Model-Based Construction

Understanding and implementation challenges

- A Case study

Master’s thesis in Design and Construction Project Management

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ABSTRACT

This study explores the challenges experienced in the implementation of Model-Based Construction (MBC) and examines how different stakeholders understand and approach the concept. The empirical work draws on a literature review and a case study of Kaj 16, an ongoing project in Sweden that is implementing model-based construction. Using a qualitative approach with semi-structured interviews and document analysis, the research investigates how stakeholders interpret MBC, the organizational and technical barriers they face, and the strategies developed to overcome them. The findings show that implementing MBC represents a significant shift in the construction sector, as it extends the use of BIM from design into site practices. The study highlights differences in how MBC is understood and reveals that full implementation has not yet been achieved due to multiple barriers spanning organizational, technical, legal, and financial domains. Addressing these challenges—supported by early standardization and strong client leadership—is essential to enable successful and complete adoption of MBC.

Key words: Model-Based Construction (MBC); Building Information Modelling (BIM); Digital Transformation; MBC Implementation Challenges; Construction Process Improvement

Modellbaserad konstruktion:

Utmaningar inom förståelse och implementering

Examensarbete inom mastersprogrammet Organisering och ledning i bygg- och fastighetssektorn

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SAMMANFATTNING

Denna studie undersöker de utmaningar som uppstår vid implementeringen av Modellbaserat Byggande (MBC) och analyserar hur olika aktörer förstår och närmar sig konceptet. Det empiriska arbetet bygger på en litteraturstudie och en fallstudie av Kaj 16, ett pågående projekt i Sverige som implementerar modellbaserat byggande. Genom en kvalitativ metod med semistrukturerade intervjuer och dokumentanalys undersöker forskningen hur aktörer tolkar MBC, vilka organisatoriska och tekniska hinder de möter, samt vilka strategier som utvecklas för att övervinna dem. Resultaten visar att implementeringen av MBC innebär en betydande förändring inom byggsektorn, eftersom användningen av BIM utvidgas från design till praktik på byggarbetsplatsen. Studien belyser skillnader i hur MBC förstås och visar att en fullständig implementering ännu inte har uppnåtts på grund av flera hinder inom organisatoriska, tekniska, juridiska och ekonomiska områden. Att hantera dessa utmaningar – med stöd av tidig standardisering och starkt ledarskap från beställaren – är avgörande för att möjliggöra en framgångsrik och fullständig tillämpning av MBC.

Nyckelord: Modelbaserad konstruktion (MBC); Byggnadsinformationsmodellering (BIM); Digital transformation; Utmaningar vid införande av MBC; Förbättring av byggprocessen

Preface

This study was conducted as part of our master's program in Design and Construction Project Management at Chalmers University of Technology. Our interest in increasing the benefits of existing technologies that are not yet fully utilized led us to select KAJ16 as a case study. This pioneering project provided an excellent opportunity to explore the implementation of the new Model-Based Construction (MBC) method, in close cooperation with several team members involved in the project.

We would like to extend our deepest gratitude to our supervisor, Dr. Duman, for her invaluable guidance and continuous support throughout this work. We are also deeply grateful to the staff of the companies involved in the Kaj16 project for their kind cooperation during the interviews and for generously sharing their data and insights. Their assistance has been indispensable, and this work would not have been possible without their contribution.

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Notations

AEC	Architecture, Engineering, and Construction
AIA	American Institute of Architects
BE	ByggnadsHandlingar (Swedish drawing standards, BH90)
BEP	BIM Execution Plan
BIM	Building Information Modelling
BIMForum	A forum for BIM standards and practices
CAD	Computer-Aided Design
CD	Construction Documentation
CDE	Common Data Environment
COBie	Construction Operations Building Information Exchange
DB	Design-Build
DBB	Design-Bid-Build
DD	Detailed Design
DT	Digital Transformation
FM	Facility Management
GDP	Gross Domestic Product
GDPR	General Data Protection Regulation
gbXML	green building XML
HBIM	Historic Building Information Modelling
HVAC	Heating, Ventilation, and Air Conditioning
ICT	Information and Communication Technology
IFC	Industry Foundation Classes
IoT	Internet of Things
LCA	Life-Cycle Assessment
LOD	Level of Development
MBC	Model-Based Construction
MBD	Model-Based Design
MBDD	Model-Based Design Delivery
MEP	Mechanical, Electrical, and Plumbing
MMI	Model Maturity Index
PDF	Portable Document Format
PM	Project Management / Project Manager
Power BI	Microsoft's business analytics tool
ROI	Return on Investment
SEK	Swedish Krona
SMEs	Small and Medium-sized Enterprises
UNEP	United Nations Environment Programme
USD	US Dollar
4D	Time/Scheduling (in BIM)
5D	Cost Estimation (in BIM)

1 Introduction

1.1 Background

The construction industry has long faced criticism for its fragmented processes, limited innovation, and inefficiencies in delivering complex projects. Despite the integration of digital technologies such as Building Information Modelling (BIM), adoption has been uneven across the sector (Lidelöw et at., 2023). Model-Based Construction (MBC) has emerged as a promising approach that builds on BIM, aiming to extend its benefits from design into the construction phase by making the digital model the primary source of project information (Disney, 2024).

MBC represents a shift from drawing-based documentation to model-driven workflows during construction, where the digital model serves as the central, up-to-date, and potentially even legally binding reference (Disney, 2024). While conceptually powerful, this approach challenges traditional practices, roles, and expectations in project delivery. It demands high levels of collaboration, digital competence, and coordination among all stakeholders throughout the project lifecycle. Furthermore, it introduces organizational, technical, legal, and financial complexities that require careful navigation.

This study explores these challenges through a detailed case study of KAJ 16, an ongoing building construction project in Gothenburg. KAJ 16 is a timber construction project initiated by Vasakronan, a client aiming to position itself as a leader in innovation and sustainability. The project employs Sweco as digital consultants and Vestia as the main contractor under a design-build contract with a collaborative (samverkan) approach. KAJ 16 aims to eliminate printed drawings and rely on digital models for all construction activities, making it a model-based project delivery.

The project vision has been defined as fully paperless and model-driven, but its implementation has faced significant challenges. This provides an empirical context to explore how innovation is achieved within the realities of construction projects. The empirical study presented below examines how the implementation of MBC unfolds in practice, including how teams understand, negotiate, and apply it across disciplines and work phases.

1.2 Aim, Objectives and Research Questions

This thesis aims to explore the challenges of implementing Model-Based Construction (MBC) by examining how stakeholders interpret, adopt, and respond to MBC processes in the KAJ 16 project. To achieve the research aim, this study is guided by the following research questions:

- How do different stakeholders interpret and understand the concept of model-based construction?
- What types of challenges - organizational, technical, legal, or financial - are encountered when implementing MBC in practice?
- What lessons from the KAJ 16 project can inform future implementation of model-based construction?

1.3 Structure of the Thesis

The thesis is structured as follows:

- Chapter 1 provides the introduction of the study, including a general overview of the thesis structure.
- Chapter 2 provides a literature review covering digital transformation in construction, BIM, and the evolution toward model-based design and construction.
- Chapter 3 describes the research methodology, explaining the rationale for the qualitative case study approach, data collection through interviews and document analysis, and the analytical framework.
- Chapter 4 presents the empirical findings from the KAJ 16 case, highlighting how stakeholders define MBC, the challenges they face, and strategies they employ.
- Chapter 5 discusses these findings in light of existing literature, offering critical insights into the understanding, implementation, and barriers of MBC.
- Chapter 6 concludes the thesis by summarizing key findings, outlining contributions to knowledge, and providing practical recommendations and directions for future research.

2 Literature review

2.1 Overview and background

The construction industry remains a vital component of the global economy, accounting for approximately 13% of worldwide GDP according to recent World Bank (2023) data. The sector generated an estimated $13.5 trillion in revenue in 2023, with projections suggesting growth to $15.2 trillion by 2030 (Robinson et al., 2021). In Sweden specifically, official statistics show the construction industry contributed 11.2% (412 billion SEK) to national GDP in 2023 while employing 12% of the country's workforce (Statistics Sweden, 2024). Despite its economic significance, the industry continues to face substantial challenges. Research indicates that 85% of construction projects exceed their budgets by more than 10%, with average delays of 17.5 months becoming commonplace (McKinsey, 2022). Productivity growth has lagged significantly behind other sectors, increasing at just 1% annually compared to manufacturing's 2.8% growth rate (TBH Consultancy, 2023).

The industry's persistent problems stem largely from its fragmented nature and poor collaboration practices. Studies have identified that 42% of project delays originate from coordination failures between contractors and subcontractors (Deloitte, 2023). The traditional separation between design and production phases in the volatile construction industry makes design changes inevitable, resulting in severe problems like productivity loss, schedule delays, and substantial cost overruns, which frequently range between 5 and 40% of the project cost, although even well-managed projects experience cost impacts of 2.1% to 21.5% (Aslam et al., 2019). Furthermore, the construction sector remains a major environmental concern, responsible for 38% of global CO_2 emissions while fewer than 15% of firms actively track their carbon footprint (UNEP, 2022). Kakitahi et al. (2016) found that the average impact of rework was a 4.53% increase in project costs and an 8.42% extension to the schedule.

Emerging solutions show promise in addressing these systemic issues. Building Information Modelling (BIM) technologies have demonstrated the potential to reduce rework up to 30% when implemented with integrated teams (Sacks et al., 2018). However, research emphasize that technological solutions alone cannot solve the industry's challenges - fundamental changes to procurement models and collaboration frameworks are equally critical (Dainty et al., 2017). The transition to more sustainable and efficient practices requires simultaneous advancements in digital tools, workforce training, and organizational culture throughout the construction ecosystem.

The construction industry has been criticized for its slow adoption of new technologies (Prebanić & Vukomanović, 2021). Despite the potential benefits of information and digital technologies, IT adoption in construction is generally limited, and predictions of future adoption have often been overly optimistic (Brandon et al., 2004), however, the construction industry lags behind other sectors in integrating innovative technologies (Prebanić & Vukomanović, 2021). Several factors contribute to this slow pace of technological integration.

First, the construction industry's high fragmentation, marked by numerous interconnected but weakly coordinated organizations often prioritizing low-cost agendas, fosters a zero-sum environment that hinders industry-wide innovation (Dainty et al., 2017). This fragmentation, with its many small, specialized firms engaged in temporary projects, ties key challenges and opportunities for change to organizational-level dynamics (Dainty et al., 2017). As a result, innovations in operations, structures, and processes often exceed the influence of any single entity (Samuelson & Stehn, 2023). Digital transformation and other systemic shifts thus demand distributed actions and collaboration across inter-organizational boundaries (Duman et al., 2022).

The industry's entrenched structures divide stakeholders into siloed groups, creating barriers for individual firms driving change. Each actor contributes only marginally to the value chain, with no clear accountability for the broader process beyond individual projects. This lack of coordination stifles progress, while the absence of firms challenging these structures further diminishes the likelihood of industry-wide transformation. To advance digital transformation (DT) effectively, a holistic approach is essential—one that simultaneously addresses individual, organizational, project, and industry or network levels (Samuelson & Stehn, 2023).

Second, the project-based nature of construction creates systemic barriers to digital transformation. Temporary project teams and constantly shifting alliances prevent knowledge transfer and consistent digital adoption across projects (Reichstein et al., 2005; Samuelson & Stehn, 2023). The lack of a clear process owner means no single entity can drive industry-wide change (Reichstein et al., 2005), while misaligned incentives discourage stakeholders from optimizing beyond their immediate deliverables (Samuelson & Stehn, 2023). Despite digital transformation primarily manifesting at the project level, research increasingly calls for organizational and industry-wide systemic change, highlighting the need to move "beyond the confined boundaries of projects" (Papadonikolaki et al., 2021). This transition is challenging because each project involves new configurations of companies and individuals, hindering knowledge transfer and the development of consistent working methods over time (Reichstein et al., 2005). Lundberg et al. (2021) argues that inconsistencies arise as construction site operations involve multiple actors with varying assumptions, expectations, and technological knowledge, further impairing digitalization efforts. These actors, rooted in different firm cultures, often have misaligned cognitions, values, and incentives, which can hinder technological adoption (Orlikowski and Gash 1994; Davidson 2006).

Collaboration (the active process of co-creation across organizational boundaries according to Samuelson & Stehn (2023)) and integration (the harmonization of processes and digital tools into a unified system according to Samuelson & Stehn (2023)) are also hindered by the industry's project-based temporality, which reinforces traditional operations and a lack of long-term alliances across the value chain, such as between design and production, clients and contractors, and contractors and subcontractors (Duman et al., 2022). Moreover, there is little incentive or mandate to drive digital technology development or implementation beyond organizational boundaries, resulting in digitalized processes that remain fragmented and insubstantial (Duman et al., 2022).

Third, Small and medium-sized enterprises (SMEs) in the construction industry encounter numerous challenges in adopting new technologies and achieving digitalization. These challenges stem from limited resources (Eadie et al., 2013; Li et al., 2019), financial constraints (Aibinu and Venkatesh, 2014), and a lack of awareness and understanding of digital transformation tools (Koseoglu et al, 2019). Many SMEs struggle to evaluate their IT needs and often lack the knowledge to select appropriate resources for digitalization (Pelletier & Cloutier, 2019). Furthermore, the absence of clear evidence showing a return on investment (ROI) from Building Information Modelling (BIM) implementation poses a significant obstacle for SMEs (Poirier et al., 2015). Issues such as lack of standardization and interoperability further hinder the development of effective digital tools for the industry (Sundquist et al., 2020). Additionally, SMEs frequently face a shortage of skilled professionals and training programs, which complicates their ability to manage the systemic changes required for digital transformation (Sundquist et al., 2020). It is also important to note that the heterogeneous nature of construction SMEs means that factors beyond size, such as business characteristics, influence BIM adoption (Acar et al., 2005).

Fourth, existing regulatory frameworks and procurement models continue to pose significant obstacles to digital transformation in construction. Despite the increasing use of digital models, many contractual and legal systems still mandate traditional 2D drawings as the primary or legally binding project documents, undermining the full adoption of model-based practices (Brooks et al., 2023). As a result, parallel processes often emerge, forcing teams to maintain both 3D models and paper-based documents, which introduces redundancy, errors, and additional costs (Gaunt, 2017).

Procurement structures such as design-bid-build (DBB) reinforce a sequential separation between design and construction, limiting opportunities for integrated digital delivery (Whyte, 2019). This traditional approach restricts early contractor involvement and hinders collaborative workflows needed for model-based project delivery. Furthermore, the lack of standardized legal frameworks and clear guidelines on the contractual status of BIM models creates uncertainty, slowing the transition towards treating digital models as the single source of truth (Morgan, 2019; Duman & Gustafsson, 2025).

2.2 Digital Transformation and BIM in the Construction Industry

2.2.1 The digital development of the construction industry

The transformation in the construction sector is typically categorized into three main stages: digitization, digitalization, and digital transformation (DT) (Whyte, 2019). These terms describe a progression from basic digital conversion to fundamental changes in industry practice.

Digitization: Digitization involves the conversion of paper-based or analogue processes into digital formats (Samuelson & Stehn, 2023). This stage primarily focuses on making information accessible in a digital medium. An example of digitization is replacing printed blueprints with PDFs (Samuelson & Stehn, 2023). This process provides the necessary foundation for further digital changes, but it does not inherently guarantee their occurrence (Papadonikolaki et al., 2018; Samuelson & Stehn, 2023). In the construction industry, this often addresses the heavy reliance on 2D documentation to describe a 3D reality, where even 3D visualizations are often disjointed and dependent on two-dimensional documents. BIM data "exchanges" are a form of digitization, where data is exported or imported without being structured or computable, such as exporting 2D CAD drawings from 3D object-based models, which results in a significant loss of geometric and semantic data.

Digitalization: Digitalization is the subsequent stage, focusing on the use of digital technologies to enhance efficiency in existing processes (Samuelson & Stehn, 2023). This is a socio-technical process that applies digitized aspects to develop new organizational procedures (Lundberg et al., 2021; Morgan, 2019). A prime example in construction is using Building Information Modelling (BIM) for coordination and clash detection (Lidelöw et al., 2023). It includes applications such as Computer-Aided Design (CAD), digitally mediated routines, and improved coordination among multiple actors through digitized information (Alsafouri & Ayer, 2018; Lidelöw et al., 2023; Sacks et al., 2018). Digitalization aims to improve efficiency, productivity, and profitability by rearranging existing business processes with IT or digital technologies (Oraee et al., 2019; Sacks et al., 2018; Samuelson & Stehn, 2023).

While progress in construction has been slower compared to other industries (Dainty et al., 2017; Samuelson & Stehn, 2023), some digital tools - such as digital checklists and issue management systems - are highly efficient but do not strictly require BIM, although they are often integrated into BIM tools (Sundquist et al., 2020). Approaches like "drawingless" or "model-only delivery" aim to remove the need for 2D information in communication to improve design efficiency, with rare examples like the Smisto project in Norway publicly pursuing drawingless design in civil engineering (Gaunt, 2017). The "Total BIM" approach involves pre-sorting information for site workers into simple tabs for easy access to relevant construction information, demonstrating an enhanced level of digitalization (Disney et al., 2023).

Digital Transformation (DT): Digital transformation represents a fundamental and profound shift in construction where digital tools reshape the way the industry operates (Duman & Gustafsson, 2025; Samuelson & Stehn, 2023). It goes beyond merely improving existing processes; it involves the use of new digital technologies to enable business improvements or completely change business models (Duman & Gustafsson, 2025; Papadonikolaki et al., 2018). This transformation encompasses changes in products, services, processes, and entire value chains (Duman & Gustafsson, 2025; Samuelson & Stehn, 2023).

