose of using BIM in terms of technological and operational levels. With advancements in BIM implementation from the design and building phases through maintenance and facility management, several functions and their dimensions are developing from 3D to nD (Charef et al., 2018). Furthermore, BIM 3D, which includes CAD representations of numerous construction aspects, is enhanced by additional dimensions such as time, cost, sustainability data, and facility management data (European Construction Sector Observatory, 2021; Turk, 2016). Turk (2016) connects the evolutionary logic to use BIM to the contemporary challenges of building projects, stating that the primary challenge for building projects was about the digital representation of buildings. As digital representation became achievable and matured, the next challenge involved creating, developing, and using digital representations most efficiently within the building lifecycle (Turk, 2016).

Diffusion of BIM functions has been studied across 118 companies in the AEC industry (Architecture, Engineering, and Construction) to demonstrate the most widely applied BIM functions, including 3D visualisation, clash detection, constructability analysis, and building design (Becerik-Gerber & Rice, 2010; Gholizadeh et al., 2018). Nevertheless, the utilisation of BIM for building lifecycle management is still limited (Becerik-Gerber & Rice, 2010). Despite the proven benefits of using BIM for facility management, facility managers are not always provided with BIM information, which prevents them from exploiting the cost-cutting opportunities (Eadie et al., 2013). Furthermore, implementation of BIM for facility management is challenging since it necessitates a comprehensive set of well-structured information about the building asset (Nical & Wodynski, 2016; Prins & Owen, 2010). In other circumstances, facility management has not been required to provide BIM data to increase the accuracy and reliability of design documentation (Kaner et al., 2008).

While recent studies propose a better grasp of BIM and its application to facility management (V. Ahmed et al., 2017; Li et al., 2019; Pärn et al., 2017; Patacas et al., 2020), there is still a need to improve the use of BIM in a variety of facility management contexts (Asare et al., 2021; Wang et al., 2022). Recently, there has been an ongoing trend towards collaborative work in line with contemporary concerns and the more executive domains like asset information management (Heaton et al., 2019), sustainable construction (Carvalho et al., 2019), supply chain management (Chen & Nguyen, 2019) and energy consumption management (C. Zhang et al., 2018). Therefore, visualisation has been an initial aim of BIM utilisation, and building lifecycle management has been the utmost aim.

BIM implementation can be viewed through the lens of various tasks. For example, BIM has been applied to inter-organisational design coordination (G. Lee & Kim, 2014), automated building design (Tang et al., 2020), and automatic hazard identification and error detection (S. Zhang et al., 2013). Besides that, BIM can be used in construction management, for example, in construction safety management to minimise construction fatalities (S. Zhang et al., 2013) and risk management and maintenance management (Zou et al., 2017). Another strategy for BIM implementation that has been investigated is vertical integration (Lehtinen, 2010, 2012). The studies have emphasised the importance of the project network's organisational structure in BIM implementation and propose management support, technology management, motivation, and job definition as structurally relevant variables in BIM implementation.

The effective BIM deployment is discussed to show variety and paradigm shifts in practices. Taylor and Bernstein (2009) indicate that the variety of existing interpretations (paradigms) of

BIM implementation increases the difficulty in developing common inter-organisational practices for reaping the benefits. The study identifies four common paradigms: *visualisation, coordination, analysis, and supply-chain integration*, inducing an evolutionary model for BIM practice paradigm trajectories in project networks (Taylor & Bernstein, 2009).

BIM implementation across the project lifecycle

BIM is meant to be used in all project lifecycle phases (Autodesk, 2002; Azhar, 2011), including design, construction, and operation, further changing the phases' components and the linkages between phases and activities (Ding et al., 2014; Succar, 2009). A project lifecycle can encompass "project inception, feasibility, design, construction, handover, operation, maintenance, and eventual demolition" (Eadie et al., 2013, p. 146). Due to the fragmentation of building projects, BIM is implemented separately in the preconstruction, design, construction, and operation stages, resulting in losing potential value in lifecycle management (Xu et al., 2014). Despite BIM's applicability during the entire construction process, BIM is currently at its early stages of realising its full potential (Alizadehsalehi et al., 2020; Gilligan & Kunz, 2007) and is used mainly in the initial phases of construction projects (Eadie et al., 2013; European Construction Sector Observatory, 2021; Zuppa et al., 2009). However, the greatest cost-saving potential lies in the construction phase, as the bulk of costs and the benefits of BIM implementation occurs downstream of the construction value chain (World Economic Forum, 2018). Therefore, the implementation of BIM during the construction phase appears as the most challenging. Halttula et al. (2015) indicate that BIM is a technology that enables integration, value co-creation, and earlier collaboration among involved parties through comprehensive data storage and simulation. To reap the full benefits of BIM across a project's lifecycle, many changes need to be made to processes and organisational rules in contractual and collaboration practices (Eadie et al., 2013; Merschbrock & Munkvold, 2012).

BIM maturity

BIM maturity aims to assess AEC firms' capacity to implement BIM within the organisation and/or future projects (Nepal et al., 2014). The BIM maturity approach shows considerable similarities with the BIM implementation methods, following almost the same logic as the evolution of the BIM usage. Just as there is an ongoing trend towards successful BIM implementation, increasing attention has been on evaluating BIM usage methods. Various BIM maturity evaluation models with varying focus areas are developed. Each model assesses different competencies based on intended user groups and evaluation styles for a range of maturity levels (Dakhil, 2017; Giel & Issa, 2014). Dakhil (2017) has categorised existing BIM maturity toolsets into three major classes: individual-focused (e.g., BIM competency), organisational-focused (e.g. BIM maturity matrix and owner maturity matrix), and project focused (e.g., VDC ScoreCard). Succar et al. (2012) propose five complementary BIM assessment metrics (capability stages, maturity levels, competency sets, organisational scales, and granularity levels), which provide opportunities to measure and improve performance.

NIBS (2007) has published several BIM maturity assessment tools: Capability Maturity Model; the BIM deliverable matrix, targeted at the type and delivery stage of BIM products (ACE, 2008); the IU BIM proficiency matrix (Eastman et al., 2018), which focuses on BIM products in phases throughout the building lifecycle; and the BIM Matrix (Succar, 2010) offering a comprehensive framework based on a comparatively exhaustive review of prior research (Dib et al., 2012; Giel & Issa, 2014). The BIM Matrix provides the most comprehensive framework for benchmarking BIM maturity—considering designers, contractors, and clients—compared to the other models mainly focused on single BIM aspects.

Succar's (2010) approach is based on project readiness for BIM implementation. BIM maturity is subdivided into three fixed stages: *object-based modelling*, *model-based collaboration*, and *network-based integration*. In the object-based modelling stage, BIM is perceived and utilised as an object-based 3D parametric software tool that generates a single-disciplinary model within a specific project phase. In the model-based collaboration stage, project players actively collaborate with other players, and the exchange of information takes place through more than a single-disciplinary model. Concurrent construction is possible in the network-based integration stage due to high BIM implementation maturity. In this stage, semantically rich integrated models, interdisciplinary nD models, are created, shared, and maintained collaboratively (Succar, 2010). The network-based integration of firms in BIM implementation facilitates the long-term BIM use vision by integrating people, systems, business structures, and practices into a process benefitting from the insights of all project players. Each stage is a prerequisite for the next one, and firms should traverse incremental, evolutionary steps to provide different prerequisites, solutions, and deliverables across the continuum.