DT involves not just technology but also the transformation of people and the alignment of technology, financial resources, and personnel toward shared goals (Morgan, 2019; Samuelson & Stehn, 2023). DT is seen as a strategic process that can improve and even disrupt the construction sector by altering traditional roles, responsibilities, and relationships among project participants (Disney et al., 2023; Lobo & Whyte, 2017; Samuelson & Stehn, 2023). The "Total BIM" approach, for instance, is considered a digital disruption that challenges conventional business models (Disney et al., 2023). However, the understanding of DT within the construction industry by scholars and practitioners is still developing, often being used broadly rather than precisely defined (Samuelson & Stehn, 2023).

2.2.2 BIM implementation

Transition from traditional 2D CAD drawings to BIM-based workflows was a fundamental shift in the construction sector, with a major challenge that many companies depended on traditional document-based workflows even after BIM usage was available (Sacks et al., 2018). According to Sacks et al. (2018) BIM is a modelling technology and associated set of processes to produce, communicate, and analyse building models. The early use of BIM was mainly in the design and planning stages, and it usually was limited to 3D visualization and clash detection rather than full coordination and project integration of all stakeholders (Sundquist et al., 2020). The aim to improve design accuracy, coordination and collaboration begun the transition from CAD to BIM, but the adoption varied among firms and even projects (Liu et al., 2022). Some companies have succeeded in implementing BIM based workflows, but many other continue using the traditional 2D documents alongside BIM models (Disney et al., 2023).

Construction historically relied heavily on 2D drawings, which created fragmented workflows, miscommunication and many errors (Sundquist et al., 2020). Thereafter, the transition from 2D based management to BIM-integrated workflows has started. aiming to offer centralized data driven project models that integrates several aspects of the project design, cost estimation, and scheduling in one model (Liu et al., 2022). In spite of all the benefits of MBC, contractors and on-site workers often shift to the traditional 2D methods, which highlights the gap between BIM availability and effective usage (Sundquist et al., 2020).

2.2.3 Digital maturity concept

Digital maturity represents the degree of adoption and application of digital technologies in corporate business models. According to Rossmann (2018), digital maturity involves integrating technologies such as BIM, IoT, digital twins, and automation into processes. Samuelson and Stehn (2023) also describe this development as the formation of specific capabilities in strategy, leadership, business and operating models, people, culture, governance, and technology to manage digital transformation. Different ways of classifying BIM maturity models exist. Sacks et al. (2018), in Chapter 8, present the key levels of BIM maturity:

1. Level 0 (Non-BIM): This is the baseline level of BIM maturity. It primarily involves traditional methods such as 2D CAD (Computer-Aided Design), with little to no digital collaboration. Characteristics include communication through printed or basic digital files (e.g., PDFs), no shared data or information models, and lastly projects are often fragmented, with limited transparency and coordination.

2. Level 1 (Managed CAD): At this stage, organizations start adopting basic digital processes. There's a mix of 2D drafting and simple 3D modelling, although these remain isolated. Key features include the introduction of Common Data Environments (CDEs) to manage project information, some degree of collaboration and standardization in processes, and lastly, minimal integration between different disciplines or trades.

3. Level 2 (Collaborative BIM): This level is considered the turning point for effective BIM adoption. Here, teams work in a more collaborative environment, leveraging

shared 3D models to enhance project delivery. Characteristics include use of 3D BIM models, where information is shared across stakeholders, interoperability standards such as IFC (Industry Foundation Classes) and COBie (Construction Operations Building Information Exchange) enable data exchange, improved clash detection, coordination, and visualization of designs, and lastly integration of scheduling (4D) and cost estimation (5D) data into models.

4. Level 3 (Integrated BIM): This is the highest level of BIM maturity, representing a fully integrated and collaborative environment. Features of this stage include: cloud-based, unified models accessible to all stakeholders in real-time, lifecycle data management, from design through construction and into operations, fully automated workflows, supported by technologies like artificial intelligence, automation, and predictive analytics, and lastly, seamless integration across all disciplines and stages of the project, leading to optimized outcomes in terms of cost, time, and quality.

Purpose and Benefits of BIM Maturity Models according to Sacks et al. (2018) is that it provides organizations with a structured roadmap for transitioning toward more advanced digital practices, it helps assess the current state of BIM implementation and identify improvement areas, and it standardizes processes across the industry, creating a more collaborative and efficient construction ecosystem.

2.2.4 Levels of Development (LOD)

The Level of Development (LOD) defines the degree of completeness of a BIM element, specifying both its geometric representation and the attached non-geometric information, at various stages of a project (Sacks et al., 2018). The term LOD is sometimes mistakenly called "Level of Detail," which emphasizes only the graphical resolution of elements. Level of Detail is just one aspect of Level of Development, which also covers the accuracy and richness of the data attached to the model elements (Sacks et al., 2018). Thus, LOD integrates both the graphical detail and the non-graphical information dimensions of BIM components, ensuring they are developed to a stage appropriate for specific project uses, such as cost estimation, fabrication, or facility management.

These levels play a crucial role in maintaining uniformity in modelling and facilitating effective communication among project stakeholders by clearly specifying the amount and reliability of detail and information required at different phases (Daniotti et al., 2020). Importantly, LOD does not necessarily imply a simple, steady increase in detail over time. For example, models intended for facility management (FM) may require less graphical detail, but highly accurate asset data compared to the richer geometric detail needed during construction phases (Sacks et al., 2018).

The most widely referenced LOD framework, based on the American Institute of Architects (AIA) definitions and detailed by Sacks et al. (2018), organizes development levels from LOD 100 to LOD 500. At LOD 100 (Conceptual), elements are represented generically with symbolic or approximate geometry, lacking detailed information. LOD 200 (Approximate Geometry) includes generic systems or assemblies with approximate quantities, size, shape, location, and orientation, along with basic non-geometric data. LOD 300 (Precise Geometry) provides accurate geometric and non-geometric information, suitable for construction documentation. LOD 350 (Detailed Components) includes specific systems or assemblies with detailed constituent parts and interface information. LOD 400 (Fabrication and Assembly) contains precise details for fabrication, assembly, and installation, including complete non-geometric information. Finally, LOD 500 (As-Built) represents field-verified elements with accurate geometric and non-geometric data, typically used for facility management (Daniotti et al., 2020).

Selecting the appropriate LOD depends heavily on the model's intended use, such as competitive tendering, construction, or maintenance (Daniotti et al., 2020). For example, interior doors may require LOD 100 at the schematic design stage, LOD 200 at design development, LOD 300 for construction documents, and LOD 500 at project handover (Sacks et al., 2018).

Despite its importance, the practical application of LOD faces several challenges. One major issue is the lack of universal standards for defining each LOD level, leading to varying interpretations among organizations and even individuals within the same organization (Aibinu & Papadonikolaki, 2019). This inconsistency undermines effective collaboration, as team members may fail to agree on an acceptable level of detail for shared models. Additionally, inconsistent adherence to LOD plans during the design process can result in models being delivered with higher or lower LOD than necessary, causing inefficiencies and rework. For example, insufficient detail in early stages (e.g., Schematic Design) can lead to significant rework in later stages (e.g., Detailed Design), while excessive detail too early can complicate design changes (Aibinu & Papadonikolaki, 2019; Sacks et al., 2018).

Another challenge is the timing of stakeholder involvement. Delays in input from contractors, subcontractors, and suppliers can disrupt effort distribution and LOD achievement, highlighting the need for early involvement to align LOD with constructability and fabrication requirements. Experts suggest that involving subcontractors and suppliers earlier in the Detailed Design (DD) phase could help reduce effort and pressure during the Construction Documentation (CD) phase, ensuring that the LOD is appropriate for constructability and fabrication requirements (Aibinu & Papadonikolaki, 2019). Tools like the LOD Planner can assist in defining LOD requirements in the BEP (BIM Execution Plan), specifying who provides the information and the standards for object identification (Sacks et al., 2018). Harmonizing LOD with performance and economic assessments remains an area of ongoing exploration to further integrate workflows (Sacks et al., 2018).

In specialized contexts, such as Historic BIM (HBIM) or existing buildings, LOD may focus on maximum precision and detailed descriptions of components rather than a progressive increase in detail, as seen in new constructions (Daniotti et al., 2020). Multiple parallel models derived from accurate surveys may be used, with "level" or "grade" indicating differences in detail or accuracy tailored to specific purposes. This approach ensures that the unique requirements of existing structures are met without unnecessary complexity (Daniotti et al., 2020).

2.2.5 Model Maturity Index (MMI)

The Model Maturity Index (MMI) is a framework closely associated with Building Information Modelling (BIM), serving as Norway's equivalent to the Level of

Development (LOD) concept (Abualdenien & Borrmann, 2022). Like the BIMForum's LOD, MMI uses a 100-500 scale but distinguishes itself by emphasizing design process control rather than just geometric specification, making it particularly valuable for establishing project milestones (Abualdenien & Borrmann, 2022). This index applies to both individual building elements and complete models, providing a structured approach to tracking design progression as information becomes more detailed and refined throughout the project lifecycle (Abualdenien & Borrmann, 2022). The construction industry's digital transformation has generated various maturity frameworks all sharing the core principles of defining information progression and process control (Gaunt, 2017; Sacks et al., 2018). Effective application requires precise definition of information requirements at each stage, ensuring all stakeholders share consistent expectations about detail level, accuracy, and completeness (Abualdenien & Borrmann, 2022; Papadonikolaki et al., 2018).

2.2.6 Evolution of BIM

The construction industry has undergone a significant digital transformation, evolving through overlapping paradigms. It began with Traditional Fragmented Processes, reliant on 2D drawings and paper-based workflows, which often led to errors, coordination challenges, and adversarial relationships (Dainty et al., 2017; Sacks et al., 2018). The adoption of Hybrid Approaches marked a transitional phase. While 3D CAD tools introduced digital visualization, they primarily supplemented 2D documentation, resulting in partially digitized yet often disconnected workflows (Morgan, 2019). A major shift occurred with the adoption of Building Information Modeling (BIM), which enabled coordinated, multidisciplinary design through rich 3D models integrated with scheduling (4D) and cost (5D) data (Hosseini et al., 2018; Oraee et al., 2019). The emerging paradigm, often termed Fully Model-based, aims to use dynamic BIM models as the single source of truth within cloud-based collaboration platforms. The goal of this approach is to minimize 2D documentation and move toward digitally native workflows, including automated compliance checking and contract execution (Disney et al., 2023; Smith, 2023). While not yet industry-standard, this represents the ongoing transformation from fragmented methods to integrated digital ecosystems.

2.3 Model-based Design (MBD)

Model-based design (MBD) is a lean design delivery process that designates the 3D design model as the single source of information and aims to eliminate unnecessary drawing production during the design phase (Gaunt, 2017). Unlike traditional workflows, which rely heavily on 2D drawings, MBD enhances efficiency of the workflows processes. Traditional 2D drawings are often criticized for being inefficient, inconsistent, error-prone, and limited in conveying complex 3D information, which can lead to misinterpretation and rapid obsolescence (Brooks, 2022; Gaunt, 2017). Producing 2D drawings from 3D models is also time-consuming (Gaunt, 2017). In contrast, MBD uses Building Information Modelling (BIM) for direct and streamlined communication and coordination (Disney et al., 2023; Brooks et al., 2022, as cited in Disney et al., 2023), which is considered critical for effective BIM implementation (Abualdenien & Borrmann, 2022). The adoption of MBD offers numerous benefits, including:

- Reduced time and cost: This approach can lead to significant savings in production efforts and is expected to offer greater future cost reductions (Gaunt, 2017). It enables faster, more accurate cost estimates and provides immediate feedback on design changes, which is crucial since cost influence is highest early in a project (Sacks et al., 2018). Some projects have reported increased efficiency, fewer mistakes, and the elimination of months of drawing production, allowing resources to be allocated to more projects (Brooks, 2022).
- Improved collaboration and model engagement: MBD fosters better communication and coordination (Dainty et al., 2017). Models can be used in presentations, aiding discussions with clients and authorities, and enabling more informed decision-making (Lidelöw et al., 2023). They also serve to collect, convey, and maintain information throughout the project, facilitating seamless data transfer between stakeholders (Lidelöw et al., 2023). This is particularly beneficial for highly coordinated teams (Gaunt, 2017).
- Streamlined design review and enhanced client engagement: Modifications made directly to the 3D model reduce design change workflows, leading to faster resolutions compared to paper-based systems (Gaunt, 2017; Sacks et al., 2018). This allows all parties to track design progress and gain confidence as it develops (Gaunt, 2017).
- Reduced ambiguity in information transfer: By establishing the model as the single source of truth, MBD minimizes misinterpretation and ensures consistency (Gaunt, 2017; Brooks, 2022).
- Enhanced future opportunities for efficient data exchange: This includes capabilities such as 4D modelling and digital markups (Gaunt, 2017; Sacks et al., 2018). BIM models convey more complex information than 2D drawings, even for large-scale, multi-story buildings where 2D drawings become impractical (Brooks, 2022).

Despite these advantages, current MBD implementations face limitations. Often, 2D drawings are still required for construction, as they remain the legally and contractually binding documents (Disney et al., 2023; Brooks, 2022). This necessity leads to a "mixed-mode" approach, where parallel processes for maintaining both 2D documents and BIM models exist—an inefficient and error-prone practice (Disney et al., 2023; Sundquist et al., 2020). For example, on the Tideway East project, despite extensive model-based construction, 4,500 drawings were still produced alongside 1,500 models (Brooks, 2022). Even in projects aiming for paperless construction, 2D drawings are often generated from the latest coordinated model to provide higher detail for on-site use (Brooks, 2022).

When the focus shifts to construction and 2D drawings are produced, consistent BIM model updates often cease (Disney et al., 2023). While BIM facilitates design coordination, construction teams frequently rely on static exported documents, limiting real-time access to updates and reducing trust in BIM on-site (Disney et al., 2023). This reliance on static documents has led workers to revert to traditional methods like phone calls and emails, particularly in challenging environments or due to hardware limitations (Lundberg et al., 2021). Research indicates that most studies on ICT in construction report only a one-way flow of information from model to site, rather than bidirectional updates (Alsafouri & Ayer, 2018).

2.4 Model-based construction (MBC)

2.4.1 Definition and key concepts

Model-based delivery emphasizes the design phase, where the design model acts as the sole source of information, replacing traditional drawing production. This approach enhances design efficiency by utilizing a 3D model for communication instead of generating 2D drawings and delivers the 3D model to the client upon completion of the design (Gaunt, 2017). Similarly, model-based construction focuses on the construction phase, leveraging a BIM model for construction activities rather than relying on traditional drawing-based methods. This involves extracting information directly from the BIM model for construction tasks, aiming to eliminate the need for 2D drawings (Disney, 2024). Consequently, BIM becomes the primary source of information for construction activities (Disney, 2024; Disney, Johansson, et al., 2022). According to Disney (2024), this represents more than just using BIM for visualization or coordination; it signifies a fundamental shift in how construction information is accessed, managed, and utilized during the construction phase. Together, these approaches form the foundation of model-based project delivery, which spans both the design and construction phases, with BIM serving as the single source of information and the legally binding document throughout the project lifecycle (Duman & Gustafsson, 2025).

2.4.2 Different definitions from paperless to hybrid MBC

The academic literature presents different perspectives on what constitutes MBC, particularly regarding the reliance on 2D drawings. Disney et al. (2024) define MBC as a fully paperless approach, where the model acts as the sole legally binding source of information throughout the project lifecycle, eliminating traditional 2D documentation entirely. This view aligns with the vision of "Total BIM," claiming for direct on-site model use without intermediary drawings. However, other literatures highlight more pragmatic, hybrid interpretations. For instance, while BIM serves as the central coordination and information tool, many projects still generate 2D outputs derived from the model for specific purposes, such as regulatory submissions or complex site tasks (Brooks et al., 2023; Sundquist et al., 2020). This hybrid approach acknowledges that even advanced MBC projects may require model-generated drawings to support certain workflows, especially when dealing with subcontractors or regulatory authorities that still mandate 2D documentation. These differing definitions illustrate an ongoing debate within both academia and practice about whether MBC should aim for complete elimination of drawings or adopt a flexible approach tailored to project realities.

2.4.3 Collaboration and data management infrastructure

Effective BIM deployment necessitates robust supporting infrastructure, beginning with cloud-based platforms that centralize project information as a single source of truth (Disney et al., 2022). These systems enable real-time collaboration by providing stakeholders with synchronized access to current models and documentation throughout the project lifecycle (Disney et al., 2022). Field operations are enhanced through mobile applications that allow on-site personnel to query models and document progress, often leveraging integrated device cameras for improved communication (Disney et al., 2022). Simplified BIM viewers with intuitive interfaces help overcome adoption barriers for less technical users while maintaining data accessibility (Disney et al., 2022). Underpinning these applications, high-capacity networks are essential to manage substantial BIM data volumes and facilitate seamless information exchange between project participants (Brooks et al., 2022).

2.4.4 Interoperability and standardization framework

The heterogeneous nature of construction software necessitates strong interoperability solutions, achieved through standardized data formats like Industry Foundation Classes (IFC) and green building XML (gbXML) that preserve information across platforms (Sacks et al., 2018; Alsafouri & Ayer, 2017). Federated database architectures further support data integration by creating unified access points for distributed project information (Sacks et al., 2018). These technical frameworks require careful coordination through comprehensive BIM Execution Plans (BEPs) that establish protocols for model development, including specified Levels of Detail (LOD) and exchange mechanisms to mitigate software compatibility issues (Sacks et al., 2018).

2.4.5 Advanced applications in construction automation

BIM's capabilities significantly enhance modern construction methods, particularly in prefabrication and automated manufacturing (Sacks et al., 2018). Advanced platforms convert design models directly into machine instructions for computer-controlled equipment by modeling components as parametric objects with manufacturing data (Sacks et al., 2018). These systems require specialized functionality including customizable part libraries, integration with production management software, and export formats compatible with automated machinery (Sacks et al., 2018). The growing implementation of robotic construction further depends on BIM's ability to provide comprehensive product data - including material specifications and assembly logic - in machine-interpretable formats (Sacks et al., 2018; Brooks et al., 2022).

2.4.6 From MBDD to MBC, gradual transitions and reuse of practices

Many projects do not adopt Model-based construction (MBC) in a fully isolated manner but rather evolve from earlier MBDD practices. Noting that teams often begin by applying familiar MBDD processes, such as model structuring, LOD planning, and clash detection, directly within the construction phase when attempting to implement MBC (Brooks et al., 2023). While some of these practices transfer well, others prove inadequate for the different demands of site execution, where immediacy, constructability, and updated sequencing are critical. This reuse of MBDD processes can serve as a pragmatic scaffold that enables teams to start transitioning toward MBC, especially in the absence of dedicated MBC standards. However, scholars caution that without deliberate adjustments, simply extending design-phase workflows into construction may undermine the core objectives of model-based construction, particularly if it perpetuates reliance on static documents or insufficiently detailed models (Disney et al., 2024). Thus, understanding this gradual and often imperfect transition is essential for framing both the opportunities and pitfalls in moving from design-centred to construction-centred model use.

2.4.7 Benefits of Model-Based Construction

Model-based construction, particularly through the use of Building Information Modeling (BIM), offers a wide range of benefits that enhance project efficiency, quality, and collaboration. One of the primary advantages is increased on-site efficiency, as BIM reduces the likelihood of mistakes and improves quality control throughout the construction process (Brooks et al., 2022). This is further supported by the ability to conduct detailed design checks in 3D, which minimizes communication errors compared to traditional 2D representations (Sacks et al., 2018; Cousins, 2017). The elimination of extraneous documentation and the provision of live data dashboards allow clients to engage directly with project data, fostering greater transparency and informed decision-making (Cousins, 2017).

Clients also benefit from more accurate as-built BIM models at project handover, which can lead to reduced insurance premiums and more efficient facilities management (Brooks et al., 2022). Additionally, contractors gain greater cost certainty during tendering due to the detailed information provided by BIM models (Sacks et al., 2018). The integration of BIM across all project phases facilitates superior design, construction, and operation processes, resulting in integrated design, improved quality, reduced costs, and shorter project durations (Trebbi et al., 2019; Disney et al., 2022). By serving as a single source of cloud-based information, BIM enhances data management and reduces the risk of uncertainty, provided the information in the bid notice is accurate and clear (Trebbi et al., 2019; Disney et al., 2022). This centralized data set also ensures a consistent format, reducing potential confusion for specialists interpreting the information (Trebbi et al., 2019; Disney et al., 2022).

Model-based construction also supports lean principles by reducing cycle times and improving information flows, which enhances overall project efficiency (Sacks et al., 2018). Visualization tools within BIM improve client understanding and align project team mental models, while simulation and analysis capabilities enhance functional design (Sacks et al., 2018). Furthermore, BIM enables early clash detection and resolution, identifying physical, soft, and logical clashes before they become on-site issues, thereby minimizing delays and additional costs (Sacks et al., 2018). The use of BIM also fosters better collaboration among project teams, as it improves the design change workflow and enhances communication by reducing the likelihood of miscommunication when reviewing design models (Gaunt, 2017). This collaborative approach, supported by a common data environment (CDE), improves information transfer and design clarity, enabling project teams to focus on design model discussions (Gaunt, 2017).

In addition to these operational benefits, model-based construction promotes digital competency among project stakeholders and integrates design and production processes, leading to significant time savings by eliminating the need for 2D drawings and streamlining on-site construction (Gaunt, 2017; Sacks et al., 2018). The approach also opens future opportunities, such as 4D model production, virtual reality operational scenarios, and temporary work coordination, which increase team awareness and further enhance project outcomes (Gaunt, 2017). Ultimately, the design model serves as the single source of truth, communicating design complexity through a coordinated model, unlike multiple 2D deliverables (Gaunt, 2017). By leveraging these advantages, model-based construction not only improves project delivery but also aligns with broader industry goals of reducing waste, improving quality, and enhancing safety (Trebbi et al., 2019; Disney et al., 2022).

2.4.8 Challenges and barriers and limitation for MBC

BIM-based construction introduces a wide range of challenges across technological, financial, knowledge, organizational, and legal domains, as highlighted by various researchers (Lidelöw et al., 2023; Sundquist et al., 2020; Disney et al., 2023). These challenges must be carefully addressed to ensure the successful integration and adoption of BIM in the construction industry.

Technological challenges are among the most significant barriers to BIM implementation. These include the complexity of BIM tools, deficiencies, and issues related to software interoperability and the handling of large models (Lidelöw et al., 2023; Fugas 2021). While many BIM tools are well-established and offer potential benefits, adoption and implementation issues persist, particularly for on-site use during the construction phase (Davies & Harty, 2012). Technical limitations in BIM models may create opportunities for new platforms, but software still requires optimization to reduce interoperability issues, especially when managing large models (Havenvid et al., 2019, p. 42; Disney et al., 2023). Interoperability problems are commonly encountered at both the software and standardization levels, further complicating collaboration between firms (Sundquist et al., 2020). Additionally, inconsistent model quality, insufficient education, lack of user-friendly software, and unclear professional roles are significant barriers (Sundquist et al., 2020). The fragmented nature of the construction industry exacerbates these challenges, making it difficult to achieve seamless integration of BIM technologies (Rashidi et al., 2022).

Financial challenges are another major obstacle to BIM adoption. The high costs associated with investing in technology, competence development, and implementation are significant barriers, particularly for smaller firms (Lidelöw et al., 2023). For many small and medium-sized enterprises (SMEs), investing in BIM may not be economically viable, especially if the expected efficiencies and productivity gains cannot be guaranteed across their entire market portfolios (Dainty et al., 2017). The construction sector exhibits significant disparities in financial capabilities, with many SMEs effectively excluded from major projects due to these financial constraints (Dainty et al., 2017). Furthermore, the difficulty of clearly measuring efficiency gains and project cost reductions discourages companies from fully adopting BIM (Sundquist et al., 2020). This financial barrier is compounded by the lack of clear evidence demonstrating the return on investment for BIM implementation, which deters many firms from committing to the necessary expenditures (Sundquist et al., 2020).

Knowledge and Competence Barriers: A general lack of BIM expertise and understanding is a significant barrier to successful implementation, as noted by multiple authors (Lidelöw et al., 2023; Sundquist et al., 2020). A shared understanding of how BIM can support business objectives, and a common knowledge of its applications are essential for effective adoption (Lidelöw et al., 2023). Additionally, expertise is required to translate technical opportunities into practical use, highlighting the need for comprehensive training and education (Lidelöw et al., 2023). The lack of education and on-site technical support further exacerbates these challenges, making it difficult for firms to fully leverage BIM's potential (Sundquist et al., 2020). Resistance to change and the need for a holistic approach that integrates strategy, technology, organization, and the broader ecosystem are critical for successful BIM implementation (Sundquist et al., 2020).

Organizational challenges include insufficient leadership, unclear client requirements, inadequate project organization, and resistance to changing existing working methods (Lidelöw et al., 2023). Attitudes toward adopting new ways of working play a critical role in maximizing the potential benefits of BIM (Lidelöw et al., 2023). Implementing BIM also demands a significant re-evaluation of contractual relationships, risk-allocation models, and procedural workflows (Succar, 2008). Resistance to change and the need for a holistic approach that integrates strategy, technology, organization, and the broader ecosystem are critical for successful BIM implementation (Sundquist et al., 2020). The tendency to revert to traditional, non-BIM methods during periods of high pressure is another significant barrier, highlighting the need for cultural and mindset shifts within organizations (Sundquist et al., 2020).

Legal and contractual challenges are also significant barriers to BIM adoption. The absence of standardization, regulations, and legal frameworks to create an ecosystem where multiple organizations can collaborate further delays BIM adoption (Sundquist et al., 2020). BIM models lack clear legal responsibility since they are not recognized as legally binding contract documents, leading organizations to continue relying on 2D drawings, which remain the legal standard (Sundquist et al., 2020). Adapting standard contracts to recognize BIM as a legally binding construction document is necessary, though it may not be feasible in some countries (Disney et al., 2023). Unfavourable BIM contractual arrangements are a root cause of the reluctance among team members in BIM-based construction networks to engage in collaborative efforts (Oraee et al., 2021). Legal risks related to proprietary rights and risk sharing can also impede successful implementation if not clearly addressed in contracts (Sundquist et al., 2020).

Effective on-site implementation of BIM remains a significant challenge, as noted by multiple researchers (Disney et al., 2023; Sacks et al., 2018). Case studies indicate that static 2D drawings are no longer necessary for construction sites, and BIM can serve as a dynamic single source of information across all project phases (Disney et al., 2023). In the future, total BIM adoption may become the preferred method, offering cost savings through fewer errors and improved communication (Disney et al., 2023). However, fostering engagement and shifting project culture and mindset is an ongoing process that requires sustained effort (Disney et al., 2023). The high costs of implementing BIM, coupled with a lack of clear evidence regarding improved efficiency and reduced project costs, can deter companies from fully embracing BIM (Sundquist et al., 2020).

2.4.9 Information needs for contractors

A Building Information Modeling (BIM)-based construction model must include detailed and accurate geometric information representing building components, similar to traditional construction drawings, to support various construction activities (Sacks et al., 2018). Beyond geometry, the model should integrate non-geometric data, such as quantity take-offs, component properties, and specifications linked to materials, finishes, quality grades, and construction procedures, which are critical for cost estimation, material procurement, and installation processes (Sacks et al., 2018, pp.

233; Sundquist et al., 2020; Daniotti et al., 2020, pp. 207). Additionally, the model should incorporate contractor-specific details, such as equipment information, production rates, and temporary works, to enhance accuracy in estimating, scheduling, and clash detection, particularly for critical systems like piping, ducts, and structural elements (Sacks et al., 2018, pp. 223, 233).

For on-site use, the BIM model must function as a dynamic, single source of information accessible via mobile devices, enabling site workers and management to independently extract construction details, visualize spatial relationships, and access production-oriented data tailored to their needs (Disney et al., 2023; Disney et al., 2022). This includes standardized building elements with coded information, such as material properties, dimensions, and subcontractor responsibilities, as well as tools for creating dynamic views, performing measurements, and filtering information by trade or area (Disney et al., 2023; Disney et al., 2022). The model should also support project management functions, such as quality control, scheduling, and issue tracking, while integrating with systems for logistics, prefabrication, and efficient material flow (Disney et al., 2023; Sundquist et al., 2020; Daniotti et al., 2020).

To ensure its utility as a legally binding construction document, the BIM model must prioritize constructability, accuracy, and completeness, replacing traditional 2D drawings and minimizing reliance on workarounds (Disney et al., 2023; Disney et al., 2022). This requires a collaborative approach, where feedback from construction workers informs model development, ensuring it meets on-site needs and supports physical construction activities effectively (Disney et al., 2023). Furthermore, the use of interoperable file formats like IFC is essential for seamless information exchange among stakeholders, while robust protocols for version control and change management are necessary to maintain data reliability and accuracy (Disney et al., 2022; Daniotti et al., 2020).

2.4.10 Implementation processes of MBC

The implementation of Model-Based Construction (MBC) represents a fundamental shift from traditional 2D methods to dynamic digital modeling, requiring coordinated strategic, technological, and organizational transformation (Brooks et al., 2023). Central to this shift is the development of production-ready BIM models capable of serving as legally binding construction documents (Disney et al., 2022), which demands comprehensive integration of all BIM uses rather than isolated applications (Lidelöw et al., 2023). Strategic planning, often driven by government mandates or client requirements (Dainty et al., 2017), must incorporate clear BIM Execution Plans and leadership commitment, with particular emphasis on resolving design issues early in the project when changes are less costly (Morgan, 2019).

Technologically, implementation relies on cloud platforms and mobile tools, though persistent interoperability challenges necessitate standardized solutions like IFC (Alsafouri & Ayer, 2018). The human dimension presents equally critical challenges, as organizational resistance must be overcome through targeted training, role clarification, and stakeholder engagement (Sundquist et al., 2020). Furthermore, legal frameworks must evolve to address outdated contracts and intellectual property concerns that currently hinder adoption (Brooks et al., 2023). Ultimately, successful

MBC implementation requires this triad of advancements - technological infrastructure, process reengineering, and legal adaptation - to work in concert (Succar, 2009).

2.4.11 MBC and procurement method

According to the U.S. Department of Transportation, Federal Highway Administration (2024), the procurement method directly shapes how BIM is implemented in practice, influencing the depth of digital integration across the project lifecycle.

In design-bid-build (DBB) projects, BIM is typically used to generate 3D models that are then converted into 2D plans for contractual purposes. This leads to inefficiencies, as contractors must reconstruct 3D details from these 2D outputs, introducing risks of information loss and errors. As the report highlights, this traditional DBB process still relies heavily on 2D documentation, with the 3D model primarily serving as a design tool rather than as a contractual or construction resource.

In contrast, design-build (DB) procurement allows for a more seamless BIM integration. Here, the design-build team is responsible for both design and construction, and thus can utilize BIM directly to convey design intent, coordinate construction methods, and update models throughout the process. This approach facilitates richer collaboration, continuous data exchange, and consistent model updates, which support better construction sequencing, clash detection, and long-term asset management.

Thus, the procurement method impacts whether BIM remains primarily a design visualization tool (as often seen in DBB) or evolves into an integrated platform actively guiding construction and lifecycle management (as more achievable in DB). This underlines the critical role of contractual frameworks in enabling or limiting the potential of BIM.

2.4.12 Future trends and directions

The construction industry is undergoing a profound digital revolution, with Building Information Modeling (BIM) positioned as the foundational technology driving this transformation. Leading researchers Brooks et al. (2022) describe BIM as the cornerstone of modern model-based construction, representing a fundamental shift from traditional 2D drawing practices. However, as Dainty et al. (2017) critically highlight, this implementation is far from a linear process and faces numerous complex challenges, particularly for smaller firms, requiring significant changes that extend well beyond mere technology adoption.

This transition, as Gaunt (2017) demonstrates, promises to deliver significant efficiencies and improvements across all phases of construction projects, from initial design through to facility management and maintenance. Yet research by Brooks et al. (2022) identifies multiple barriers that must be addressed, including the considerable costs associated with developing high-quality BIM models - a particular burden for smaller practices - and persistent technical issues surrounding software interoperability. Additional obstacles involve data integrity problems during file exchanges, performance limitations when handling complex projects, evolving legal and contractual frameworks, and perhaps most critically, the need for widespread cultural adoption across all levels of the workforce.

3 Methodology

3.1 Methodological approach

This study employs a qualitative case study methodology to investigate how stakeholders perceive Model-Based Construction (MBC) and what challenges hinder its implementation in the KAJ 16 project. This approach was selected to provide an in-depth understanding of this contemporary phenomenon, addressing "how" and "what" research questions with little control over behavioural events. Data was gathered through a review of relevant literature and semi-structured interviews with team members directly involved in the project.

3.2 Justification of the method

A qualitative approach was selected for this study to facilitate a comprehensive exploration of phenomena, enabling researchers to examine how individuals interpret their actions, contexts, and experiences. It focuses on experiences, perspectives, and meanings, aiming to provide rich, in-depth insights into human behaviour, social processes, and cultural contexts according to Leavy (2017).

The case study approach was selected for investigating Model-Based Construction (MBC) due to significant limitations of alternative research methods. Experimental designs prove unsuitable because MBC implementation involves complex real-world variables that cannot be controlled or replicated, like laboratory conditions. Survey methods are equally impractical given MBC's emerging status - the limited pool of experienced practitioners and lack of standardized practices would yield insufficient reliable data. Archival or historical analysis also cannot be applied effectively, as MBC's recent development means comprehensive documentation and longitudinal data are unavailable. This methodological choice directly aligns with the study's primary objectives: to explore how industry professionals conceptualize MBC, identify implementation challenges, examine their underlying causes, and develop recommendations for improving future applications. The case study method is uniquely positioned to provide the depth of understanding required for this novel and complex subject matter, allowing for detailed examination of real-world MBC implementations in their natural contexts.

According to Yin (2018), case studies are especially appropriate when the phenomenon under investigation is deeply embedded in its real-life context and cannot be separated from it. This applies directly to MBC which is shaped by how construction teams interact with digital models in specific project environments. In our case, the KAJ 16 project exemplifies this embeddedness, where technological tools, organizational structures, team workflows, and behavioural patterns collectively influence the implementation of MBC. These interdependent variables make it impossible to isolate the phenomenon from its setting, reinforcing the need for an in-depth case study.

Yin (2018) further emphasizes that case studies are particularly suitable for answering “how” and “why” questions, questions that seek to explain processes over time rather than measure frequency or correlation. This research is guided by such questions: how is MBC understood by practitioners, why do implementation challenges arise, and what are their underlying causes?

Another core justification is the complexity of MBC itself. According to Yin (2018), this research setting, with many variables and limited observations, requires a design that can manage and interpret complexity. The case study allows this through triangulation and holistic analysis.

3.3 Description of the case (KAJ 16)

KAJ 16 project is defined as a 16-story hybrid timber structure under construction. It is located in Gothenburg, Sweden. With a height of 78.5 meters and a total floor area of 30,000 square meters, the project represents a significant case to search how digital construction practices is implemented on site. Developed by Vasakronan with an estimated budget of 1.6 billion SEK, the turnkey project began in June 2023 and is expected to be completed by 2027. The architectural design was led by Dorte Mandrup A/S, while Vestia Construction Group serves as the main contractor. Sweco provides project management, supported by specialist consultants such as Liljewall arkitekter, Ramboll, Rejlers, Bengt Dahlgren, Land & Energy Builders, and Hercules. (Reference different internet pages).

According to Sweco website, a key innovation in the KAJ 16 project is its full adoption of MBC, marking a significant step toward digital transformation in the industry. The project is aiming to operate entirely paperless, with all controls and administrative processes managed through a centralized, cloud-based 3D model (StreamBIM). This model acts as the single source of project information, ensuring real-time transparency for all stakeholders. Critical functions - including spatial coordination, document management, and contractor tendering - are conducted within this digital framework. Notably, the 3D model replaces traditional 2D drawings in procurement, signifying a fundamental shift toward model-based construction delivery.