BIM capabilities could potentially push building projects' boundaries and enhance collaboration and integration, including supply chains. BIM encourages collaboration (Succar, 2009), coordination (Antwi-Afari et al., 2018), and integration (Eastman et al., 2018; Merschbrock & Munkvold, 2012; Zuppa et al., 2009), improving productivity and project performance (Ghaffarianhoseini et al., 2017) throughout the construction lifecycle (Eadie et al., 2015; Zuppa et al., 2009). Furthermore, there is a synergetic connection between the full potential of BIM implementation and supply-chain integration (Aram et al., 2013; Getuli et al., 2016; Irizarry et al., 2013; Papadonikolaki & Wamelink, 2017; Taylor & Bernstein, 2009).

Supply-chain integration and supplier coordination

Supply chain management is viewed as corresponding to collaboration (Fawcett & Magnan, 2002) and defined as "the network of organisations that are involved, through upstream and downstream linkages, in the different processes and activities that produce value in the form of products and services in the hands of the ultimate customer" (Christopher, 2011, p. 13). A construction supply chain is complex because of the number and diversity of players (project clients; main and sub-contractors; labour, material, and equipment suppliers; and consultants) (Meng, 2013). It makes supply-chain integration necessary for reaching an advanced level of supply chain management (Fawcett & Magnan, 2002). Currently, suppliers' relationship in the construction supply chain is short term and adversarial (Bresnen & Marshall, 2000; Fulford & Standing, 2014; Meng, 2013; Saad et al., 2002), which calls for a shift toward more collaborative methods of managing supply chains (Vrijhoef & Koskela, 2000). Building projects characterised by an adversarial and risk-shedding attitude do not employ compatible information systems and suffer from the lack of interoperability, cooperation, and information exchange (Papadonikolaki et al., 2016; Succar, 2009). BIM can be expected to play a vital role as a *supply chain integrator* (Taylor & Bernstein, 2009). It is widely acknowledged that BIM can provide semantically rich, integrated, and interdisciplinary models utilisable by a network of players. Indeed, the focus of BIM technology should be on process integrity, participant initiative, and consistency of behaviour based on supply chain management's main concepts (Wu & Xu, 2014). Despite the broad agreement on BIM's capability to improve the efficiency of construction projects by providing integrated collaboration within supply chains (Aram et al., 2013; Getuli et al., 2016; Irizarry et al., 2013; Papadonikolaki & Wamelink, 2017), most BIM-related studies have been realised by isolated actors, neglecting second-level actors such as suppliers (Papadonikolaki et al., 2017). It is desirable to review supply chain integration literature about BIM use beyond project boundaries with a project life cycle perspective.

There is a strong commonality between the stages of BIM implementation across the project lifecycle and supply-chain integration attitudes. The object-based modelling stage (Succar, 2010) can be compatible with the traditional supply chain management view, the arm's length concept. The arm's length concept encourages maximising buyers' bargaining power and decreasing buyers' dependency on suppliers to maintain suppliers at arm's length without any commitment (Dyer et al., 1998). Both approaches share competitive and risk-avoiding attitudes embedded in a context with minimal communication and data-sharing. In contrast, the partner model emphasises the collaboration benefits that lead to improved performance and quality through the flow of information and task coordination (Dyer et al., 1998). The partner model of supplier management is in harmony with the BIM practice paradigms at an analysis level (Taylor & Bernstein, 2009) and could be compatible with model-based collaboration and network-based integration stages of BIM implementation proposed by Succar (2010). All of the mentioned approaches emphasise the necessity of integrated models, which are interdisciplinary nD models created, shared, and maintained collaboratively across the project network and supply chain (Dyer et al., 1998; Succar, 2010; Taylor & Bernstein, 2009).

Spekman et al. (1998) propose key transition stages from being an important supplier to becoming a supply chain partner. The most traditional attitude of *open market negotiation* is similar to the arm's length model (Dyer et al., 1998). The relationship between buyers and suppliers is adversarial and based on price. Longer-term contracts with fewer suppliers are used in the *cooperation* stage to advance relationships among parties. Next is the *coordination* stage, during which the process efficiency, information sharing, and teamwork improve dramatically. The final stage of supply-chain integration is the *collaboration* stage, which overlaps with the supplier management partner model (Dyer et al., 1998), in which the supply chain is integrated, and parties benefit from joint planning and technology sharing (Laiho, 2015; Mejias-Sacaluga & Carlos Prado-Prado, 2002; Spekman et al., 1998).

Contractor and supplier inefficiencies may hinder successful project delivery by generating poor communication and coordination (Alaloul et al., 2016; Alzahrani & Emsley, 2013; Gomarn & Pongpeng, 2018). Specific coordination mechanisms could manage supplier relationships and achieve mutual advantages (Jayaram et al., 2010; Xue et al., 2005). Supplier coordination might be driven by a variety of objectives, including resource sharing (Narus & Anderson, 1996), resource dependency (H. Lee, 2000), mutuality and interdependencies between supply chain units (Simatupang et al., 2002), information system and coordination (McLaren et al., 2002), cultural and strategic implementation of supply chain coordination (Barratt, 2004), joint decision making (Hill & Omar, 2006) and coordination mechanism linkage with supply chain performance (Arshinder, 2008; Hines et al., 2000).

Hines et al. (2000) presented a four-stage framework for improving supply-chain performance by strengthening integration and alignment of buyer-supplier relationships. The no-coherent strategy is similar to object-based modelling (Succar, 2010). The arm's length approach (Dyer et al., 1998) is the first stage in which the suppliers lack a shared working approach and do not cooperate. As a result, many unstable suppliers operate in an adversarial relationship with minimal integration and information exchange. The following two stages are piecemeal coordination and systematic coordination, in which companies take a proactive approach in close cooperation with more stable partnerships. Like BIM model-based collaboration (Succar, 2010), extensive data sharing takes place based on mutual advantages. The ultimate integration in supplier coordination occurs in the final stage, network coordination, where companies take a proactive role to develop consistent working methods for mutual benefits throughout the supply chain. Finally, suppliers work together in long-term partnerships within the network through accurate and detailed data exchange via digital platforms, similar to BIM network-based integration (Succar, 2010), collaboration stage (Spekman et al., 1998), and partner model

of supplier management (Dyer et al., 1998). Dallasega et al. (2018) looked at the effects of industry 4.0 principles on construction supply chains and found that using digital collaboration technologies can improve collaboration and supply chain operations. Concerning information technology, Getuli et al. (2016) conclude that BIM-based monitoring systems improve the coordination, control, and productivity of construction supply chain activities.

Synthesis of different avenues of describing BIM utilisation maturity

The purpose of BIM, the rationale for BIM application throughout the construction lifecycle, the development stages in its implementation, as well as the integration and coordination of the supply chain, are all reviewed to assess organisational readiness to adopt BIM, BIM's capability to perform, and its performance maturity. Figure 2 depicts an explanatory synthesis of the studied avenues. Any overlaps between the avenues can be argued. The root cause is that all the investigated options contribute to realising BIM's full potential. It is, however, important to note that the purpose of this study is to highlight the tentatively untapped potential of BIM from many viewpoints, not to compare or equalise the avenues. Furthermore, the graphic lines that separate the stages within each avenue do not represent a clear separation. Individual paths advance in stages, from ad hoc to optimised, with the possibility of overlaps between them.