This case study research focuses on understanding implementation challenges of MBC project where the client sets a clear goal but provided no predefined plan, requiring each stakeholder to develop their own approach. As an ongoing project, it reflects current challenges and solutions in real time, with participants learning through practice while navigating complexities in design, materials, modeling, and processes. The study captures these rich dynamics to provide deeper, broader insights into MBC implementation. By analysing real-world challenges, adopted solutions, and stakeholder interactions, it aims to enhance understanding of MBC's role in digital transformation and serve as a practical reference for improving workflows and supporting industry-wide adoption of MBC methodologies.

3.4 Data collection

3.4.1 Literature articles

The start was with searching and reviewing literature related to Model-Based Construction. We began by defining the topic and the objectives of the research, then continued to develop and finalize the research questions based on what we found. Because MBC is a new and developing area in construction, it was difficult to find academic papers, so we depended also on reports, project documents, and related studies on BIM and digital construction. At the same time, we worked on the first version of the thesis structure to keep the work organized and focused.

The thesis focused on identifying articles most relevant to digital transformation and the implementation of MBC, especially those published in the last ten years, to find the current knowledge and understanding of the topic. To find these papers, Chalmers library, Google Scholar, and Scopus were used with string combinations including the keywords: model-based construction, construction digitalization, site digitalization, digital transformation, total BIM, challenges, and paperless construction. Irrelevant articles were excluded, such as those focusing only on technical implementation of BIM, cost estimation, digital twins, and 4D/5D modeling. From the literature, it was noted that that model-based construction is a new concept and there are limited empirical resources explaining the details of its implementation. Most of the articles refer to model-based construction as an extension of model-based design (MBD) but applied on site (e.g. Disney et al., 2023).

3.4.2 Interviews

This research adopts a qualitative approach, beginning with four pilot interviews conducted in a semi-structured format with open-ended questions. These preliminary interviews provided valuable insights that helped refine both our understanding of the subject matter and the subsequent interview questions. The study then focused on the KAJ 16 case study, employing twelve additional semi-structured interviews with open-ended questions. Participants were encouraged to respond freely and introduce relevant topics, which occasionally required improvising follow-up questions to explore emerging themes. Despite the flexible nature of the discussions, five key questions guided the interviews, serving as the foundation for analysis:

- Defining and understanding Model-Based Construction (MBC).
- What are the differences between Model-Based Design and Model-Based Construction?
- What are the challenges encountered in MBC implementation?
- What are the benefits of adopting MBC?
- What are the future improvements and implementation strategies for MBC?

To ensure a comprehensive and diverse perspective, interviewees were selected from various disciplines and stakeholder roles involved in the KAJ 16 project. This approach allowed for a multi-faceted examination of the research topic.

Participant Overview

ID	**Position**	**Stakeholder Role**
INT01	BIM Specialist	Construction Management
INT02	Design Management	Contractor
INT03	BIM Coordination	Construction Management
INT04	Consultant	Construction Management
INT05	Project Management	Client
INT06	Site Management	Contractor
INT07	Supervisor	Subcontractor (Electrical)
INT08	Architect	Subcontractor (Architectural)

INT09	Engineer	Subcontractor (Electrical)
INT10	Consultant	Subcontractor (Ventilation)
INT11	Site Management	Subcontractor (Civil Works)
INT12	Supervisor	Contractor

3.5 Data analysis process

All interviews were conducted virtually via Microsoft Teams, during which we recorded the sessions and subsequently generated interview transcripts. The initial phase of data processing involved a thorough review of the transcripts to correct any spelling errors. Following this, we refined the content by removing irrelevant digressions and providing English translations for any Swedish terms used during the discussions. Next, we systematically started analysing the interviews according to the stages described by Braun and Clarke (2006) method which involves six steps as following:

- Familiarization: This step involves reading the data thoroughly to gain a deep understanding. and then summarizing. We began by thoroughly reading all transcripts, correcting spelling errors, and translating any Swedish terms into English. This helped us gain an initial understanding of the content.

- Generating initial codes: The goal in this step is to identify meaningful features of the data by creating labels that break it into smaller, organized pieces. We systematically highlighted key ideas using a color-coded system and bold formatting to visually distinguish relevant data points. This allowed us to break the data into smaller, meaningful segments.

- Searching for themes: A theme captures something important about the data in relation to the research question and represents a patterned meaning. Based on our codes, we organized interview insights into a matrix structured around main research areas. The matrix included categories such as “Understanding the MBC,” with subcategories like “Paperless Processes” and “Tool.”

- Reviewing themes: This step acts as a quality check for the themes identified, ensuring they align with the research aims. So, we examined the matrix to identify recurring patterns and ensure that emerging themes were consistent with our research questions and reflected the content across interviews, and this included some iterative working.

- Defining and naming themes: Each theme in the matrix was given a clear label and description, capturing the essence of participants’ views and illustrating both shared and contrasting perspectives.

- Writing up: In the final step, we presented the thematic findings in the analysis chapter, supported by direct quotes and interpretations. This helped to clearly connect empirical data with the study’s objectives.

This was important to make the analysis balanced between theory and practice and to build strong answers to the “how” and “why” questions in the research. This process led us to the final conclusions of the study.

3.6 Ethical considerations, limitations

3.6.1 Ethical considerations

This study followed established ethical principles to ensure the protection of participants. All interviewees were informed about the purpose of the research and gave their consent to participate. They were offered the option to remain anonymous, and their identities have been kept confidential in the thesis. Interviews were recorded with permission, and data has been securely handled in line with GDPR (Diener & Crandall, 1978; Kvale & Brinkmann, 2009). And lastly, they are presented in the research by a coding type that keeps them anonymous. Participants were also given the opportunity to review and confirm their statements to ensure accuracy (Bell et al., 2018).

3.6.2 Limitations

This research was limited in scope to a single case study (KAJ 16), within the Swedish construction sector. The findings are context-specific and may not be generalizable to other countries or project types. Due to time limitations and a mid-study shift from a general interview approach to a focused case study, the research was unable to conduct additional interviews with key disciplines such as structural engineers and fire protection engineer who are essential in such temper structure. consequently, restricting both the breadth of participant perspectives and depth of analysis. Additionally, the exploratory nature of the study meant that some findings emerged during the research process, which influenced the final structure and theoretical framing (Elsa Harnström, 2016). The study focused primarily on the AEC industry, with emphasis on the involved stakeholder's perspectives varying between the client, the contractor, sub-contractors and management according to Lucas Hansson & Neo Tacking, (2022).

A significant ethical and methodological consideration in this study is the potential for language barriers. As participants communicate primarily in Swedish and the research is conducted and analysed in English, there is a risk that the nuances and complexities of their responses may not be fully captured or accurately conveyed. This concern is rooted in the ethical principle of ensuring participants' voices are genuinely represented, as any loss of meaning due to linguistic constraints would impact the integrity of the data and the validity of the interpretations.

3.6.3 Use of Artificial Intelligence

This thesis involved the supporting use of Artificial Intelligence (AI) tools to support specific non-core research tasks. The use of AI was strictly supplemental; all critical thinking, analysis, interpretation, and original writing remains the work of the author. The tools were applied as follows:

- Transcription: AI-based transcription services (Microsoft Teams) were used to convert interview audio data into text format. This served as a first draft to increase efficiency. The author manually verified and corrected every transcript against the original recordings to ensure the integrity of the qualitative data used for analysis.

- Ideation and Literature Mapping: In the exploratory phase, generative AI was prompted to provide overviews of current research trends and to generate summaries of academic articles. This was used solely as a practical tool to identify potentially relevant literature quickly. The final selection, deep reading, and critical engagement with all sources were performed by the author.
- Writing and Editing: AI grammar and style checkers were used in the writing process to identify grammatical errors, improve sentence clarity, and suggest adjustments to enhance the academic tone of the manuscript. All suggestions were evaluated and adopted at the author's discretion.

4 EMPIRICAL FINDINGS

The purpose of this chapter is to present the findings from the analysis of the empirical data collected from the interviews and document analysis. As described in Section 2.6 Data analysis process, the empirical data has been subjected to thematic analysis. The thematic analysis led to the identification of a number of themes that provided insights into the understanding of MBC.

4.1 How practitioners define model-based construction

This section addresses the first research question by examining how industry professionals perceive and define MBC. The interviews explored participants' interpretations of MBC in practice, aiming to identify commonalities and divergences in their conceptualizations.

4.1.1 Paperless or hybrid use of drawings

A key point in the interviews was whether MBC is a fully paperless approach or permits a hybrid model incorporating both digital models and traditional drawings.

Hybrid Approach - Model as the Single Source of Truth

Several participants argued that MBC does not require complete elimination of paper outputs, provided that the digital model remains the single source of information. For instance, the BIM specialist emphasized:

"Model-based construction could be defined that we have models that are the actual data, that we use in the project. But in that milestone, we decide that we publish drawings. And making sure that the published drawings are updated during the time, during the construction". (INT01)

The above quote suggests that the essence of MBC lies in being an up-to-date digital model, regardless of whether information is accessed digitally or via printed derivatives. The electrical engineer further supported this hybrid viewpoint stating:

"I like 2D drawings, they still fulfil the purpose. It's much easier to orientate on a 2D drawing than in a 3D world. You get a much quicker view of where you are and what you have to solve... we use StreamBIM, they haven't crossed out the 2D 100%. It's still available to use the 2D beside the 3D. So, in combination... is powerful. if you look in the gaming world, you act and move in a 3D world, all you see around you and all you have to act with is in 3D, but you still [need] this mini map to see where you are." (INT09)

A Fully Digital Approach - Strictly Paperless

On the other side, another group of interviewees emphasized MBC as a fully paperless method, where all construction data is accessed exclusively through digital interfaces. This is exemplified by the consultant in the construction management firm:

"You don't have any traditional drawings on site. You only look at your computer and use the model. And all the information about what kind of materials, what kind of products, everything is in the model. But working in KAJ 16 for quite a few years, for me now, it's more like you have everything in one place." (INT04)

Ultimately, even participants who described MBC as fully paperless mentioned that some printed drawings were still used when needed, for example to support specific tasks or communication on site.

4.1.2 MBC as a methodology: from tool to organizational shift and advanced

Interviewees described MBC from two distinct but interconnected perspectives. The first group viewed MBC as a practical digital tool used in the construction phase, while the second viewed it as a broader process-oriented methodology that transforms key practices in construction. A BIM specialist offered a nuanced perspective on the terminology itself, stating:

"When I'm presenting our way of working... we call it model-based construction, model-based design. I would rather present it as data-driven construction, data-driven design. Because we are talking about the parameters and data... it's about extracting data and consuming data." (INT01)

This highlights the shift from a visual understanding of the model to a data-driven one, focusing on the use and extraction of embedded parameters.

MBC as a Tool for Construction Site

A group of interviewees view MBC primarily as a tool that is utilized extensively during the construction phase, integrating information originating from the design phase into a centralized digital environment. A project manager noted:

"It is about collating all the information required for the construction... using the building information model... as a basis for sharing the knowledge required for the construction phase." (INT05)

One of the site managers supported this by saying:

"We are doing everything in the 3D model... we are picking all of the amounts of the material. Everything is from the model." (INT06).

These accounts indicate that some project participants directly associate MBC with StreamBIM and the features the program supports.

MBC as a Methodological and Organizational Shift

In contrast, other interviewees viewed MBC not just as a tool but as a fundamental shift in methodology, impacting several aspects of construction such as collaboration and responsibility sharing among various stakeholders. An architect stated:

"I kind of call it building with the model as a sort of primary and legally binding source of information instead of producing drawings out of the model." (INT08)

This perspective highlights a significant difference with traditional construction processes where drawings are often derived from the model, and legal status is derived via drawings solely. Shifting to this primary and legally binding status, by making the model itself the authoritative source, MBC necessitates different information workflows, to support the central role in driving actual construction activities. This was noted by a BIM coordinator:

"You do everything in the model, and you use the model in the production" (INT06)

Furthermore, this was highlighted by a BIM specialist:

"What we do in the KAJ 16 is, we extract the data from the models and make them available in Power BI... we have live information extracting." (INT01)

This quote indicates a shift from static documentation to dynamic, real-time data use. Finally, the responses reflect a shared understanding that MBC not only replaces traditional documents with digital tools but also enables new ways of working through real-time data extraction. While some participants focused on using the model directly in daily construction tasks, others emphasized how this method represents an organizational shift that requires new workflows and legal interpretations.

4.1.3 Core concepts of MBC's understanding

The empirical data highlights several core concepts that the interviewees used in defining and viewing their perception of MBC, with perspectives varying across disciplines and roles.

The understanding of MBC differs by discipline

While many of the interviewees shared a general view of the model as central to construction processes, the focus and expectations differed across disciplines, showing that the perspectives on MBC are shaped by professional role and responsibilities. For example, the architect emphasized the shift in workflow and the legal role of the model during construction, stating:

"I kind of call it building with the model as a sort of primary and legally binding source of information instead of producing drawings out of the model." (INT08)

This idea was reinforced by the BIM specialist, who stated:

"How I see model-based construction; looking at which challenge we have when one looks at model-based construction, it's very different based on which discipline you're looking at." (INT01)

The client's representative focused on the ability to provide early visibility of the final product and enable more reliable estimations of cost and quality, by saying:

"You have the ability to see the finished product before it is finished. You can see what you get. And that means that both quality and price is much easier to estimate." (INT05)

While for on-site workers, MBC is understood and experienced practically, primarily through the use of StreamBIM, rather than as a methodology. Their responses focused on describing how the tool (StreamBIM platform) changed their work environment. As the site manager noted:

"We use StreamBIM for everything... We don't use printed drawings anymore." (INT06).

The Model as a centralized information platform

Many interviewees described the model as a central digital platform supporting various project functions, including planning, communication, task management, and decision-making. Its role in integrating diverse project data, such as time schedules, procurement details, and drawing references, was emphasized. A construction manager explained this:

"For me … the whole thing is just in one site. You don't have one website where you handle the time planning. One site where you handle information. One site where the drawing is. It's like everything is in one place." (INT04)

Application of the Model Across Both Design and Construction Phases

A recurring theme in the interviews was expanding the role of the model beyond the design phase into the construction site. Participants highlighted the shift from earlier uses of the model, which focused and was limited to coordination and clash detection. As the architect described this evolution in practice:

"Before, we used the model for clash control and coordination. Now it's a very different way of working. You use the model more directly on site." (INT08).

Model as the Source of Actual and Object-Based Data

Another core concept identified by participants was the model's role as the actual source of project data, not just a visual representation. Interviewees emphasized that the model contains embedded, object-specific information, making it a data-rich environment essential for decision-making and construction execution. As a BIM specialist stated:

"We have models that are the actual data that we use in the project… When you work model-based, you have to work with object-based." (INT01).

Model-Based Quantity take-offs

One of the most frequently mentioned uses of the model was for generating quantity take-offs. This capability was particularly valued by managers and designers, who emphasized that using the model to calculate material quantities directly has introduced a more structured and consistent approach. The process was described as more accurate and systematic compared to previous methods. The design manager discussed the use of the model, commenting:

"We use it for all of mängdning [quantities take-offs]. If you see how much floor we have? How much ceiling do we have? We have never done that before in this strict way." (INT02)

Communication and collaboration in MBC

Interviewees consistently emphasized that communication and collaboration are essential for the successful MBC implementation. These two elements were described as closely interconnected, helping project participants align across disciplines and solve problems early. A design manager highlighted the importance of mutual clarity:

"The importance of communication is very high and critical for the result... and communication to understand each other. Everybody's needs to make the best of it." (INT02)

Coordination was supported through scheduled meetings that maintained shared understanding and early issue detection. This emphasis was reinforced by a BIM coordinator who explained the value of structured interaction:

"Weekly model coordination meetings are mentioned as essential for maintaining alignment and identifying issues early." (INT03)

Participants also described collaboration as an extension of communication, where helping each other and maintaining trust among stakeholders were key to project success, as a design manager said:

"It is a communication to collaboration. Helping each other, that is the way forward" (INT02)

StreamBIM as a Tool for Digital Collaboration

Alongside these human-driven practices, StreamBIM was frequently cited as the platform that enabled collaboration in real time. Its live update features, tagging system, and open access were seen as critical to maintaining transparent and effective communication among teams, as noted by a site manager:

"Model and tasks are shared live; tagging team members for issues or changes allows fast, documented responses…. Everyone openly shares what they write and note down." (INT06)

Complexity in Working Model-Based

The interviews consistently indicated a perceived high level of complexity associated with MBC, as it was mentioned by a BIM specialist, by stating:

"Working model-based is actually very complex. It's not just the geometry; it's the data and the collaboration between different teams." (INT01)

These core concepts shaped about MBC from the interviews reveal that MBC is not understood as a single practice, but rather as a combination of a tool, workflows, and responsibilities shaped by each actor's role. While the model serves as a central platform, its meaning and use vary depending on the tasks and expectations of each discipline.

4.1.4 Clarity and confusion between MBC and MBDD

The empirical data shows that the interviewees recognize a difference between MBDD (or BIM-based design delivery) and MBC, although the exact boundary and practical implementation of MBC remain somewhat unclear and continue to evolve.

MBC as an extension to MBDD

Interviewees described MBC not as a completely new methodology but as a natural progression from MBDD. A foundational similarity noted was the shared use of a single model as the main source of information, often referred to as the single source of truth. An architect explained:

"We've always worked with one model, the singular source of truth. We develop our documents and derive information from that model." (INT08)

This shared principle has been a common feature in design delivery processes. However, MBC was seen as extending the model's role beyond documentation into daily on-site use. As the architect clarified:

"MBC is just one step more. You use the model more directly on site." (INT08)

This perspective highlights continuity between MBDD and MBC, while also underlining a shift in the model's function, from supporting coordination to directly guiding construction work.