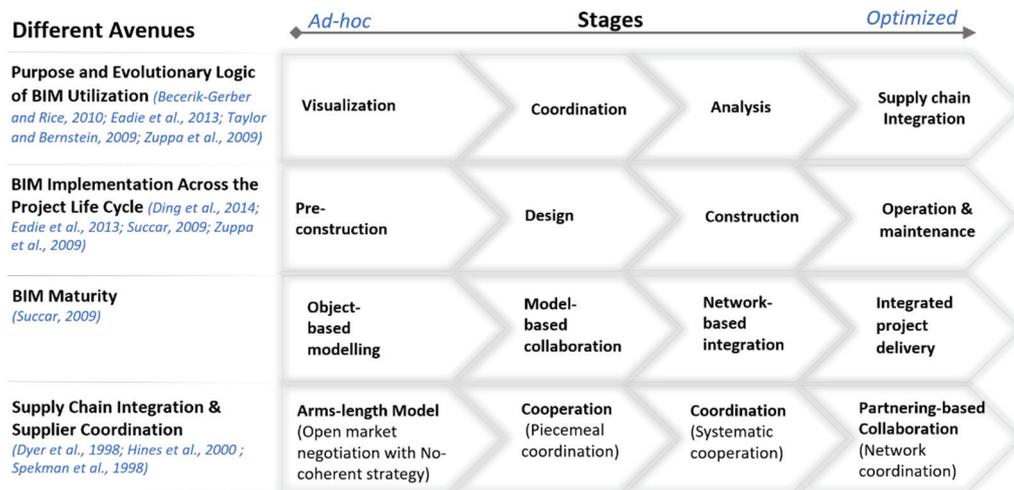


Figure 2: Explanatory synthesis of different avenues of describing BIM utilisation maturity

Data analysis and findings

The explanatory synthesis of different avenues of describing BIM utilisation maturity is used in this study for two purposes: first, a version of the BIM iceberg is developed with a side-by-side comparison of the synthesis (Figure 2) to explain the full potential of BIM compared to its realised application (Figure 3); second, the synthesis (Figure 2) is used as a basis to develop a BIM implementation status framework that indicates the level of BIM implementation and to test its practical applicability through a case study.

BIM iceberg

The iceberg model depicts how a small portion of each phenomenon is apparent, with the majority hidden beneath the water's surface. In a vertical view, the early stages of each identified BIM utilisation avenue, the already realised capacity, form the tip of the iceberg. The steps required from ad-hoc to mature form the base of the iceberg. BIM iceberg breaks down BIM's potential into sub-categories to make it more understandable, namely "initial BIM," "collaborative BIM," and "integrative BIM". It's worth noting that combining these three classifiers facilitates BIM implementation through the project lifecycle. Initial BIM refers to

stand-alone modelling and visualisation, which makes use of BIM's limited, apparent and achievable capabilities in the early project stages (Small BIM)(Jernigan, 2007).

The bulk of the iceberg (Big BIM)(Jernigan, 2007) consists of two sections and is termed as "collaborative BIM" and "integrative BIM". The bulk of the iceberg refers to the incredible potential of BIM (Jernigan, 2007), which is crucial to the effective implementation of BIM but is concealed from observation and difficult to achieve. Collaborative BIM refers to the next step of BIM implementation just below the surface and is about to be realised. At this level, BIM implementation is expected to move to the construction phase as an enabler of collaboration. Model-based collaboration as an effective tool for analysis may enable a more proactive approach to work with suppliers to eliminate waste through open-market negotiations. Integrative BIM, the deepest section of the BIM iceberg, refers to BIM's most challenging to achieve functionality. Integrative BIM may be further developed to be used in construction, operation, and maintenance phases and manage entire construction projects. The common method of working based on mutual advantages (partnering-based supply chain) spreads across the highly collaborative supply chain. Network-based integration, integrated supply chain, and integrated project delivery as the ultimate BIM goal reside in the deepest portion of the iceberg.

The synergetic link between full BIM implementation potential and integrated supply chain is visible. However, at the tip of the iceberg, where the building projects use compatible information systems, they are characterised by adversarial and short-term relationships and lack interoperability. Along with mature BIM implementation towards the bulk of the iceberg, supply-chain performance can improve by increasing integration and alignment of buyer-supplier relationships.

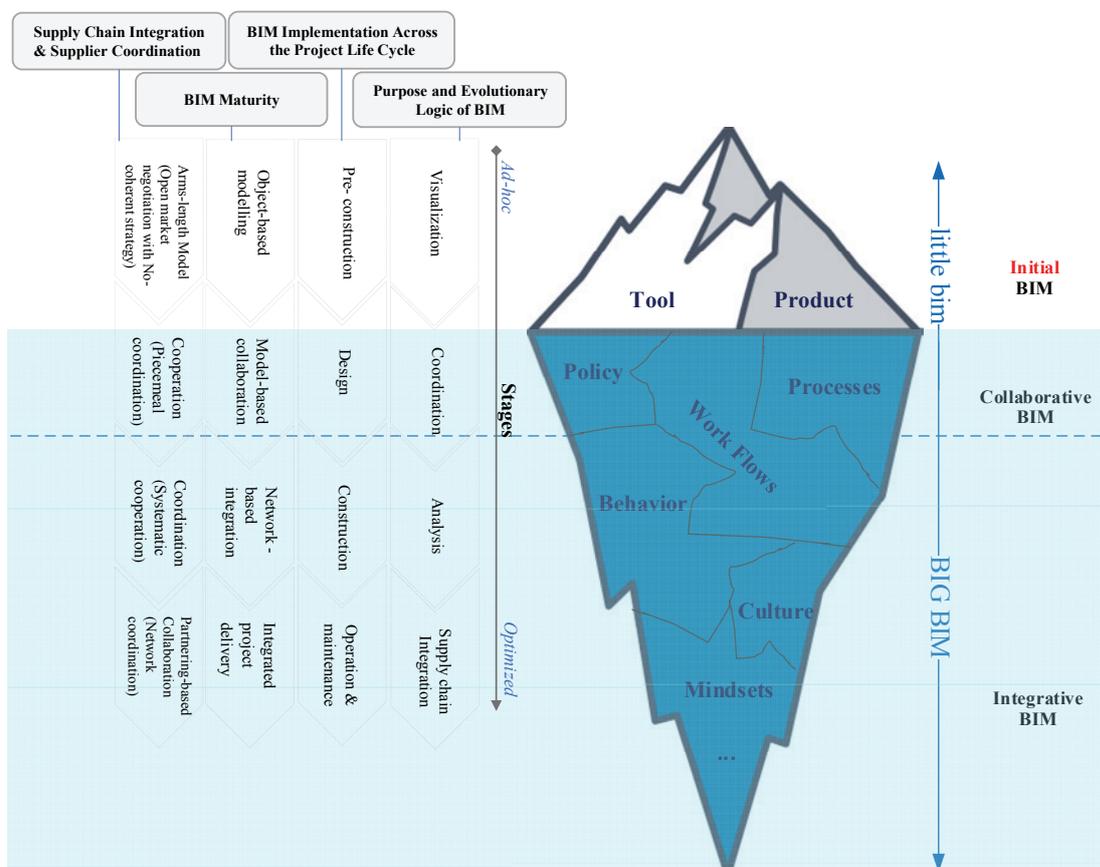


Figure 3: BIM iceberg

Hypothesis: *The level of BIM implementation might be possible to assess and indicate through the compliance with the avenues of BIM implementation maturity that seem to correspond with the related penetration across the BIM iceberg model. The BIM implementations status could be indicated by visually showing the compliance with the maturity stages.*

The case company (Company X) representation of BIM utilisation

The synthesis (Figure 2) is used as the basis for the BIM implementation status framework, and its practical applicability is tested. A traffic light indicator is included to add a visual indication of the status of BIM implementation. The avenues of the synthesis were used as a guide to outlining the required steps towards the full potential of BIM utilisation. Based on that, an interview guide was created (Appendix A). The interview guide offers detailed explanations about the meaning and aims in each individual stage of the avenues to make it more reasonable and understandable for interviewees in construction projects. The status of BIM implementation in construction projects is specified and visualised using the framework.