The design manager expressed a similar interpretation, noting that while the working method remains familiar, the model is enriched with significantly more detail and information for use on site:

"[MBC] it's an upgraded model this time. When you put so much more information in it. So that's the big difference. But more or less I feel it's the same. Same way of working [MBDD] but you use the model, even more advanced which is perfect. It's the right way." (INT02)

This view illustrates another key distinction: MBC involves significantly higher levels of detail and precision in the model, tailored for direct application during construction.

Discipline-Specific Needs Are Unclear

The interviews show that the use of MBC is not experienced uniformly across all disciplines. Participants explained that some fields, especially technical ones like

HVAC, still rely on 2D drawings to complete certain tasks. This is primarily because some small-scale or discipline-specific elements are not visible or not detailed enough in the model. A design manager said:

"The HVAC guys, for example, they still need their 2D drawings. They can't always use the model because it doesn't show all the small things they care about." (INT05)

The BIM coordinator confirmed that this gap is partly due to the lack of discipline-specific information within the model:

"For some of the MEP stuff, you can't find everything directly in the model... they still ask for drawings because not everything is tagged the way they need it." (INT03)

For on-site teams, the model was mostly used through tools like StreamBIM, but not all features were relevant to their daily tasks. As one site supervisor explained:

"We use the model, but not all the layers. Some of it is too detailed for what we need to see during the actual work." (INT06)

These findings suggest that MBC is not experienced as a single unified approach across disciplines. Instead, its implementation is filtered through the specific responsibilities, expectations, and information needs of each role.

Struggling with Detail Level

While it was more specified and even practiced with established practices in MBDD, interviewees described the expected level of detail in MBC models as a shared source of confusion, especially during early project phases. While the model was intended to include all necessary information for on-site use, several participants noted that there was no clear agreement on what that should include. As the architect explained:

"Everyone says everything should be in the model, but nobody knows exactly what that means. It's very hard to decide what is worth putting in and what's not." (INT08)

This uncertainty made it difficult for teams to align their modelling efforts, leading to inconsistency between what was delivered and what was expected. For example, a design manager commented on the lack of guidance early on:

"At the start, no one said clearly what we had to model. Some people assumed one level; others did something else." (INT02)

Additionally, interviewees emphasized that the right level of detail depends heavily on how the model is used by different disciplines. What was essential for designers was not always useful for on-site teams, and vice versa. As a BIM coordinator summarized:

"It's always a balance, too much detail can slow things down, but too little and it's not useful for production. And each discipline thinks differently about what's needed." (INT03)

These responses reflect that deciding how much detail to include in a model is not just a technical task, but a coordination challenge that requires clear agreements across roles from the outset.

The legal and contractual role of the model

A key distinction between MBDD and MBC mentioned by the interviewees was the legal status of the model. In MBDD, traditional 2D drawings continue to serve as the legally binding documents. In contrast, MBC aims to make the model itself the contractual reference throughout the construction process. Which was highlighted by the architect:

"With the model as a sort of primary and legally binding source of information instead of producing drawings out of the model." (INT08)

While this principle was recognized, some participants noted uncertainty around how this works in practice. For example, a project manager reflected on possible complications:

"It's one thing to say the model is the main source, but what happens when there is a mistake? Who owns it? Who's responsible?" (INT05)

These reflections suggest that although the model is increasingly positioned as the central legal document, the lack of clear contractual procedures and defined responsibilities can create ambiguity. The interview data indicates that MBC's legal role is still developing and requires clearer structures to support its full implementation in future projects.

Level and Depth of Collaboration

Interviews showed that collaboration also differs between the two methods. MBC demands earlier and deeper collaboration among project actors, as everything must be finalized and embedded in the model before site activities commence. This was emphasized by a project manager:

"In MBC, the collaboration has to happen earlier and at a higher level because everything must be in the model" (INT04)

Participants explained that this early collaboration is essential because all project details need to be defined in the model before site work begins. This requires more structured interaction across disciplines and earlier involvement of contractors and subcontractors. As the same project manager further explained:

"You need to make more time for preparations together with the subcontractors and the main contractors so that you understand everybody's part and where and when in the construction phase they should get in... Subcontractors need to be more aligned with the designers." (INT04)

Ultimately, participants described that while MBDD mainly involves coordination among design disciplines, MBC requires more emphasis on communication between the design teams and those working on site during construction.

Problem-solving shift

The interviewees described that MBC places greater pressure on resolving design issues earlier in the process, shifting the focus from traditional clash detection to ensuring constructability. As an architect commented:

"Because you have to find all the solutions. That's the thing. You have to work it out. You can't just say: 'Oh, we'll fix that on site.' " (INT08)

This reflects a significant difference between MBDD and MBC. In MBDD, the emphasis is primarily on collaboration among design disciplines, aiming to eliminate geometric clashes. However, as participants explained, MBC requires deeper communication between design and construction teams to ensure that what is designed can actually be built, as the BIM coordinator explained:

"In MBC, the collaboration has to happen earlier and at a higher level because everything must be in the model. You're not just coordinating to avoid clashes; you're coordinating to actually build from the model." (INT03)

This shift was consistently highlighted across the interviews as a key change in working practice, requiring earlier and more integrated problem-solving that addresses not only technical alignment but practical feasibility on site.

Uncertainty about Benefits and Method
Some interviewees expressed doubt about the actual value MBC would bring, especially in the early stages of the project when the model was still evolving. A construction manager shared uncertainty about the efficiency of relying only on the model:

"I don't know if it's better. Because there are a lot of things you can't take out from the model. And you have to do manual calculations as well." (INT05)

Others noted that MBC sounded promising in theory, but it was unclear whether its implementation would truly replace traditional methods or just add new layers of work. The general sentiment among several participants was a wait-and-see attitude toward the return on effort invested in MBC.

Uncertainty about the Best Procurement Method

Several interviewees expressed uncertainty about which procurement method is most compatible with MBC method. While MBC was implemented in the project, participants showed different views on whether certain contract types better support the model-based approach.

A project manager raised this issue by comparing two common procurement models: partnering and contract management. Partnering refers to a collaborative arrangement where project stakeholders work closely and share responsibilities and risks. In contrast, contract management involves more traditional, structured roles, with responsibilities defined by fixed contracts. The interviewee stated:

"It probably is better for a partnering project... but maybe it is better actually for the contract management role." (INT05)

This quote reflects how MBC does not yet have an obvious fit within standard procurement models. Participants noted that procurement strategy alone does not determine the success of MBC. Instead, several emphasized the importance of team dynamics, motivation, and communication over formal contract structure. As the same project manager added:

"Team quality and flexibility are more important than the contract form." (INT05)

This suggests that, from the interviewees' perspective, the effectiveness of MBC relies more on the mindset and collaboration of the project team than on the specific procurement framework used.

4.2 MBC Challenges

The empirical data highlights several difficulties that project actors face in implementing MBC. While some challenges are broad and shared across disciplines, others are specific to certain professions. Additionally, some challenges were unique to the particular project context.

4.2.1 Organizational challenges

Resistance to change emerged as a key challenge highlighted by most interviewees. While the reasons behind this resistance varied among participants, a common theme was the reluctance to adopt a new way of working, requiring individuals to learn unfamiliar processes and abandon established methods in which they had experience. Additionally, human and organizational factors further reinforced the tendency to revert to traditional practices.

4.2.1.1 Skill gaps challenges

Empirical data shows that MBC was a new concept for most interviewees. As BIM specialist noted:

"I know that in the beginning, it's very new, they don't know how to work (in MBC), and they have been forced into it, but when they started working with it and using the tools, they understood it wasn't that hard." (INT01)

This perspective was echoed by multiple participants. The common phrases were 'by the time you get comfortable with this new way of working' or 'It's a new thing for everyone'. However, the shift from hybrid working processes (using both the model and 2D drawings) to using model as the single source of project seems to have bigger impact on two key groups:

Finding shows that the field personnel emerged as the group facing the most significant adaptation challenges. Due to the different nature of the site structure, there are many old workers familiar with 2D paper drawings and not familiar with the new technologies they 'cannot even use smartphones, they use button phones' which make the MBC work 'far too detailed' for them. The project manager elaborated:

"The people on site have worked in the industry for maybe 35-40 years using 2D drawings, asking them to review the same information as 3D [model], on an iPad. They think you're out of your mind. I think that is the biggest challenge for the industry" (INT05)

In contrast the findings shows that the younger generation may be more open and find it easier to adapt to and use MBC due to their familiarity with digital technologies. The electrical site supervisor notes

"The younger generation will find it easier because they're more used to digital environments, like video games and virtual simulations." (INT07)

Linking gaming habits to easier adaptation. According to the BIM coordinator, effort is made to include "Some younger people" in teams struggling with MBC, implying they are seen as potentially more adaptable. However, findings also show that simply being young or tech-savvy does not eliminate the fundamental challenges of adapting to MBC. The difficulty often lies in the complexities of finding and filtering specific information from the model compared to traditional drawings.

Design team emerges as the other most impacted team by the requirements of MBC. While office-based professionals typically possess BIM proficiency, the findings provide ample evidence that designers and architects faced significant unfamiliarity challenges related to the level of detail required, the way information needed to be structured, and the shift in responsibility when moving from model-based design delivery to model-based construction. The architect elaborated

"We've always produced the drawings, and we've delivered an IFC model, and there's been clash detection and all that sort of stuff. But we haven't had to solve every little bit. It's still the drawings... and if it's not going to be a clash problem, then it's kind of doesn't matter. But when it is the model-based delivery, then everything has to work." (INT08)

This highlights that MBC requires architects and designers to resolve design issues, including fine details and connections, much more precisely and earlier in the process, shifting the responsibility away from site resolution which traditionally, designers might leave some details to be figured out on site, where experienced workers would solve problems not explicitly shown on 2D drawings. With the model as the primary source of information, everything has to work within the digital environment, demanding a higher level of upfront detail and accuracy in the model itself. This shift directly necessitates those designers possess and apply knowledge about constructability. Architects and designers need to design how something will be built from within the model, understanding the practicalities and constraints of construction on site.

In this section the study tried to investigate how the participants perceive the failure to grasp MBC's principles, purposes, and values of MBC. While most participants expressed willingness to abandon traditional 2D drawings in favour of direct model use, their accounts revealed fundamental uncertainties about how to operationalize this shift. As project management asked:

"When the contractors and the stakeholders signed the contract for KAJ 16, they knew that they were going to use BIM coordination and BIM models. they knew they had to, but did they actually understand what it meant?" (INT05)

This pointed question underscores the disconnect between theoretical acceptance and practical execution. The architect further clarified this conceptual confusion by distinguishing between conventional BIM and MBC:

"A lot of people are doing BIM-based delivery, but not model-based construction." (INT08)

This statement can be seen as an example that highlights a critical blurring of boundaries between Model-Based Design (MBD) and MBC, particularly regarding the scope and purpose of model information, a point of confusion agreed on by all across disciplines.

The empirical data showed knowledge gaps regarding MBC principles among the majority of participants. Despite the contractual agreements to use models, some stakeholders who signed contracts later stated, ' how to work with it' in addition it's not stated in the contract how to use the model. Participants lacked clarity about information requirements in the MBC process demonstrates uncertainty about essential model content when pushing the model to the constructors, subcontractors, contractors. Findings showed that design teams struggled to determine appropriate Levels of Detail (LOD) and implement necessary construction parameters. The electrical and mechanical engineers explained that:

"It wasn't clear from the start what system we were going to use for those different statuses and stages of design". (INT09)

"We have about a million objects in our models. And we need to tag everything with an MMI. And MMI came pretty late into this. It was not from the beginning", (INT10)

Software-specific knowledge limitations emerged, particularly for the architectural team transitioning from ArchiCAD to Revit. This knowledge gap necessitated hiring additional specialized personnel to handle complex modelling tasks, representing an organizational adaptation to compensate for technical knowledge deficiencies.

The finding also showed that extracting information from StreamBIM was a 'struggle' as highlight by several participants who experienced difficulties in using models and the associated software specially for contractor and people on the production side. According to the BIM specialist and the design management

"To navigate in the model is not as easy as for who is familiar with [model]... Is harder to extract from the 3D. It takes more time." (INT01)

"Contractor [need] to learn how to navigate in the model and how to use all the filters and select [needed information]." (INT02)

These findings collectively demonstrate that while MBC was contractually mandated, the lack of corresponding knowledge about implementation principles, technical requirements, and software applications created significant barriers to effective adoption.

4.2.1.2 Change resistance and culture challenges

Several interviewees explicitly mentioned *'fear'*, *'being afraid'*, *'hesitation'*, or *'insecurity'* as significant challenges to implementing and adopting MBC. This feeling appears to stem primarily from the 'unfamiliarity' with the new methods and a reliance on traditional ways of working. Construction management identified the fear among co-workers, from subcontractors to the highest chiefs, who are used to the traditional way and are 'kind of afraid' because they don't know what MBC means for them personally. Mechanical engineer attributed adaption of MBC to 'insecurity' because they 'have never done this before' and noted that 'a lot of our clients are scared to do it'. Project management participant highlighted 'fear' as a significant challenge for the industry as some people, particularly on the MEP side have been 'quite hesitant' mentioned that they have a belief that their site teams, who are used to traditional drawings will not understand the detailed model, feeling that just a line drawing would be sufficient. BIM specialist said:

"I'm surprised. Because MEP disciplines, which should be easier for them to work model-based. But they say that they can't accept the challenge… And I'm surprised. Because of all the projects that I have worked on, MEP disciplines have been the easiest disciplines to have them on the road… The challenge is that I'm sure that they are capable of doing that. But they don't want to change in the organization."

Empirical data shows that generational cultural differences pose significant challenges in acquiring the digital competencies required for model-based workflows, particularly among site workers. As noted by site management:

"A few of our supervisors have been concrete workers themselves. So, they don't have the same computer experience that maybe you get from doing a lot of office work or [university background] when you ... are familiar with much of the software."(INT11)

Participants emphasized that such differences often lead stakeholders to revert to traditional methods. This tendency is further compounded by the construction industry's old -fashioned nature and slow adoption of innovation, as highlighted by a mechanical engineer. Several interviewees noted that some professionals 'haven't changed their mindset' and remain more comfortable with familiar workflows. This cognitive inertia indicates a preference for established practices over newer, less-understood approaches.

Findings also highlight practical challenges, with workers opting for paper-based systems due to their tangible nature and ease of information retrieval compared to digital models. Additionally, a BIM coordinator attributed resistance to a 'lack of interest' in adopting MBC, noting that many workers simply 'want to do what they always do.' Project management, however, stressed the importance of mindset in facilitating this transition, stating:

"Get the best team on board... where people are really passionate about using it [MBC approach] and wanting to drive the change and to use it in that way. I think hunger is more important than experience." (INT05)

According to the findings, the cultural variation stands as a clash between established, often non-digital, site practices and the increasingly complex digital demands placed upon them by MBC. The mindset difference is rooted in the psychological barriers of fear and insecurity associated with abandoning familiar methods and embracing a new, complex, and often misunderstood process, hindering the implementation of MBC.

4.2.2 Technical challenges

The empirical data shows that BIM coordination team and site teams experience technical challenges with Model-Based Construction (MBC). These challenges were grouped into three categories: digital ecosystem challenges, model-related challenges, and StreamBIM-related challenges.

4.2.2.1 Digital ecosystem challenges

Findings indicate that successful implementation of Model-Based Construction (MBC) on-site requires all project members to have access to appropriate equipment, such as iPads and computers. However, this requirement remains particularly unclear. A construction management team member identified the lack of necessary equipment as 'a project problem' emphasizing the challenge of ensuring all personnel have both the proper devices and the knowledge to use them:

"How do you make sure that everybody in the project has the right equipment? What do you need, iPads or computers? How do we make sure that they have the right thing and know how to use it?... Is it the subcontractor's responsibility to make sure they have the required tools?" (INT04)

Furthermore, the electrical site supervisor emphasized that computers are more efficient than iPads for supervisory tasks. A good computer is essential, as it allows for comfortable, focused work. Additionally, larger screens enable multitasking by letting users open multiple views at a time. The supervisor also raised practical concerns about device distribution, including whether workers should use smaller iPads, share devices, or have a designated number of devices per floor to ensure easy access to their specific work views.

The findings also refer to unreliable internet connectivity as a significant operational challenge, particularly for on-site teams. As reported by site management, despite the contractor's considerable financial investment in establishing a robust internet infrastructure, service interruptions still occur, leaving workers without access to the models or a construction drawing, a situation that has already took place on-site. The electrical supervisor further detailed the complications arising from connection instability, stating:

"If you lose connection and reconnect, you might upload something to the wrong place... And once uploaded, you can't remove it." (INT07)

This highlights the risk of irreversible errors caused by connectivity issues. Additionally, another site supervisor emphasized site specific challenges, particularly in areas with weak signal coverage such as basement floors, describing it as 'a big problem'. In such cases, personnel must relocate to areas with stable internet access to retrieve necessary data, often resorting to memorization or screenshots before returning to their work areas, a process that significantly disrupts workflow efficiency.

The findings show that devices used on site, such as iPads, are vulnerable to falling, breaking, or other accidents and damage in the harsh construction environment. Additionally, applications displaying a large amount of data in the model (like StreamBIM) can sometimes be slow. The site supervisor reported significant difficulties when operating touch screen iPads during rainy conditions, particularly while wearing protective gloves:

"It's a touch screen and those kinds of things are not working.". (INT12)

Furthermore, emphasized the reduced battery performance of these devices in cold weather conditions.