The empirical data was collected through a formal group interview held in the case company. To clarify the discussion, the researcher presented the synthesis topics, supporting the interview guide (Appendix A). The steps in the interview guide were followed during the interview. The main agenda revolved around the status of BIM implementation from diverse approaches in the company's projects. The interviewees discussed the topics interactively, and the company gave impressive comments and examples. The framework and the interview guide were also shared with other personnel who contributed but could not participate in the interview. Examples and comments are given for each framework step to describe the level of BIM implementation in the company.

It is noteworthy that the evaluation was carried out based on the company's current practices, not their plans. Therefore, the steps of each avenue are analysed one by one, and the status of BIM implementation in practice concerning each step is discussed collectively. The traffic light indicator is used to make it easier to interpret the status of each step. Green indicates that the avenue steps are successfully complied with, yellow indicates that they are partially complied with, and red indicates they are recognised but not complied with. The diagonal stripes suggest that the steps are not recognised at all. The status of each avenue is briefly described below.

Avenue 1: Purpose and evolutionary logic of BIM utilisation

The case company uses data for visualisation, clash detection using IFC combination models, and scheduling. BIM is used to visualise, for example, design solutions. Combination models are used for visualisation and clash detection. Therefore the 'visualisation' step is successfully utilised, so coloured green. The coordination function of BIM implementation (e.g., error detection) is not Company X's everyday business. Error correction and model improvement are time-consuming. In design contracts, it should be specified that errors should be fixed immediately, particularly if the error is in a critical path. Otherwise, designers will delay the project, requiring more time to fix the errors than what is needed. Therefore, the coordination function of BIM partially complies with Company X, and the 'coordination' step is coloured yellow.

The Analysis step of the framework is coloured red. This stage aims to explore a variety of analytical options in using BIM. This functionality is recognised but hardly utilised in Company X. For example, flow sizes have been specified in a model regarding the flow of wind and ventilation. Supply chain management, the last step, is not recognised yet, so diagonal stripes colour it." I know that we have kind of company-level whole. The case company level -supply agreement, I do not know if they are tied to any of the modelling stuff so, that, by the way, is

one of the problems also that you have big company-level agreements. You missed the link from the models, and it's even more difficult for the processes."

Avenue 2: BIM implementation across the project lifecycle

The preconstruction as the first step of this avenue is coloured yellow. Company X is developing some requirements for designers and how they should model, taking place in a couple of concurrent projects. The company proposes requirements from designers, doing a certain level of modelling based on the 'Talo 2000' standard. Requirements are not that high since they are expensive, and the potential benefits are uncertain. Architectural 4D (3D+ schedule) models provide designers with data interchange, clash detection, preliminary material requirement planning, site geometry structures, bidding competition, product models, and numbers. So, it means that BIM is partially complied with in the preconstruction, feasibility, and project development phase. For Company X, the model is of the building itself instead of the building process. The maintenance phase is also considered in a special project undertaken in Company X, as consumers demand: "It's the first experience of the Company X using the model for later phases". For example, an old building was laser scanned and made applicable to the later design in the feasibility and project development phase.

In the design step, BIM is used successfully in some cases but only partially in others. So, the design step is coloured somewhere between yellow and light green. In this step, designers can provide requested data to some extent. For example, rooms that have been designed can be redesigned. In addition, it is possible to take off preliminary quantities from the model for procurement (contract pre-survey), cost-planning, and scheduling. Spaces are also used for quantity take-offs.

BIM is only used in a few circumstances and is rarely utilised in the construction step, even when recognised. Therefore, the construction step is coloured red with a light-yellow corner. At this level, sourcing from the construction site is utilised. Company X uses on-site supervision for clash detection, scheduling, and visualisation in special cases. There is some concern over using new technologies, and it is assumed that background software is required to implement BIM. In Company X, it is quite rare that a built model be used for maintenance. The special tasks of operation and maintenance were recognised by the case firm but were not used. Therefore, the operation and maintenance step is coloured red.

Avenue 3: BIM Maturity

The Object-based modelling step is coloured green with a yellow corner. The company uses the BIM model, but PDF files are still being transferred and often printed, depending on the project type, partner working methods, age, and skill level. It signifies that BIM object-based modelling is successfully used, but there are still some areas where it is only partially implemented. Models are object-based, but once users take a PDF, they are not fully object-based anymore (as indicated by the yellow corner). The model's collaborative implementation is extremely project-based, depending on the partners. Active collaboration between single or multiple project phases through a single collaborative model (multi-user model) is yet to be accomplished. Consequently, the model-based collaboration step is coloured partially green, partially yellow, and mostly red.

Network-based integration is recognised and used to some extent. Therefore, the step contains a single yellow corner but is otherwise red. In specific instances, Company X has preferred designers, sub-suppliers, and sub-contractors, but at a system level, they cannot use the same systems used by the company. Limited concurrent construction occurs in special cases when a model-based schedule is in place or the currently installed component can be inferred from the

model. “They don’t use the model necessarily at all but start to report the level of readiness, but it’s not based on the model, but they did it with the model”. The last step, integrated project delivery, is yet to be recognised and is coloured with diagonal stripes.

Avenue 4: Supply-Chain Integration and Supplier Coordination

This avenue explores whether BIM provides critical solutions for supply chain integration and vice versa. The commercial model typically used in projects excludes many excellent collaboration features, as it calls for a bidding competition for construction when the designs are complete. As a result, collaborative opportunities have been severely limited, and building contractors cannot influence the design. As a result, over half of the design experience is lost. The Arm's Length Model/Open Market Negotiation, the first stage of the avenue, is successfully used in Company X, and the step is coloured green. Adversarial relationships exist based on risk-shedding attitudes within a low communicative and data-sharing atmosphere. The cooperation stage of supply chain integration is coloured yellow, as the company's relationships shift gradually towards joint work among partners. Therefore, the cooperation stage of the avenue is recognised but not used.

There is no evidence that coordination is recognised or understood. Company X would occasionally share some data with contractors, and, within the project, Company X influences other parties and preferred suppliers and designers. In some special projects, influence is possible, but there are projects where influence is not possible. Hence, the coordination step is coloured red partially, and the remaining part of the step is coloured with diagonal stripes for non-recognised coordination values. The last step, the Collaboration/Partnering Based Model, is yet to be recognised, and therefore filled with diagonal stripes: “The last stage has diagonal stripes, maybe understood but seen as hard to realise, as the full system would be necessary including model and management practices”. The resulting model, tested by the interview findings, is presented in Figure 4.

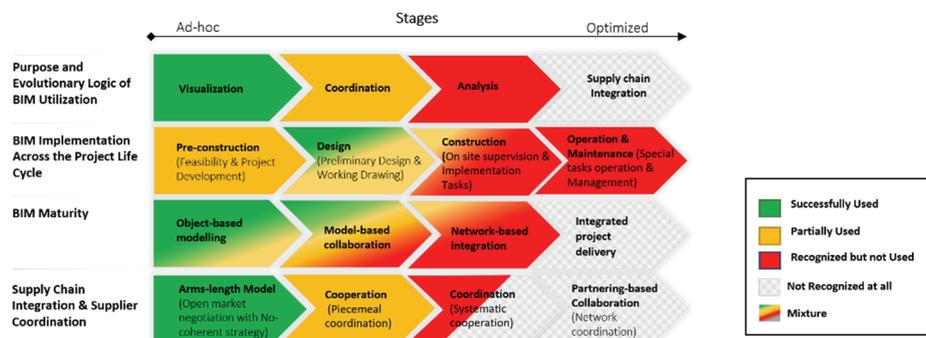


Figure 4: BIM implementation status framework with Company X status indication.

Discussion

This research takes a building project lifecycle view to unite perspectives to BIM utilisation to indicate BIM maturity the extent of BIM utilisation and show the potential yet to be fulfilled through the construction project lifecycle. Understanding the BIM implementation status is vital as the fragmentation of the construction lifecycle cause challenges for the use of intelligent data. Four avenues of BIM implementation maturity are combined into a status framework to indicate compliance with the maturity stages. The corresponding analogy with the BIM iceberg and the related penetration supports the understanding. The early, easy-to-obtain BIM capabilities form the tip of the BIM iceberg (the initial BIM – ad hoc in the created status framework).

In contrast, the challenging-to-acquire integrated practices form the iceberg's bulk (stages towards the optimised in the created status framework). The bulk is critical to fully realise BIM's potential benefits and create true value, the collaborative & integrative BIM. The findings support the idea of BIG BIM in that integrated practices could induce collaboration and integration of parties across the supply chain and improve the built environment as a whole (Jernigan, 2007, 2017; Papadonikolaki & Wamelink, 2017). Each avenue and the corresponding stages highlight the steps to realise BIM's full potential. This is in line with the adjustments needed (Eadie et al., 2013; Merschbrock & Munkvold, 2012) to get the most out of BIM throughout the project lifecycle.

Assessing the created BIM implementation status framework together with a significant construction actor provides value to the existing literature-based discussion. The findings indicate that BIM is successfully used in the early stages of construction projects corresponding to the *initial BIM* of the iceberg. *Collaborative BIM* is partially applied but still suffers from the lack of a consistent approach to working with suppliers to reduce waste through open market negotiations. It is shown that the *Integrative BIM*, in the bulk of the iceberg, is not well recognised and is far from being achieved soon. The framework may enable construction projects to assess the BIM implementation status. This research provides additional value to the BIM iceberg model (Jernigan, 2007, 2017) by providing linkages to the avenues of BIM implementation maturity to assess the status of BIM implementation over the project lifecycle. The findings support research that endeavor to realise BIM's full potential (Barbosa et al., 2017; Eadie et al., 2013; Ghaffarianhoseini et al., 2017; Merschbrock & Munkvold, 2012). The framework indicates the necessity to understand the more obvious BIM capacities in early project stages as a prerequisite for more advanced BIM use. BIM implementation is an evolutionary process of BIM use experience. The similar colour pattern of the avenues in the created framework highlights the synergetic effect between the full potential of BIM implementation and supply-chain integration. This supports the previous works (Aram et al., 2013; Getuli et al., 2016; Irizarry et al., 2013; Papadonikolaki & Wamelink, 2017; Taylor & Bernstein, 2009).

Conclusion

This research focuses on the BIM phenomenon by describing BIM implementation maturity through alternative approaches. The main objective is to provide a perspective on BIM's potential and identify the hidden and unused capacity over the lifecycle of construction projects. A BIM implementation status framework is developed to indicate compliance with the maturity stages of four avenues of BIM implementation maturity. The developed framework analogies the BIM iceberg and the related penetration. The paper makes two significant contributions. First, the BIM iceberg analogy reveals that the initial use of BIM is a prerequisite but not sufficient to achieve the full potential of BIM. Under the surface, BIM has invisible but crucial potential that is massively valuable but challenging to recognise and realise. The importance of collaborative and integrative capabilities throughout the project lifecycle is highlighted as a necessity to come closer to the full potential of BIM, embedded in the bulk of the BIM iceberg. Secondly, the developed framework allows assessing the status of BIM implementation in specific situations. The framework can guide to recognise the status of BIM implementation on a lifecycle scale by including a variety of actors.

The managerial implications of this research involve supporting the facilitation of successful BIM implementation. Companies can use the framework as a reference for working towards the mature use of BIM. The framework clarifies the status of BIM implementation for construction projects by illustrating the necessary steps towards achieving mature BIM over the lifecycle of construction projects. Particular attention should be paid to the challenging-to-

achieve under-the-surface aspects of the BIM iceberg. The comparative viewpoint on the four avenues the presentation of the approaches can be valuable for future studies by allowing to recognise any overlaps. The limitations include the framework being tested only in one case company, which is a typical construction company. The proposed framework has undergone weak validation through discussions with relevant practitioners. Testing and validating the framework by a larger sample in multiple case studies are reserved for future studies. Also, the vertical implementation of related variables (Lehtinen, 2010, 2012) is not considered in the presented framework. The study focuses on a limited number of avenues but considers many aspects in greater detail.

References

- ACE. (2008). *Building Information Modeling: An introduction and best methods approach* (p. 28). Alliance for Construction Excellence. <https://www.coursehero.com/file/32152822/ACE-2008-BIM-Introduction-Best-Methods-Manual1pdf/>
- Ahmed, A. L., & Kassem, M. (2018). A unified BIM adoption taxonomy: Conceptual development, empirical validation and application. *Automation in Construction*, *96*, 103–127. <https://doi.org/10.1016/j.autcon.2018.08.017>
- Ahmed, V., Tezel, A., Aziz, Z., & Sibley, M. (2017). The future of Big Data in facilities management: Opportunities and challenges. *Facilities*, *35*(13/14), 725–745. <https://doi.org/10.1108/F-06-2016-0064>
- Alaloul, W. S., Liew, M. S., & Zawawi, N. A. W. A. (2016). Identification of coordination factors affecting building projects performance. *Alexandria Engineering Journal*, *55*(3), 2689–2698. <https://doi.org/10.1016/j.aej.2016.06.010>
- Alizadehsalehi, S., Hadavi, A., & Huang, J. C. (2020). From BIM to extended reality in AEC industry. *Automation in Construction*, *116*, 103254. <https://doi.org/10.1016/j.autcon.2020.103254>
- Alzahrani, J. I., & Emsley, M. W. (2013). The impact of contractors' attributes on construction project success: A post-construction evaluation. *International Journal of Project Management*, *31*(2), 313–322. <https://doi.org/10.1016/j.ijproman.2012.06.006>
- Antwi-Afari, M., Li, H., Pärn, E., & Edwards, D. (2018). Critical success factors for implementing building information modelling (BIM): A longitudinal review. *Automation in Construction*, *91*, 100–110.
- Aram, S., Eastman, C., & Sacks, R. (2013). Requirements for BIM platforms in the concrete reinforcement supply chain. *Automation in Construction*, *35*, 1–17. <https://doi.org/10.1016/j.autcon.2013.01.013>
- Aranda, J. Á., Martin-Dorta, N., Naya, F., Conesa-Pastor, J., & Contero, M. (2020). Sustainability and Interoperability: An Economic Study on BIM Implementation by a Small Civil Engineering Firm. *Sustainability*, *12*(22), 9581. <https://doi.org/10.3390/su12229581>
- Arayici, Y., & Aouad, G. (2010). *Building information modelling (BIM) for Construction Lifecycle Management* (pp. 99–118).
- Arshinder, K. (2008). *An integrative framework for supply chain coordination* [Doctoral thesis]. Indian Institute of Technology Delhi.
- Asare, K. A. B., Liu, R., & Anumba, C. J. (2021). Building information modeling to support facilities management of large capital projects: A critical review. *Facilities*, *40*(3/4), 176–197. <https://doi.org/10.1108/F-11-2020-0124>
- Autodesk. (2002). *Building Information Modeling*. Autodesk Inc.
- Azhar, S. (2011). Building information modeling (BIM): Trends, benefits, risks, and challenges for the AEC industry. *Leadership and Management in Engineering*, *11*(3), 241–252.
- Barbosa, F., Woetzel, J., Mischke, J., Ribeirinho, M. J., Sridhar, M., Parsons, M., Bertram, N., & Brown, S. (2017). *Reinventing construction: A route to higher productivity*. McKinsey & Company. <https://www.mckinsey.com/~media/mckinsey/business%20functions/operations/our%20insights/reinventing%20construction%20through%20a%20productivity%20revolution/mgi-reinventing-construction-a-route-to-higher-productivity-full-report.pdf>
- Barratt, M. (2004). Understanding the meaning of collaboration in the supply chain. *Supply Chain Management: An International Journal*. <https://doi.org/10.1108/13598540410517566>
- Becerik-Gerber, B., & Rice, S. (2010). The perceived value of building information modeling in the US building industry. *Journal of Information Technology in Construction (ITcon)*, *15*(15), 185–201.
- Bresnen, M., & Marshall, N. (2000). Partnering in construction: A critical review of issues, problems and dilemmas. *Construction Management and Economics*, *18*(2), 229–237. <https://doi.org/10.1080/014461900370852>
- Bryde, D., Broquetas, M., & Volm, J. M. (2013). The project benefits of building information modelling (BIM). *International Journal of Project Management*, *31*(7), 971–980.