4.2.2.2 Model challenges

A predominant theme emerging from the interviews was the inherent complexity of the model, which participants directly attributed to the building's design and scale. As projects increase in size and incorporate intricate geometries or extensive installations, the corresponding models become significantly more complex. The architect articulated this relationship clearly:

"The big challenge with this building is that it's got no roof. It's walls, terraces, walls, terraces, walls, terraces, walls, terrace. That's it. It finishes with a terrace—and nothing that complex has ever been done in Sweden."(INT08)

All participants identified the massive data volume as a primary source of model complexity, stemming from the stakeholder's expectation that 'everything should be modelled'. This approach results in models containing exceptionally high information density, as emphasized by the electrical engineer and mechanical engineer:

"We have like 50,000 objects, and we have to keep ... the status and the object information up to date every week. That is a big challenge." (INT09)

"There are a lot of challenges like some of our installations that have already been built like sewer pipes in the concrete in the basement, because everything was modelled in detail [among other things] the steel reinforcements. Normally, we would just draw a pipe, and they would solve everything on site. But now we had to model everything in absolute detail and avoid the rebars, it was a challenge."(INT10)

The electrical supervisor expanded on these difficulties, particularly regarding electrical installations. The need to coordinate multiple integrated systems (including fire, alarm, power, and data networks), combined with the phased implementation across different building areas, presented significant coordination challenges.

The findings identified recurring concerns regarding model accuracy, stemming from the fundamental principle that output quality depends entirely on input quality. As expressed by participants, errors in the model inevitably translate to errors in physical construction. This issue significantly eroded trust in digital models, as noted by the BIM specialist:

"The contractor doesn't trust the designer's model. They design their own model to make it able to extract the quantities and build on that." (INT01)

This illustrates a lack of confidence in the designer's model's accuracy or completeness for crucial downstream tasks like quantity take-off, cost estimates, and actual site execution and progress tracking.

Findings show that inaccurate model data directly affected material quantification (quantity take-offs), leading to procurement discrepancies. A specific example emerged regarding insulation calculations, as explained by the BIM coordinator:

"The volume of the insulation got wrong when the contractor should take the quantities from the model... We couldn't solve it, so we informed the contractor that you can't use the quantity for this object [from the model]. You have to [calculate it manually]" (INT03)

The findings indicated significant challenges in cost estimation due to data inaccuracies. The design management team expressed particular concern about 'the wrong information' that would lead to 'the wrong price'. Project management highlighted these concerns:

"We found that much of the data is not entirely accurate. There are information gaps, and contractors rely heavily on the database generated from the model." (INT05)

This dependence on potentially flawed model data highly impaired contractors' ability to produce accurate cost estimates.

There was an emphasis on difficulties regarding progress tracking, particularly in quantifying partially completed work. The electrical site supervisor explained:

"You can filter for what has been completed and what has not; they have different statuses, if they are not installed and not started, then they are red. So, you can activate a filter that shows everything that is red making it green, and it's completed… [we are not] able to create our own different stages. So, it's "not done" but "20% done" or "30% done" in that part." (INT07)

This illustrates that while core BIM-based progress tracking relies on status assignments and visual filtering to denote construction readiness, it is still hard to provide a more accurate understanding of partially completed work, addressing a limitation of binary "done/not done" statuses in complex, continuous construction activities.

The participants reported that the project encountered unique security challenges stemming from the client's stringent clearance requirements. These protocols restricted access to the primary BIM model exclusively to personnel with approved security clearance, creating significant operational limitations.

The architect explained that the model contained sensitive data that could not be disclosed to external stakeholders, as confidential information remained structurally embedded in the model even after data filtration attempts. This necessitated the development of a parallel modelling system. However, this workaround introduced considerable administrative overhead, as the architect elaborated:

"When external parties request a model, we must provide a version with excluded spaces since removing individual parameters or metadata requires completely stripping the model each time. With frequent deliveries, this process demands significant administrative effort." (INT08)

This finding shows that maintaining both security compliance and daily operational efficiency requires substantial resources.

The interviewees reported that the Revit software is highlighted as the primary software used for producing models in the project. This was a big challenge for the architectural team to shift from their primary software, ArchiCAD, to Revit. Conversely, the electrical engineer highlighted limitations in Revit's functionality for specific tasks:

"Drawing a 3D cable wasn't possible in that [Revit] software we have now." (INT09)

Findings demonstrate how some project requirements exceeded Revit's native capabilities, forcing team members to acquire programming skills to develop custom solutions.

4.2.2.3 StreamBIM challenges

A significant challenge highlighted is the massive amount of data in the IFC files that can cause performance problems in StreamBIM, the platform used in the project. As the mechanical engineer explained:

"There have been performance challenges with the StreamBIM, because our IFC files are huge... what we had to do with the pipe models, we had to split it into six different IFC files, because it was too big to handle with one... If we would have had it in one IFC, it would be way over one gigabyte. so, it takes like an hour to open the file? Yeah, it would just take a whole day to export it." (INT10)

Which emphasized that this process remains time-consuming, impacting workflow efficiency and platform performance.

The findings identified significant constraints in StreamBIM's documentation capabilities. Site management participants reported that the platform lacks comprehensive features compared to specialized document management systems, necessitating the use of supplementary software. As one site manager explained:

“We had the documentation part on StreamBIM. It's not so much connected to production, but general administrative work in the project for engineers and site managers, for example, is quite limited [to] reviewing documents and sending links for documents and all document management, [the way] it would be handled [using] Microsoft SharePoint. It's simpler. You basically need to download the documents in order to edit and [resend it].” (INT11)

The finding highlighted an additional challenge with accidental uploads that can’t be deleted as it immediately becomes construction documents which users can't remove. The electrical site supervisor elaborated:

“it's more about connectivity, that you always have to have internet. And if you lose connection and then reconnect, you can end up in the wrong place. And if you keep doing that for a while, it's easy to accidentally upload the wrong picture to the wrong place, for example, clicking on a spot and uploading a picture of a product, and then realizing it was the wrong floor and then it's done, you can't remove it because it ends up in a status 500 which is a construction document, meaning it's finalised, as a protective measure so that you can't go in and remove other people's stuff. But it means that you might have to redo a lot and write comments that it is wrong." (INT07)

This means users must manually correct the error by adding explanatory comments rather than simply deleting the mistaken upload.

Furthermore, findings reported difficulties in utilizing StreamBIM for daily report functionality, particularly for recording labour, working hours, productivity, and weather-related notes, forcing reliance on external tools like Excel.

The findings highlighted a significant issue with the lack of persistent visual indicators for changes. While the model updates daily with the newest revisions, temporary annotations (like "clouds" used in traditional digital drawings to highlight changes) disappear with each update. This makes it difficult for site teams to immediately identify what has changed from one day to the next, requiring extensive manual follow-up to track impacts. As the site management described the problem:

"You can make a cloud around an area... And the next day, this cloud will be gone [due to the updates]. You have to follow up because you can't see the changes in that way." (INT06)

While StreamBIM facilitates frequent updates and provides a centralized platform for information, the project teams face ongoing difficulties in efficiently managing, visualizing, and precisely tracking changes directly within the interface.

Multiple participants reported graphical performance issues. One user noted encountering 'white line' issues that seemed related to the graphics and couldn’t be controlled, stating they were "graphic… it wasn't so smooth like in Dalux”. BIM coordinator expanded on these technical constraints, noting that many users lack knowledge of optimal computer settings (e.g., graphics card configurations) to improve performance and potentially solving the graphical issues. Additionally, a few participants talked about the absence of pre-set views, which, unlike traditional paper drawings, requires users to create custom filters and share images via external applications for example, WhatsApp, according to a site supervisor. Navigation challenges were particularly noted for specialized layers such as reinforcement, which proved difficult to manipulate effectively.

4.2.3 Financial challenges

Financial challenges were identified as a major barrier to the successful implementation and adoption of MBC. Interviewees pointed to high initial costs, difficulties in achieving accurate cost estimations, and the added expenses associated with the required level of model detail and complexity.

4.2.3.1 High initial costs

A significant concern raised by multiple participants was the high initial costs associated with the design phase in MBC. These initial costs were linked to different factors like the significant investment needed for 'the education for the contractor's organization' Which should have been borne by the contractor company but in this project the client bear it to push forward adopting and implementing MBC. In addition to the costs associated with 'license for different software'. The financial burden was further compounded by the need to incorporate detailed information directly into the model, information that was traditionally managed through documentation and on-site interpretation. However, the most critical financial challenge, as articulated by project management, is the additional time and effort required from designers during the early stages of MBC projects.

"The early stages, the design work requires more hours from the designers. So, in the early days, it was more expensive than just sketching things out and working two-dimensional" (INT05)

The disconnect between the detailed design efforts (which require more hours from designers in early stages compared to traditional 2D sketching) and the actual cost outcome, combined with the difficulties in accurately derived quantities and reliable estimates from the model, was described as ‘frustrating’, with project manager adding,

"It's the design costs and the project management cost and all the side costs apart from the actual building... And as everything didn't come through into the cost estimate, you have one cost that is not linked to the actual product anymore. Very frustrating, a lot of money. Very difficult to understand" (INT05)

Complex elements, such as basement reinforcement and sewer systems, were particularly costly and time-consuming to model. The mechanical engineer remarked that the sewer design in the project was 'probably the most expensive design of the sewers in concrete ever made’ taking 'a year and a half compared to a usual two weeks'. This extended timeline and higher resource allocation in the design phase were echoed by several participants, who all emphasized that MBC demands more upfront investment in planning and modelling.

While the project experienced initial challenges and increased costs in the design phase, the underlying belief among many involved, particularly the contractors and site managers, is that these upfront investments will lead to overall savings, the design manager expected that the cost saving could be achieved during production phase.

"The idea is to put a little more money in the design phase to reduce costs during the production" (INT02)

The thing that confirmed by the site manager added that initial investments will be recovered through time savings later in the project. However, with the project still in progress, there is currently no verifiable data to substantiate these expected cost reductions.

4.2.3.2 Difficult to make cost estimation

While cost estimation was not extensively discussed by all participants, the findings reveal that architects faced significant challenges in this regard. As the architect explained their difficulties in adapting traditional estimation methods to MBC, stating:

"We have estimated quite a traditional cost or based on traditional BIM project methods and then added a little bit, but it's quite random". (INT08)

This approach proved problematic due to the fundamental differences between MBC and conventional BIM projects, making accurate price estimation particularly challenging. As the project progressed, architect encountered many discrepancies between initial expectations and actual costs, noting that the need to resolve numerous unforeseen details significantly increased workloads. This led to frequent discoveries of unanticipated costs, 'we didn't calculate on this, we didn't think about this, this is extra'. While contractors were generally accommodating of these additional costs, the architect described them as 'reasonably open to it'.

Site management participant corroborated these findings, highlighting how project changes compounded cost estimation difficulties: 'It was quite hard to follow up what the actual cost would have been from the zero'. The frequent modifications, including a change in main designer, resulted in extensive unplanned work hours 'Just setting the budget for the designer, I wouldn't do. It is very hard', suggesting that realistic estimates might require 'taking a budget and then multiplying it by two'.

A consensus emerged among stakeholders that these additional costs would ultimately be borne by the client. the BIM specialist’s positive reception to cost increases 'The client pays for it' and 'The client [is] responsible and it increases the cost' was reinforced by the architect's observation that 'They have accepted a lot of the things that we've said are extra'. However, client project management acknowledged the limitations of initial estimates saying that:

"We've seen that the estimated cost of this building has just soared. The cost that we're signing now for a contract is much, much higher than the first cost estimates that we had… Quite a lot of the data is not quite accurate… there are gaps in the

information [making it] quite difficult [to rely on the model as the] only tool of understanding what is the built cost". (INT05)

4.2.3.3 Higher relative cost for small projects

As mentioned in the previous section 4.2.3.1, the design requirements result in higher initial costs when contrasted with conventional 2D sketching methods. Mechanical engineer mentioned that the effort required to develop the necessary processes, templates, and ways of working for MBC can be costly for smaller-scale projects that may also not require as many drawings or as much detailed information as a large, complex projects, and explained:

"It will cost too much to develop everything in a small project… The larger project will benefit most from it." (INT10)

One of site management provided comparative data on cost implications across project scales:

"In the small projects, you probably will double the design phase in cost. But in the bigger projects, there won't be as much of a cost difference as the smaller ones." (INT11)

4.2.4 Legal and contractual challenges

The study found no contractual barriers to using models as legally binding documents, as model ownership and status were clearly defined in project agreements.

"The design shall be model-based and significantly fewer 2D drawings shall be produced than traditionally. Documents from BE that are normally reported on drawings, according to BH90 (ByggnadsHandlingar 90 (Swedish drawing standards), will be reported in the following formats: Models, Databases, and other documents in other software. Models and databases will supplement or completely replace drawings that would have been included in a traditional drawing delivery from BE (client)... In the KAJ 16 project, the parties will strive for a completely paperless construction." (Project Documents)

However, participants reported persistent resistance stemming from external authorities, particularly government and municipal agencies who continue mandating traditional documentation for official approvals like building permits, as noted by the site manager.

"There is an issue with Statsbyggnadskontoret (City Planning Office) in Gothenburg. They are not yet fully used to model-based workflows, so while they can accept a 3D model, we still have to provide them with traditional 2D printed documents or drawings for building permits. [paraphrased]" (INT06)

Authorities responsible for city-level infrastructure (e.g., heating or water systems) often depend on conventional 2D documentation. As a site manager noted, project teams must create model mock-ups to coordinate with these authorities, who continue to use their own legacy drawings. The persistent use of traditional documentation by external infrastructure authorities - due to their limited digital adoption - forces project teams to maintain conventional coordination practices where model-based construction meets existing city networks. This requirement for producing and exchanging paper-based drawings at these interfaces presents a major obstacle to fully paperless project delivery.

The findings highlighted the absence of a clear project standard as a major challenge in MBC implementation. Although the contract requires stakeholders to use the model, there was no defined strategy for how to do so. As a result, teams had to develop procedures through trial and error. a site manager explained:

"But since we were sort of pilots, we set up the routine for reviewing the drawings and how we use the model for question-based issues and stuff like that. So, and also the routine for implementing the model in total as well. it was like trial and error... and then we adjusted it a little bit on the way." (INT11)

The study also found that without standardized practices, there is ambiguity about what the model should include and who is responsible for providing the information. Determining necessary details and value-adding elements becomes a project-specific effort that evolves over time. Designers face difficulties in deciding the appropriate level of detail, often debating whether to model every component. When asked what should be included, participants frequently responded "everything", yet none could define what "everything" entailed or how they would use it in their work.

4.3 MBC Implementation

The findings indicate that implementing MBC in the KAJ 16 project has been a complex, ongoing, and collaborative effort, primarily driven by the client's mandate to use the model as the single source of truth for all project information. This approach necessitated the use of Revit for modelling and StreamBIM as the primary BIM viewer and communication platform, enabling faster feedback loops between the construction site and the design team. As the architect explained:

"A lot of requirements coming from clients to deliver and work in Revit… StreamBIM is the platform we're working on. We can filter different information and different views to get the coloured filters and see and check the information." (INT08)

For the interviewees, this way of working requires strong collaboration and communication among all stakeholders, including designers, main contractors, and subcontractors. This coordination is achieved through weekly model-based meetings, where teams discuss necessary model inputs, identify challenges, and share knowledge. According to design and site management participants:

"We help each other, and we have these model-based meetings where we discuss together how we can make progress, what can be an issue, and how we can solve it, so we're working together a lot." (INT02)
"The different stakeholders had quite good teamwork throughout the project, and we get all of the necessary demands and information into the model." (INT11)

The empirical data show that continuous support and training provided by the BIM team were essential to the effective implementation of MBC in KAJ 16. BIM coordinators and specialists actively train users on navigating the model and tools, offering prepared views, shortcuts, and supplementary documentation alongside in-person training sessions. A BIM coordinator elaborated:

"I have to confirm that everyone knows how to find the information… We have a project studio day on Tuesdays… I've held some courses on this day for some people… It works quite well, everyone has learned a lot about computer settings, graphics cards, and [other optimizations] to make StreamBIM [run faster]. I sit with them one-on-one… for 15 minutes… I've also [created small guides on StreamBIM for searching and navigating the model] … I've printed these and put at the site." (INT03)

Beyond the BIM team, project managers and supervisors also contribute by helping team members to extract information from the model.

Additional factors facilitating MBC implementation include automated processes and model structuring. The BIM coordinator noted the efficiency of export robots for IFC files:

"It's very nice to have the export robots to always ensure models export at the right time and with the correct settings." (INT03)

Some disciplines have to split their large IFC file into multiple files for manageability. A ventilation consultant stated:

"We had to split it into six different IFC files because it was too big to handle as one."

The design management team linked the model to Power BI for streamlined quantity take-offs, while the electrical engineer developed custom Revit plugins using Python. These initiatives significantly enhanced MBC implementation.