- Carvalho, J. P., Bragança, L., & Mateus, R. (2019). Optimising building sustainability assessment using BIM. *Automation in Construction*, *102*, 170–182. Scopus. <https://doi.org/10.1016/j.autcon.2019.02.021>
- Charef, R., Alaka, H., & Emmitt, S. (2018). Beyond the third dimension of BIM: A systematic review of literature and assessment of professional views. *Journal of Building Engineering*, *19*, 242–257. <https://doi.org/10.1016/j.jobe.2018.04.028>
- Chen, P.-H., & Nguyen, T. C. (2019). A BIM-WMS integrated decision support tool for supply chain management in construction. *Automation in Construction*, *98*, 289–301. <https://doi.org/10.1016/j.autcon.2018.11.019>
- Christopher, M. (2011). *Logistics & supply chain management* (4. ed). Financial Times Prentice Hall.
- Dakhil, A. J. (2017). *Building Information Modelling (BIM) maturity-benefits assessment relationship framework for UK construction clients* [PhD, University of Salford]. <http://usir.salford.ac.uk/id/eprint/42554>
- Dallasega, P., Rauch, E., & Linder, C. (2018). Industry 4.0 as an enabler of proximity for construction supply chains: A systematic literature review. *Computers in Industry*, *99*, 205–225. <https://doi.org/10.1016/j.compind.2018.03.039>
- Dib, H., Chen, Y., & Cox, R. (2012). A framework for measuring building information modeling maturity based on perception of practitioners and academics outside the USA. *CIB W78*, *10*.
- Ding, L., Zhou, Y., & Akinci, B. (2014). Building Information Modeling (BIM) application framework: The process of expanding from 3D to computable nD. *Automation in Construction*, *46*, 82–93. <https://doi.org/10.1016/j.autcon.2014.04.009>
- Dyer, J. H., Cho, D. S., & Cgu, W. (1998). Strategic supplier segmentation: The next “best practice” in supply chain management. *California Management Review*, *40*(2), 57–77.
- Eadie, R., Browne, M., Odeyinka, H., McKeown, C., & McNiff, S. (2013). BIM implementation throughout the UK construction project lifecycle: An analysis. *Automation in Construction*, *36*, 145–151.
- Eadie, R., Browne, M., Odeyinka, H., McKeown, C., & McNiff, S. (2015). A survey of current status of and perceived changes required for BIM adoption in the UK. *Built Environment Project and Asset Management*, *5*(1), 4–21. <https://doi.org/10.1108/BEPAM-07-2013-0023>
- Eastman, C. M., Teicholz, P. M., Sacks, R., & Lee, G. (2018). *BIM handbook: A guide to building information modeling for owners, managers, designers, engineers and contractors* (Third edition). Wiley.
- European Construction Sector Observatory. (2021). *Digitalisation in the construction sector* (p. 159) [Analytical Report]. European Commission. file:///C:/Users/smansoor/AppData/Local/Temp/ECSO_AR_Digitalisation_2021.pdf
- Fawcett, S. E., & Magnan, G. M. (2002). The rhetoric and reality of supply chain integration. *International Journal of Physical Distribution & Logistics Management*, *32*(5), 339–361. <https://doi.org/10.1108/09600030210436222>
- Fulford, R., & Standing, C. (2014). Construction industry productivity and the potential for collaborative practice. *International Journal of Project Management*, *32*(2), 315–326. <https://doi.org/10.1016/j.ijproman.2013.05.007>
- Getuli, V., Ventura, S. M., Capone, P., & Ciribini, A. L. C. (2016). A BIM-based construction supply chain framework for monitoring progress and coordination of site activities. *Procedia Engineering*, *164*, 542–549. <https://doi.org/10.1016/j.proeng.2016.11.656>
- Ghaffarianhoseini, A., Tookey, J., Ghaffarianhoseini, A., Naismith, N., Azhar, S., Efimova, O., & Raahemifar, K. (2017). Building Information Modelling (BIM) uptake: Clear benefits, understanding its implementation, risks and challenges. *Renewable and Sustainable Energy Reviews*, *75*, 1046–1053.
- Gholizadeh, P., Esmaeili, B., & Goodrum, P. (2018). Diffusion of Building Information Modeling functions in the construction industry. *Journal of Management in Engineering*, *34*(2), 04017060. [https://doi.org/10.1061/\(ASCE\)ME.1943-5479.0000589](https://doi.org/10.1061/(ASCE)ME.1943-5479.0000589)
- Giel, B., & Issa, R. R. A. (2014). *Framework for Evaluating the BIM Competencies of Building Owners*. 552–559. <https://doi.org/10.1061/9780784413616.069>
- Gilligan, B., & Kunz, J. (2007). VDC use in 2007: Significant value, dramatic growth, and apparent business opportunity. *TR171*, *36*.
- Gledson, B., & Greenwood, D. (2016). Surveying the extent and use of 4D BIM in the UK. *Journal of Information Technology in Construction (ITcon)*, *21*, 57–71.
- Gomarn, P., & Pongpeng, J. (2018). *Causes of construction delay from contractors and suppliers in Thailand's oil and gas platform projects*. 192. Scopus. <https://doi.org/10.1051/mateconf/201819202008>
- Gu, N., & London, K. (2010). Understanding and facilitating BIM adoption in the AEC industry. *Automation in Construction*, *19*(8), 988–999.
- Halttula, H., Aapaoja, A., & Haapasalo, H. (2015). The contemporaneous use of building information modeling and relational project delivery arrangements. *Procedia Economics and Finance*, *21*, 532–539.
- Hardin, B., & McCool, D. (2015). *BIM and construction management: Proven tools, methods, and workflows*. John Wiley & Sons.

- Haron, A. T., Marshall-Ponting, A. J., & Aouad, G. (2009). *Building information modelling in integrated practice*. 2nd Construction Industry Research Achievement International Conference (CIRIAC 2009), Kuala Lumpur, Malaysia. <http://usir.salford.ac.uk/id/eprint/16624>
- Heaton, J., Parlikad, A. K., & Schooling, J. (2019). A Building Information Modelling approach to the alignment of organisational objectives to Asset Information Requirements. *Automation in Construction*, *104*, 14–26. Scopus. <https://doi.org/10.1016/j.autcon.2019.03.022>
- Hill, R. M., & Omar, M. (2006). Another look at the single-vendor single-buyer integrated production-inventory problem. *International Journal of Production Research*, *44*(4), 791–800. <https://doi.org/10.1080/00207540500334285>
- Hines, P., Lamming, R., Jones, D., Cousins, P., & Rich, N. (2000). *Value stream management: Strategy and excellence in the supply chain*. Financial Times Prentice Hall.
- Hull, J., & Ewart, I. J. (2020). Conservation data parameters for BIM-enabled heritage asset management. *Automation in Construction*, *119*, 103333. <https://doi.org/10.1016/j.autcon.2020.103333>
- Irizarry, J., Karan, E. P., & Jalaei, F. (2013). Integrating BIM and GIS to improve the visual monitoring of construction supply chain management. *Automation in Construction*, *31*, 241–254. <https://doi.org/10.1016/j.autcon.2012.12.005>
- Jayaram, J., Tan, K.-C., & Nachiappan, S. P. (2010). Examining the interrelationships between supply chain integration scope and supply chain management efforts. *International Journal of Production Research*, *48*(22), 6837–6857. <https://doi.org/10.1080/00207540903358329>
- Jernigan, F. (2007). *Big BIM, Little Bim: The Practical Approach to Building Information Modeling: Integrated Practice Done the Right Way!* 4Site Press. <https://books.google.fi/books?id=-ajbGQAACAAJ>
- Jernigan, F. (2017). *BIG BIM 4.0: Ecosystems for a Connected World* (M. Bordenaro, Ed.). CreateSpace Independent Publishing Platform.
- Jung, Y., & Joo, M. (2011). Building information modelling (BIM) framework for practical implementation. *Automation in Construction*, *20*(2), 126–133. <https://doi.org/10.1016/j.autcon.2010.09.010>
- Kaner, I., Sacks, R., Kassian, W., & Quitt, T. (2008). Case studies of BIM adoption for precast concrete design by mid-sized structural engineering firms. *Journal of Information Technology in Construction (ITcon)*, *13*(21), 303–323.
- Kassem, M., & Succar, B. (2017). Macro BIM adoption: Comparative market analysis. *Automation in Construction*, *81*, 286–299.
- Korpela, J., Miettinen, R., Salmikivi, T., & Ihalainen, J. (2015). The challenges and potentials of utilising building information modelling in facility management: The case of the Center for Properties and Facilities of the University of Helsinki. *Construction Management and Economics*, *33*(1), 3–17. <https://doi.org/10.1080/01446193.2015.1016540>
- Kuiper, I., & Holzer, D. (2013). Rethinking the contractual context for Building Information Modelling (BIM) in the Australian built environment industry. *Construction Economics and Building*, *13*(4), 1–17. <https://doi.org/10.5130/AJCEB.v13i4.3630>
- Laiho, A. (2015). *Orchestration of External Resources*. Aalto University.
- Lee, G., & Kim, J. (2014). Parallel vs. sequential cascading MEP coordination strategies: A pharmaceutical building case study. *Automation in Construction*, *43*, 170–179. <https://doi.org/10.1016/j.autcon.2014.03.004>
- Lee, H. (2000). Creating value through supply chain integration. *Supply Chain Management Review*, *4*(4), 30–36.
- Lehtinen, T. (2010). *Advantages and disadvantages of vertical integration in the implementation of systemic process innovations: Case studies on implementing building information modeling (BIM) in the Finnish construction industry* [Master's Thesis]. Aalto-yliopisto.
- Lehtinen, T. (2012). Boundaries Matter – The Pros and Cons of Vertical Integration in BIM Implementation. In J. Frick & B. T. Laugen (Eds.), *Advances in Production Management Systems. Value Networks: Innovation, Technologies, and Management* (Vol. 384, pp. 578–585). Springer Berlin Heidelberg. https://doi.org/10.1007/978-3-642-33980-6_62
- Li, Y., Zhang, Y., Wei, J., & Han, Y. (2019). Status Quo and Future Directions of Facility Management: A Bibliometric – qualitative Analysis. *International Journal of Strategic Property Management*, *23*(5), 354–365. <https://doi.org/10.3846/ijspm.2019.9943>
- Love, P. E. D., Simpson, I., Hill, A., & Standing, C. (2013). From justification to evaluation: Building information modeling for asset owners. *Automation in Construction*, *35*, 208–216. <https://doi.org/10.1016/j.autcon.2013.05.008>
- Marshall, M. N. (1996). Sampling for qualitative research. *Family Practice*, *13*(6), 522–526. <https://doi.org/10.1093/fampra/13.6.522>
- McGraw-Hill Construction. (2012). *The business value of BIM in North America: Multi-year trend analysis and user ratings (2007-2012)*. McGraw-Hill Construction.