In summary, interview prove that MBC implementation in KAJ 16 was achieved through a combination of central digital platforms, client requirements, intensive collaboration, robust training, and utilizing external software. It is less about following a predefined standard and more about learning-by-doing approach *"we're just learning. It's a fascinating but frustrating journey at times" (INT05, Client)*

4.4 Benefits of MBC

Several participants noted that the benefits of MBC become more pronounced as the project progresses, especially during subcontractor procurement and on-site construction, when the model's detailed information is fully developed. As the developer noted:

"The real benefits of the model and all the detailed information, it gets more and more beneficial as you move towards realization. When you're procuring subcontractors and building the thing on site" (INT05)

Enhanced Information Usage

A key benefit of MBC identified in this study is its significant advantages in enhancing information management and accessibility. Specifically, the implementation of MBC facilitates the efficient obtaining of highly specified information through filters and customized views. This was highlighted by site management:

"You just have to dig out, what you need to do right now… You can press and see only what you want." (INT06)

Furthermore, MBC is described as enabling rapid access to object-specific data. For the interviewees, this capability allows stakeholders to quickly retrieve crucial information associated with particular building elements, as illustrated by the design management:

"They use the model and click on every object... what's the fire rating, what's the acoustic rating…" (INT02)

In addition, the continuously updated model was highlighted by the majority of participants as a significant advantage. It was described as …. (Correct the rest clearly) which reflects that the modification in real time ensures that all stakeholders maintain a consistent understanding of the project's current state. This feature is highlighted as mitigating the risk of relying on outdated information, as emphasized by the site management:

"Everything is updated every evening… we eliminated the risk that we work with the wrong PM [Revisions] ... We don't have the issue of outdated drawings anymore because it's live." (INT06)

Enhanced Collaboration and Coordination

A significant theme emerging from the interviews was enhanced collaboration and coordination among diverse stakeholders when utilizing MBC, particularly through their involvement from the early stages of the project. Several participants, especially the BIM team, highlighted the positive impact of this early engagement on mitigating potential obstacles in later phases. This aligns with what a BIM coordinator mentioned about proactively addressing issues through early collaborative can lead to effective problem-solving, saying:

"It's more like the contractors are with us in the design process now… that helps avoid all the problems … We solved two of twenty complex places in the building by having meetings and working in the model." (INT03)

That idea was further supported by the site management, indicating the quick reactions to raised problems enabled in the practice of MBC, saying:

"They can take a picture, write on the drawings, ask me a question, and I can send it back with a comment; ... all in StreamBIM." (INT06)

Enhanced Efficiency

A prominent theme emerging from the interviews was the role of MBC in enhancing operational efficiency by minimizing errors, accelerating issue resolution, reducing rework, and enhancing visual clarity. A critical factor contributing to this efficiency was described as the early collaboration facilitated by MBC, which allowed stakeholders to address discrepancies in advance before they escalated. As the design manager noted when describing the importance of coordination:

“We avoided many mistakes just by having better coordination” (INT02)

The interviewees also highlighted that MBC enables rapid detection and systematic resolution of issues. The platform’s (StreamBIM’s) real-time notification system ensured immediate stakeholder awareness and prompt corrective action, as highlighted by the supervisor:

“You can mark issues, and everyone instantly gets a notification, so the responsible person takes action very soon.” (INT07)

Moreover, interviewees emphasized MBC’s capacity to mitigate rework through proactive problem-solving in digital environment. By resolving conflicts in the virtual model prior to physical construction, teams avoided costly on-site modifications. This in advance approach was underscored by the client representative:

“We try to meet and review problems before production… the goal is to solve problems digitally before they reach the site.” (INT04)

Further efficiency gains were achieved through MBC’s enhanced visual clarity, which simplified task interpretation compared to traditional 2D drawings. The site engineer emphasized the superiority of MBC’s spatial representation, stating:

“It’s easier to isolate objects or see the whole space ... we don’t have that with drawings.” (INT07)

Quality Assurance and Cost Reliability

Quality assurance emerged as a continuous benefit of MBC in the interviews. Participants emphasized that MBC prevents reliance on outdated data by ensuring all project information is centralized and continuously updated within the model. This eliminates discrepancies caused by obsolete drawings or conflicting revisions. As one consultant explained:

“First one being it's quite a quality assurance because you always know that when everybody opens their computer or iPad to see what to do, everybody gets the latest information. If something's changed, you don't have drawings that you don't know if it's accurate or if it's an old one, if there have been some changes. It's all in the model, it's the latest things that we should build from now.” (INT04)

Another significant benefit of MBC is its ability to enhance cost estimation accuracy. Cost estimation issues and challenges were discussed earlier in the challenges section. As the model matures and incorporates more detailed data, it provides a more reliable basis for budgeting compared to traditional methods. An architect involved in the project confirmed this advantage, noting:

“The more we get in the model and the more mature it becomes, and the more they base the cost on the model, [the estimation] is going up. So you can be sure that model-based construction gives a much better price estimation.” (INT08)

Sustainability

From a sustainability perspective, MBC offers significant advantages by enabling data-driven environmental accountability and long-term resource efficiency. A key benefit highlighted in interviews is the ability to track and optimize carbon emissions through model-derived data. As emphasized by a project manager:

"We've seen great benefits in terms of CO_2 estimates… largely thanks to the model." (INT05)

This capability extends to facilitating precise life-cycle assessments (LCA), where the model's detailed material quantities support thorough sustainability analyses. The design management team elaborated on this functionality:

"We use PowerBI… everything in the model will get exact amounts of materials." (INT02)

Furthermore, MBC enhances sustainable facility management by embedding maintenance-specific data during the design phase. This proactive approach ensures operational efficiency post-construction, as noted by the design manager:

"They want to use the model for routing and how to take care of the building… we add more information before handover." (INT02)

Scalability Considerations

Finally, another key factor shaping the effectiveness of MBC is project scale. The interviews finding shows significant consensus regarding the relationship between project scale and MBC benefits, with most participants identifying larger, more complex projects as the primary beneficiaries of this approach. While some interviewees acknowledged potential applications for smaller projects, a prevailing view emerged that the relative advantages might be proportionally limited due to implementation costs. As a consultant engineer noted:

"I think the larger project will benefit most from it... In the future? Yeah. Not yet. We need to be more prepared for small projects because just starting all these processes and all this must have a template for it. Apply it. It will cost too much to develop everything in a small project." (INT10)

4.5 Reflections for future MBC project

Client's leadership and vision

A key critical factor emphasized in the interviews is the pivotal role of the client's proactive leadership style and clear vision as a critical drive for the successful implementation of MBC. Without such commitment, the project would likely not have followed the MBC approach. A dedicated client who establishes clear expectations, allocates necessary resources, and shapes the project's ambitions is essential for methodologies like MBC that necessitate organizational, cultural and workflow adaptations. This perspective was explained by a design manager:

"I think the most important thing to accelerate model-based construction is to have a brave client. In this case it is ... the client is the most important and then we all the contractors follow their lead… someone has to point out the direction." (INT02)

Early Establishment of Standards and Structured Processes: Contrasting Views on Project Scale for Development

A key consideration for future MBC projects is the early establishment of clear standards and reusable workflows to ensure cost-effective and smoother implementation. Several practices developed during the KAJ 16 project were identified as adaptable to other projects, as mentioned by a site supervisor:

"We have developed quite a lot and adapted. We have picked things from different projects and adapted them to KAJ 16… most of it could be used in other projects" (INT10)

However, the interviews revealed two distinct perspectives on the most effective way to develop these MBC standards, particularly concerning the scale of the initial projects, potentially reflecting different priorities regarding risk mitigation and upfront investment.

Perspective 1: Starting with Simpler Projects for Incremental Standardization. A group of participants reflected on the challenges of applying MBC to highly complex projects without sufficient preparation. Describing the KAJ 16 project as overly ambitious in its early stages, leading to unforeseen complexities and delays, this experience encouraged recommendations to begin future projects with simpler scopes or adopt a phased implementation approach. The logic here, as illustrated by the architect, suggests a desire to build foundational knowledge and develop standards incrementally with less risk:

"Maybe we've bitten off a bit more than we can chew." (INT08) and "This is really going extreme... I think the challenge would not be as big if it were a simpler building, smaller scale, but here it's just everything at once." (INT08)

This sentiment for example was mentioned by the client's representative:

"We would tone down that a bit more… Do things a bit easier in the early days." (INT05)

Perspective 2: Developing Standards on Larger Projects. On the other hand, another group highlighted that creating these standards during work on a smaller project could be costly and inefficient. They argued that larger projects provide the necessary scale and resources to justify the initial investment in developing comprehensive and broadly applicable frameworks. This viewpoint was mentioned by a site supervisor:

"We need to be more prepared for small projects because just starting all these processes and all this must have a template for it to apply it. It will cost too much to develop everything in a small project." (INT10)

Introducing MMI and Levels of Detail Early
An important point in MBC was frequently highlighted during the interviews is MMI (Model Maturity Index), which makes it clear for the model work's stage as a site manager said:

"We work with MMI status... you put the status on every object. That's a lot of work behind it. But then you can on the site you can show only what's done. So, you don't build something that we're still working within the design phase." (INT02)

highlighted that MMI was introduced late and should have been implemented earlier, explained by a site supervisor:

"MMI came pretty late into this. It was not from the beginning." (INT10)

Provide Structured Training for All Team Members

The participants declared clearly that the training they have got was essential for the work progress. Beyond technical modelling, successful MBC implementation requires that all stakeholders know how to interact with and extract relevant data from the model. One of the BIM team emphasized that the value of modelling is only fully realized when everyone can use the model effectively:

"I think it's a learning process in the whole project and everyone has to be on the same level… I have to confirm that the entrepreneur and the guy that should buy the things know how to find the small pieces of objects in the model." (INT03)

Parallelly, those who missed the training strongly emphasized the importance of training and guidance for working with MBC. As was explained by site supervisor:

"If we could have courses or basic guides early on, it would save time and confusion ... It's about setting up the right foundations from the start." (INT07)

Select Teams with Prior MBC Experience, but Value Motivation and Adaptability
Several interviewees emphasized that prior experience with MBC significantly improves project outcomes. Teams familiar with MBC are better equipped to handle its demands and can reduce the need for onboarding, resulting in more reliable planning and cost estimation. As noted by the client representative:

"Absolutely. I think it will make it cheaper using the same team or at least many parts of the same team. It will definitely make it easier and cheaper and more reliable ... So, we would probably get a much better cost estimate from the very start and it would be an easier journey." (INT05)

This prior experience not only enhances efficiency but also gives organizations a considerable advantage in future projects. As the client's representative answered when asked if the experience of working with MBC gives advantage saying:

"Of course, if you've been through this race, you've gathered more experience using the model-based construction than your competitors have, then, of course, you're in a better position." (INT05)

A design manager answered to the question if people without MBC working experience will be excluded in future MBC project saying:

"Companies and individuals who worked with MBC will have a big advantage."
(INT10)

However, experience alone is not sufficient. Interviews information also stressed the importance of selecting teams based on motivation, adaptability, and a willingness to learn. These points were considered just as important as the technical skills, this was highlighted by the client's representative as follows:

"Get the best team on board… the hunger is more important than the experience … Working with MBC is not only a matter of prior experience, but also mindset."
(INT05)

5 DISCUSSION

This chapter presents a critical analysis and discussion of the empirical findings from the KAJ 16 case study, interpreted through the lens of the research questions and supported by relevant academic literature. The discussion is structured around four central research questions that guided the thesis. Each section discusses the findings in relation to the relevant literature. The analysis includes both the pilot interviews and those from the KAJ 16 project.

5.1 Defining and understanding MBC

This section answers the first question exploring how various project stakeholders understand and define MBC in practice. Starting from the interview findings, it highlights different interpretations of MBC as a tool or a methodology. These interpretations influence implementation and the working way of MBC and reflect the current ambiguity around digital construction practices. The discussion also addresses the conceptual distinction between MBDD and MBC, a topic that emerged repeatedly during the interviews.

5.1.1 Paperless or hybrid use of drawings

When interviewees were asked to define MBC, many of the participants described it as a paperless process in which the model is used directly on site during the construction phase. This aligns with Disney et al. (2024), who define MBC as an approach where no 2D drawings are produced and the model serves as the sole contractual document throughout the project lifecycle. However, several interviewees added that MBC is a hybrid approach where the updated model is used to issue updated 2D drawings, referring to the traditional BIM method. And this doesn't align with the pure purpose of the MBC highlighted by Disney et al. (2024) and majority of the academic papers. Even if some still refer to the use of 2D drawings for specific cases. As a result of both the literature and the interviews, MBC was not clearly defined as paperless, which means it might contain a small number of model-updated drawings when needed.

It is essential to recognize that the overarching goal of MBC is to fully leverage the benefits of BIM, particularly in improving economic efficiency and streamlining work processes. Therefore, insisting on a fully paperless approach, even in cases where producing a few model-derived 2D drawings would be more cost-effective or practical, may counteract these objectives. The purpose of MBC is not to eliminate paper at any cost, but to enhance project outcomes through smarter information use. As such, flexibility in implementation, where 2D outputs from the model are used strategically, can be more aligned with the core principles of MBC than rigid adherence to paperless ideals.

5.1.2 MBC as tool and methodology

The findings revealed two distinct interpretations of MBC. One group, mostly site workers, viewed MBC primarily as a practical digital tool. For them, MBC was associated with software such as StreamBIM and was valued for its role in improving efficiency, visualizing information, and replacing 2D drawings. This understanding aligns with the findings of Brooks et al. (2023), who noted that many practitioners continue to treat BIM and MBC as enhancements rather than transformational frameworks. Similarly, Duman and Gustafsson (2025) found that some stakeholders, especially in the early phases of the New Slussen project, perceived the model mainly as a visualization tool, focusing on its practical utility rather than its role in reshaping project delivery before the transition to using the model throughout the construction phase.

In contrast, the second group described MBC as a broader methodological shift. They viewed the model not merely as a technical asset but as the central, legally binding source of information that drives coordination, decision-making, and collaboration throughout both the design and construction phases. This group included designers, design managers, office staff, and BIM team members. Their understanding of MBC aligns with the approach described by Gaunt et al. (2017), who explicitly advocate for model-based construction as a methodology. Similarly, Sacks et al. (2018) and Disney et al. (2024) describe BIM as a methodology, emphasizing its role as the sole contractual document and its continuous use on-site. Brooks et al. (2023) also position MBC within the early industry movement toward deeper operational use of models.

Finally, we found that MBC aims to push the use of BIM to its full potential, there is a gap in recognizing MBC as a methodological shift appears to be more common among site workers, and this have an impact on the working processes.

5.1.3 Confusion between MBC and MBDD

The interviewees commonly understood the transition from MBDD to MBC as a natural extension. As a result, many participants applied familiar MBDD practices, such as model structuring, LOD, coordination routines, and cost estimation methods, directly within MBC implementation. This approach led to mixed outcomes: while some practices were transferable and supported the process, others proved inadequate when applied in the construction phase, where demands on usability, accuracy, and timing differ significantly.

Academic literature has largely emphasized the limitations of reapplying traditional BIM and MBDD frameworks within MBC. In particular, the continued reliance on exported 2D drawings is seen as undermining the central goal of a fully model-driven workflow (Disney et al., 2024; Brooks et al., 2023). However, the interview data, particularly from designers such as the architect, revealed a more pragmatic and transitional perspective. In the absence of clearly defined MBC standards, the reuse of established MBDD methods served as a practical starting point. Rather than representing a barrier, these familiar practices acted as a temporary scaffold, enabling teams to progress with implementation while gradually adapting to the unique demands of model-based construction.

This insight suggests that, when strategically improved and critically adapted, reused design-phase methods may enable the development of MBC-specific standards. Instead of viewing reuse as purely regressive, it can be seen as a bridge that supports digital continuity and enables a more accessible and scalable transition toward full MBC adoption.

5.1.4 Differing expectations among stakeholders

The data revealed diverse MBC expectations across stakeholders, mainly shaped by their roles and responsibilities. For example, finance teams emphasized cost reduction, reflecting industry claims but overlooking early-phase investments and coordination demands, a concern aligned with Brooks et al. (2023) regarding inflated digital savings. In contrast, the BIM team viewed MBC as a centralized information source rather than a paperless mandate, which is in contrast with literature (e.g., Disney et al., 2024) that ties full benefits to eliminating 2D dependencies. These conflicting perspectives led to implementation challenges, including ambiguity over modelling responsibilities, required detail, and on-site information reliability.

The findings reveal a persistent gap between MBC's theoretical promise and on-ground application. Although MBC implementation was contractually mandated, several stakeholder assumptions about its purpose led to fragmented adoption. This underscores that contractual compliance alone is insufficient as success requires treating MBC as a flexible solution, with aligned expectations established through proactive communication.

Ultimately, the important point in the understanding of MBC lies in establishing a mutual understanding among the manager level workers and more specially the construction management team, while the understanding of some groups of the workers of the method does not reveal much importance on the implementation.

5.2 Challenges in implementing MBC

This chapter examines the empirical findings addressing the research question: "What are the challenges encountered in MBC implementation?" The analysis explores the underlying reasons for these challenges, interprets their implications, and evaluates how the results compare with existing literature, whether they align with, contradict, or expand upon prior theoretical frameworks.

Following the structure of the findings chapter, the discussion is organized into four key challenge categories: Organizational challenges, technical challenges, financial challenges, Legal challenges. By systematically analysing each category, this chapter aims to provide a comprehensive understanding of the obstacles hindering MBC adoption while situating the findings within the broader academic and industry discourse.

Our analysis of challenges in the KAJ 16 project revealed their deeply interconnected nature. These challenges cannot be accurately represented as isolated categories, as organizational issues often trigger financial consequences, while financial solutions may be a prerequisite to resolving legal matters. This systemic interdependence suggests that effective problem-solving may require addressing multiple challenges simultaneously rather than through piecemeal approaches.

5.2.1 Organizational challenges

One of the most challenges that highlighted in KAJ 16 project was the organizational challenges as the finding showed it arise due to skill gaps issues due to the unfamiliarity and despite the contract condition of using the model-based construction in the project but when the stockholders tried to implement it, they faced organizational challenges arising from two points.

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Change Resistance and Culture Challenges

The transition to full MBC in KAJ 16 faced resistance due to psychological and cultural factors. It started with a pervasive sense of apprehension and reluctance across all organizational levels, primarily stemming from unfamiliarity with digital workflows and a strong preference for traditional methods. This resistance was particularly pronounced among experienced workers with limited digital literacy, who expressed fear of the unknown and concerns about potential failures due to misunderstanding MBC requirements particularly in the absence of legal standards and clear methodology. For site teams, the priority was receiving accurate, easily interpretable information, not merely extracting data from models but ensuring it could be reliably translated into physical construction. Their reluctance to abandon trusted methods stemmed from the high stakes involved; any misinterpretation or error in execution could lead to costly mistakes in the final physical product.

These findings align with existing literature on digital transformation barriers in construction. Gamage and LIGS University (2021) highlight how institutional inertia, rooted in established professional hierarchies, conventional contracts, and entrenched operational practices, fosters resistance to change. This resistance is compounded by a lack of awareness regarding digital benefits and a cultural predisposition toward familiar approaches. Brooks et al. (2022) further emphasize that unrealistic expectations of model-based construction often led to workarounds when digital tools fail to meet practical on-site needs.

We argue that this cultural resistance might persist for the foreseeable future, particularly as companies continue operating both traditional and MBC projects simultaneously. This dual approach creates a temporary adoption mindset among workers at KAJ 16 - once their assignment concludes, they revert to conventional methods. Even when workers recognize MBC's benefits, this constant switching between methodologies reinforces their preference for traditional approaches, which remain industry-standard. The uncertainty about future MBC opportunities (compared to clearly planned traditional projects) further discourages adaptation. This challenge becomes particularly acute when laborers must work across parallel projects using different methodologies, creating additional friction and resistance to change.