- <https://damassets.autodesk.net/content/dam/autodesk/www/solutions/building-information-modeling/bim-value/mhc-business-value-of-bim-in-north-america.pdf>
- McLaren, T., Head, M., & Yuan, Y. (2002). Supply chain collaboration alternatives: Understanding the expected costs and benefits. *Internet Research*, 12(4), 348–364. <https://doi.org/10.1108/10662240210438416>
- Mejias-Sacaluga, A., & Carlos Prado-Prado, J. (2002). Integrated logistics management in the grocery supply chain. *The International Journal of Logistics Management*, 13(2), 67–78.
- Meng, X. (2013). Change in UK construction: Moving toward supply chain collaboration. *Journal of Civil Engineering and Management*, 19(3), 422–432. <https://doi.org/10.3846/13923730.2012.760479>
- Merschbrock, C., & Munkvold, B. E. (2012). A Research Review on Building Information Modeling in Construction—An Area Ripe for IS Research. *Communications of the Association for Information Systems*, 31. <https://doi.org/10.17705/1CAIS.03110>
- Narus, J. A., & Anderson, J. C. (1996). Rethinking distribution: Adaptive channels. *Harvard Business Review*, 74, 112–120.
- Nepal, M. P., Jupp, J. R., & Aibinu, A. A. (2014). *Evaluations of BIM: Frameworks and perspectives*. 769–776. <https://doi.org/10.1061/9780784413616.096>
- NIBS. (2007). *National Building Information Modeling standard version 1—Part 1: Overview, principles, and methodologies* (p. 183). National Institute of Building Sciences. https://buildinginformationmanagement.files.wordpress.com/2011/06/nbimsv1_p1.pdf
- Nical, A. K., & Wodynski, W. (2016). Enhancing Facility Management through BIM 6D. *Procedia Engineering*, 164, 299–306. <https://doi.org/10.1016/j.proeng.2016.11.623>
- Olanrewaju, O. I., Kineber, A. F., Chileshe, N., & Edwards, D. J. (2022). Modelling the relationship between Building Information Modelling (BIM) implementation barriers, usage and awareness on building project lifecycle. *Building and Environment*, 207, 108556. <https://doi.org/10.1016/j.buildenv.2021.108556>
- Papadonikolaki, E., Verbraeck, A., & Wamelink, H. (2017). Formal and informal relations within BIM-enabled supply chain partnerships. *Construction Management and Economics*, 35(8–9), 531–552. <https://doi.org/10.1080/01446193.2017.1311020>
- Papadonikolaki, E., Vrijhoef, R., & Wamelink, H. (2016). The interdependences of BIM and supply chain partnering: Empirical explorations. *Architectural Engineering and Design Management*, 12(6), 476–494. <https://doi.org/10.1080/17452007.2016.1212693>
- Papadonikolaki, E., & Wamelink, H. (2017). Inter- and intra-organizational conditions for supply chain integration with BIM. *Building Research & Information*, 45(6), 649–664. <https://doi.org/10.1080/09613218.2017.1301718>
- Pärn, E. A., Edwards, D. J., & Sing, M. C. P. (2017). The building information modelling trajectory in facilities management: A review. *Automation in Construction*, 75, 45–55. <https://doi.org/10.1016/j.autcon.2016.12.003>
- Patacas, J., Dawood, N., & Kassem, M. (2020). BIM for facilities management: A framework and a common data environment using open standards. *Automation in Construction*, 120, 103366. <https://doi.org/10.1016/j.autcon.2020.103366>
- Prins, M., & Owen, R. (2010). Integrated design and delivery solutions. *Architectural Engineering and Design Management*, 6(4), 227–231. <https://doi.org/10.3763/aedm.2010.IDDS0>
- Saad, M., Jones, M., & James, P. (2002). A review of the progress towards the adoption of supply chain management (SCM) relationships in construction. *European Journal of Purchasing & Supply Management*, 8(3), 173–183. [https://doi.org/10.1016/S0969-7012\(02\)00007-2](https://doi.org/10.1016/S0969-7012(02)00007-2)
- Sacks, R., Girolami, M., & Brilakis, I. (2020). Building Information Modelling, Artificial Intelligence and Construction Tech. *Developments in the Built Environment*, 4, 100011. <https://doi.org/10.1016/j.dibe.2020.100011>
- Siebelink, S., Voordijk, H., Endedijk, M., & Adriaanse, A. (2021). Understanding barriers to BIM implementation: Their impact across organisational levels in relation to BIM maturity. *Frontiers of Engineering Management*, 8(2), 236–257. <https://doi.org/10.1007/s42524-019-0088-2>
- Simatupang, T. M., Wright, A. C., & Sridharan, R. (2002). The knowledge of coordination for supply chain integration. *Business Process Management Journal*. <https://doi.org/10.1108/14637150210428989>
- Son, H., Lee, S., & Kim, C. (2015). What drives the adoption of building information modeling in design organisations? An empirical investigation of the antecedents affecting architects' behavioral intentions. *Automation in Construction*, 49, 92–99. <https://doi.org/10.1016/j.autcon.2014.10.012>
- Spekman, R. E., Kamauff, J. W., & Myhr, N. (1998). An empirical investigation into supply chain management: A perspective on partnerships. *Supply Chain Management: An International Journal*, 3(2), 53–67. <https://doi.org/10.1108/13598549810215379>
- Succar, B. (2009). Building information modelling framework: A research and delivery foundation for industry stakeholders. *Automation in Construction*, 18(3), 357–375.

- Succar, B. (2010). Building information modelling maturity matrix. In *Handbook of research on building information modeling and construction informatics: Concepts and technologies* (pp. 65–103). IGI Global.
- Succar, B., Sher, W., & Williams, A. (2012). Measuring BIM performance: Five metrics. *Architectural Engineering and Design Management*, 8(2), 120–142. <https://doi.org/10.1080/17452007.2012.659506>
- Tang, S., Shelden, D. R., Eastman, C. M., Pishdad-Bozorgi, P., & Gao, X. (2020). BIM assisted Building Automation System information exchange using BACnet and IFC. *Automation in Construction*, 110, 103049. <https://doi.org/10.1016/j.autcon.2019.103049>
- Taylor, J. E., & Bernstein, P. G. (2009). Paradigm trajectories of building information modeling practice in project networks. *Journal of Management in Engineering*, 25(2), 69–76.
- Torraco, R. J. (2005). Writing Integrative Literature Reviews: Guidelines and Examples. *Human Resource Development Review*, 4(3), 356–367. <https://doi.org/10.1177/1534484305278283>
- Tsai, M.-H., Mom, M., & Hsieh, S.-H. (2014). Developing critical success factors for the assessment of BIM technology adoption: Part I. Methodology and survey. *Journal of the Chinese Institute of Engineers*, 37(7), 845–858. <https://doi.org/10.1080/02533839.2014.888811>
- Turk, Ž. (2016). Ten questions concerning building information modelling. *Building and Environment*, 107, 274–284. <https://doi.org/10.1016/j.buildenv.2016.08.001>
- Vrijhoef, R., & Koskela, L. (2000). The four roles of supply chain management in construction. *European Journal of Purchasing & Supply Management*, 6(3), 169–178. [https://doi.org/10.1016/S0969-7012\(00\)00013-7](https://doi.org/10.1016/S0969-7012(00)00013-7)
- Wang, T., Ali, A. S., & Au-Yong, C. P. (2022). Exploring a body of knowledge for promoting the building information model for facility management. *Ain Shams Engineering Journal*, 13(4), 101717. <https://doi.org/10.1016/j.asej.2022.101717>
- Wilson, J. (2014). *Essentials of business research: A guide to doing your research project* (Second edition). SAGE.
- World Economic Forum. (2018). *An Action Plan to accelerate Building Information Modeling (BIM) Adoption*. World Economic Forum.
- Wu, Y., & Xu, N. (2014). BIM Information Collaborative Framework Based on Supply Chain Management. In *ICCREM 2014: Smart Construction and Management in the Context of New Technology* (pp. 199–207).
- Xu, X., Ma, L., & Ding, L. (2014). A framework for BIM-enabled lifecycle information management of construction project. *International Journal of Advanced Robotic Systems*, 11(8), 126. <https://doi.org/10.5772/58445>
- Xue, X., Li, X., Shen, Q., & Wang, Y. (2005). An agent-based framework for supply chain coordination in construction. *Automation in Construction*, 14(3), 413–430. <https://doi.org/10.1016/j.autcon.2004.08.010>
- Yin, R. K. (2009). *Case study research: Design and methods* (4th ed). Sage Publications.
- Zhang, C., Nizam, R. S., & Tian, L. (2018). BIM-based investigation of total energy consumption in delivering building products. *Advanced Engineering Informatics*, 38, 370–380. <https://doi.org/10.1016/j.aei.2018.08.009>
- Zhang, S., Teizer, J., Lee, J.-K., Eastman, C. M., & Venugopal, M. (2013). Building Information Modeling (BIM) and safety: Automatic safety checking of construction models and schedules. *Automation in Construction*, 29, 183–195. <https://doi.org/10.1016/j.autcon.2012.05.006>
- Zou, Y., Kiviniemi, A., & Jones, S. W. (2017). A review of risk management through BIM and BIM-related technologies. *Safety Science*, 97, 88–98. <https://doi.org/10.1016/j.ssci.2015.12.027>
- Zuppa, D., Issa, R. R., & Suermann, P. C. (2009). BIM's impact on the success measures of construction projects. *Computing in Civil Engineering (2009)*, 503–512. [https://doi.org/10.1061/41052\(346\)50](https://doi.org/10.1061/41052(346)50)

Appendixes

Appendix A: Interview guide