Therefore, these insights underscore a critical paradox in construction digitalization: while the industry acknowledges the need for technological progress, successful implementation requires addressing both macro-level structural barriers and micro-level human factors. A balanced strategy is essential, one that tackles institutional constraints while ensuring digital solutions are tailored to real-world workflows and user competencies. Without this dual focus, the transition to MBC will continue to face significant psychological and cultural resistance.

Skill gaps challenges

A primary barrier emerges from workforce resistance to MBC adaptation, particularly among experienced field personnel accustomed to traditional 2D workflows. This resistance appears most strongly in older, less educated site workers who struggle with digital tools, contrasting sharply with younger, university-educated office staff who demonstrate greater adaptability. These findings align with Lidelöw et al. (2023), who identify age structures, personal characteristics, and ingrained work habits as critical factors inhibiting MBC adoption across various project stakeholders.

In KAJ 16, the skill gap challenge stems not from a lack of software awareness but from understanding how to work with the model effectively. Traditionally, the workforce relied on clear, direct, and straightforward 2D drawings, where all necessary information was explicitly written and easily readable. In contrast, extracting the same details from a 3D model requires workers to navigate complex steps: orienting themselves within the model, locating the correct floor and room, clicking on the object to access its data, and - if details are missing - generating sections, adjusting views, and toggling system visibility. This process becomes even more challenging when workers lose their way while zooming or navigating, ending up in the wrong part of the model.

We believe that while the average worker, even with basic education, is capable of processing 3D models, the learning curve is steep. Unlike a 3D game where movement is intuitive (e.g., walking through streets or chasing targets), model navigation demands meticulous attention to construction-specific details. This complexity requires significant time to master, and the challenge will persist, taking longer to resolve than anticipated.

The transition to MBC requires substantial changes in work processes and responsibilities, particularly for design teams. Where traditional workflows allowed for on-site resolution of construction details, MBC demands comprehensive upfront modeling that incorporates constructability knowledge. This shift requires designers to develop new site awareness and adapt to unfamiliar software platforms, such as architects transitioning from ArchiCAD to Revit. These changes have necessitated organizational restructuring, including new roles and responsibilities, as noted by Dainty et al. (2017). However, persistent skill gaps, as highlighted by Alshorafa and Ergen (2019), continue to hinder effective implementation, particularly in finding personnel with adequate BIM expertise.

A critical implementation challenge lies in the fundamental misunderstanding of MBC requirements among stakeholders. Despite contractual commitments to MBC, many participants confused it with conventional BIM applications, lacking clarity on information requirements, Level of Detail (LOD) standards, and model navigation protocols. This knowledge gap extended to software-specific competencies, with many teams struggling with tools like StreamBIM for information extraction. As Lidelöw et al. (2023) emphasize, overcoming these barriers requires not only substantial training investments but also a fundamental cultural shift in work practices. Without addressing these competence deficits, organizations risk failing to realize MBC's potential benefits in productivity, error reduction, and collaborative efficiency.

5.2.2 Technical challenges

The KAJ 16 project revealed several technical barriers to MBC implementation. These included issues with equipment and connectivity, model usability, and platform limitations. This section discusses how these challenges affected daily work and how they compare with insights from existing literature.

Digital Ecosystem challenges

The implementation of MBC faces persistent challenges in equipment provisioning, connectivity, and on-site usability. These barriers reveal gaps between theoretical frameworks and practical execution, as evidenced by the KAJ 16 project's struggles despite prior literature identifying similar issues.

A critical barrier is the unresolved responsibility for providing digital devices (iPads, computers, or smartphones). This ambiguity disproportionately affects subcontractors engaged in short-term tasks, should they invest in expensive equipment, or should the main contractor standardize provision? Compounding this, device suitability varies by role, while Davies and Harty (2012) advocate tablets as all-in-one workstations, the electrical supervisor emphasized computers' superiority for multitasking and screen space. This contradiction suggests that MBC requires flexible equipment policies tailored to task complexity, with tablets potentially suiting field workers accessing basic data and computers reserved for supervisory roles.

Reliable internet access remains a requirement for MBC, yet KAJ 16's intermittent connectivity-particularly in basements- forces workers to revert to paper, undermining dynamic model use (Disney et al., 2023). Unlike the New Slussen project, where site-wide Wi-Fi was prioritized (Disney et al., 2022), KAJ 16's failures highlight a planning gap. Weak signals in critical zones suggest infrastructure designs must account for site-specific dead spots through redundancy (e.g., localized boosters) or offline access solutions.

Even with adequate devices, harsh environments hinder MBC adoption. Tablets are prone to damage, touchscreens fail in rain or with gloves, and cold weather drains batteries. While Davies and Harty (2012) proposed styluses as a workaround, this fails for model navigation (e.g., zooming). Such issues demand pragmatic solutions: Protective cases and lanyards to prevent damage, Specialized gloves with exposed fingertips for touchscreen use, and on-site spare devices to mitigate battery failures.

KAJ 16's recurring ecosystem problems, despite prior literature warnings, underscore the need for adaptive strategies. A tiered approach should clarify equipment responsibility in contracts, with main contractors provisioning standardized devices for short-term trades, deploy redundant network infrastructure informed by pre-construction signal mapping, and lastly integrate user-specific solutions (e.g., ruggedized cases) into BIM execution plans.

While usability fixes address immediate barriers, long-term success requires aligning technology with workflows, recognizing that MBC's value erodes if workers default to paper due to unresolved practical hurdles.

Model-related Challenges

Beyond infrastructure and hardware challenges, the implementation of MBC in the KAJ 16 project was significantly challenged by issues related to model complexity, data accuracy, and alignment with construction needs. These difficulties reflect a fundamental gap between design-driven modelling practices and the practical requirements of executing a project directly from the model on site.

One of the most commonly mentioned technical barriers in the KAJ 16 project was the excessive complexity of the model. Participants described how the ambition to include every detail, from reinforcement to extensive service layers, resulted in large, difficulty in navigating files. The model's size and density became a burden for many users, especially on the construction side. This aligns with concerns raised by Brooks et al. (2023), who emphasizes that over-modelling introduces inefficiencies when too much information is embedded without clear prioritization.

Importantly, interviewees repeatedly pointed out that trying to model everything created confusion about responsibility and value, what must be included, what could be left to the site, and what is optional. This uncertainty led to significant effort spent on modelling elements that were never actually used, while some critical site-relevant information was still missing.

These findings highlight a core tension in MBC: while detailed models are essential, the absence of clear guidance leaves teams uncertain about what to include. Without defined modelling boundaries, teams risk over-delivering unnecessary details or under-delivering critical elements, both of which undermine constructability. This shows that the lack of shared modelling standards is not just a procedural gap but a strategic issue, reinforcing the need for early, discipline-specific agreements on what should be modelled, excluded, or resolved through cross-disciplinary coordination.

Another major technical challenge in the KAJ 16 project was the lack of trust in the model's accuracy. Several participants explained that contractors often rebuilt parts of the model themselves in order to extract reliable quantities or prepare for construction. As one BIM specialist noted, "The contractor doesn't trust the designer's model. They design their own model to extract the quantities." This practice reveals a breakdown in one of the core goals of MBC is using a single, reliable model as the main source of project information.

This issue is supported by Disney et al. (2024), discussing that for MBC to be effective, the model must be fully trusted both in content and structure. When models are incomplete or contain errors, site teams are forced to fall back on manual calculations or duplicate work. Similarly, Whyte et al. (2022) highlights that digital workflow can only function if the data produced in design meets the practical needs of construction.

In KAJ 16, this misalignment resulted in material quantity errors, unreliable cost estimations, and inconsistent model use. These findings make it clear that model accuracy is not just a technical issue, it is central to trust. Without confidence in the model, MBC becomes fragmented, and teams revert to traditional methods.

The interviews revealed that the model's progress tracking system was limited to a binary structure, allowing elements to be marked only as "done" or "not done." However, participants emphasized that construction progress is gradual, often requiring the ability to track partial completion (e.g., 30% or 70% installed). This mismatch between the model's functionality and real-world needs led to practical limitations in site coordination. Whyte et al. (2022) supports this, explaining that effective MBC implementation requires status-aware and process-reflective tools. Without such features, the model cannot function as a reliable platform for real-time management or decision support. This shortcoming highlights a legacy limitation, while MBDD workflows did not demand granular progress tracking, MBC depends on it to accurately reflect on-site conditions and support continuous updates. The addition of more nuanced status indicators would not require major technological innovation, only that the need be recognized and built into the tools. As MBC evolves, such feedback loops between site requirements and software development become essential to close the gap between model intent and operational use.

Moreover, the interviews revealed that designers struggled to determine the appropriate LOD to include in the model, while engineers were unclear about how to apply Model Maturity Index (MMI) status labels. This lack of early guidance led to mismatched expectations and inconsistent modeling across disciplines. Several participants noted that both LOD and MMI were introduced too late in the process, which caused confusion during implementation.

Disney et al. (2024) emphasizes the importance of establishing information requirements early, particularly when the model is intended to serve as a legally binding document. They show that unclear or delayed LOD definitions can lead teams to either over-model unnecessarily or missing critical information required on site. This confusion also affected the constructability of the model, as some site personnel reported that models lacked key details needed to guide physical work. Unlike MBDD, where drawings leave room for interpretation, MBC requires digitally complete and constructable representations.

Importantly, this issue is not technical in nature but procedural. Defining LOD and MMI from the outset does not require major additional effort; rather, it should be integrated into the evolving standardization of MBC workflows. Early agreement on these parameters would reduce ambiguity and support more consistent, constructable models.

Information Extraction Difficulties, Especially for Subcontractors

The challenge of information extraction, especially for subcontractors, was noted in the interviews. As discussed earlier in the report, this issue stems from several factors: subcontractors limited digital skills, lack of prior experience with platforms like StreamBIM, absence of predefined trade-specific views, inconsistent model structures, and overly detailed models that were not adequately filtered for task relevance. These factors are resulting in delays, repeated clarification requests to designers, and, in some cases, a return to traditional drawing-based workflows for clarity, reinforcing that extracting information from the model remains a central and unresolved barrier in MBC implementation, especially for subcontractors.

The literature supports many of these points, as Disney et al. (2024) highlight that even with access to model viewers, some site workers struggle to extract measurements on-site, pointing to persistent challenges in user experience and data presentation. In the Tideway East project, Brooks et al. (2023) observed that subcontractors reverted to 2D drawings because they were unable to operate effectively within the 3D model environment. This reflects a broader issue wherein digital tools are often not adapted to users' varying skill levels. The same study warns of a loss of practical site knowledge when experienced field operatives are marginalized due to digital complexity. Brooks et al. further emphasize the need for intuitive software interfaces and trade-specific filters to make models more usable in production settings.

These findings reinforce the view that extracting information from the model remains a central and unresolved barrier in MBC implementation, particularly for subcontractors. Addressing this challenge is critical to enabling broader adoption of MBC as a standard industry practice.

StreamBIM limitations

The implementation of MBC in the KAJ 16 project revealed several limitations in the use of StreamBIM, particularly in handling large-scale models and supporting documentation workflows.

One technical limitation in the KAJ 16 project was the performance slowness caused by large IFC files. In some cases, models exceeded one gigabyte in size, making them slow to handle, export, and open. Teams addressed this by splitting the model into several smaller files, which allowed continued use but introduced complexity and coordination challenges, undermining the model's role as a single integrated source of information.

This specific issue with the performance limitations of large IFC files in platforms like StreamBIM, is not directly addressed in current MBC literature. While authors such as Disney et al. (2024) emphasize the benefits of StreamBIM for site coordination and live access, they do not engage with its technical constraints in large-scale use. Whyte et al. (2022) notes that digital tools often fail to meet the operational demands of site-level work, especially when scaled, but they do not focus on file size or performance breakdowns. In our view, this challenge is not unique to MBC. It remains present even in the older more mature MBDD practices, where model segmentation is still required. Given that MBC demands even more detail and frequent updates, it is natural that performance issues persist. Although future software developments may reduce this impact, the issue currently presents a real barrier to model-based workflows in large projects.

Interviewees reported that StreamBIM was insufficient for handling administrative and production-related documentation, such as editing reports, managing daily logs, or tracking working hours. As a result, teams were required to rely on external tools like SharePoint and Excel to perform this routine but essential tasks. This created a fragmentation of the workflow, where model-based coordination was separated from core project administration, reducing efficiency and increasing the risk of miscommunication or data inconsistencies. Another reported limitation was the lack of persistent change tracking. For example, site teams noted that temporary revision annotations, such as visual clouds, disappeared after updates, making it difficult to identify what had changed. This forced users to rely on manual follow-ups, reducing the model's usefulness as a live communication platform. Finally, participants reported several interface and usability issues. Graphical glitches, such as "white lines," affected viewing performance. Users also noted the absence of predefined view filters, requiring them to create custom filters or share screenshots informally via tools like WhatsApp. Additionally, upload errors, such as placing an image in the wrong model location, could not be corrected once finalized, forcing users to rely on manual comments to clarify mistakes.

In contrast, academic literature tends to focus on StreamBIM's strengths, particularly its capabilities for visualization, information filtering, and real-time model access (e.g., Disney et al., 2024). However, these studies rarely address the tool's limitations in supporting full project documentation workflows, especially at the site level. Similarly, the literature highlights StreamBIM's benefits for real-time collaboration but does not engage with problems related to revision tracking, usability, or correction of errors.

This discrepancy points to a gap between theoretical potential and actual usage. While StreamBIM succeeds in enabling model access and coordination, it currently lacks the flexibility to manage broader site documentation needs. A possible solution would be to connect StreamBIM to complementary systems in a more structured way, making them extensions of the same workflow rather than isolated tools. Regarding the revision tracking problem, this is a basic functionality in most drawing-based environments, and it is surprising that the current tools do not yet offer a stable alternative for MBC. We think that improvements in platform responsiveness, filtering pre-sets, and error correction mechanisms are not difficult to implement if platform providers prioritize them based on real user feedback from construction sites.

Ultimately, many of the limitations noted with StreamBIM, including performance issues with large models, lack of revision tracking, insufficient administrative features, and usability concerns, point to a broader need for targeted platform development. These challenges are not unique to KAJ 16, but reflect gaps between current software capabilities and the real demands of on-site model-based work. Addressing them requires improved responsiveness to user needs, such as better filtering tools, support for non-design workflows, error correction features, and integration with complementary documentation systems. Streamlining these aspects through coordinated feedback loops between site users and software providers is essential to fully support MBC at scale.

5.2.3 Financial challenges

The KAJ 16 project experienced high initial costs during the design phase, and participants cited several reasons for this issue, including the extended time required for high-detail modeling, the learning curve (especially for older staff), and the expenses related to hardware and software. However, these factors do not pose a significant challenge to implementing MBC, at least for large-scale projects like KAJ 16.

The real challenge lies in distinguishing between the increased costs attributable to using timber structures rather than conventional concrete or steel - particularly for what the architect described as Sweden's most complex timber project - and those costs specifically associated with implementing MBC. A significant portion of the initial costs originates from the inherent complexity of timber as a primary construction material. Researches indicate that timber structures typically demand more intensive early-stage planning and additional considerations such as enhanced fire protection measures.

Furthermore, the project's design was initially created by a Danish architect following Danish standards. Later, a Swedish architect took over to adapt the design to Swedish standards, incurring additional design costs unrelated to the construction method. The Swedish architect noted that they were not doing original design work but rather fixing problems in the existing design and model, which was time-consuming and costly.

Given these factors, we cannot attribute all the initial costs to MBC, especially the client is frustrated by the high expenses, blames initial design stages in model-based projects to increased hours required from designers, compared to less detailed 2D sketching without clearly understanding whether the costs arise from MBC implementation or from the timber structure's complexity and design challenges considering that client's decision to implement MBC in KAJ 16 was driven by positive results and cost-effectiveness observed in previous projects like Celsius. This confusion in cost expectations could negatively impact the adoption of MBC in future projects.

However, even if these initial costs or transition costs (e.g., modeling time, learning curve and hardware and software costs) do not present a major obstacle for KAJ 16 (as they are necessary for MBC implementation), they still create prohibitive financial barriers for smaller firms and projects. In such cases, the cost-benefit ratio often makes MBC economically unviable, effectively rendering the method impractical for many small-scale projects which aligns with the literature mentioned before.

Another financial challenge in the KAJ 16 project related to cost estimation, which impacted two key areas: First, subcontractors like architects and MEP engineers faced high uncertainty in cost estimation. As one participant noted, "no one really knew how much extra work this would mean," with tasks that previously took two weeks requiring over a year to complete under MBC requirements. Designers used traditional cost estimation methods, but these proved inadequate for MBC. Unclear deliverables, missing details, and frequent changes - compounded by ambiguous Level of Detail (LOD) requirements - led to guesswork adjustments and unexpected costs. Architects acknowledged these issues would likely persist in future MBC projects. Second, using the model for direct cost estimation remained problematic. Many participants argued against modeling everything, which contradicts MBC's core concept of being a single source of truth. Omitting details inevitably leads to inaccurate cost estimations. While Sacks et al. (2018) confirm BIM's capability for precise material quantification, they note its inability to automatically account for labour, temporary materials, equipment, or site-specific complexities - all critical factors requiring human estimator judgment. This discrepancy risked financial losses for subcontractors, potentially discouraging model use.

However, participants remained optimistic about MBC's long-term anticipated benefits such as eventual cost savings, enhanced accuracy, and reduced construction/operational reworks and risks as justification for the transitional costs. Nevertheless, determining a clear feasibility of adapting to MBC remains challenging. As a unique pilot project, KAJ 16 has no direct comparable in terms of its innovative structural design and construction methodology, making reliable financial assessment difficult both in the current stage and for the foreseeable future.

5.2.4 Legal challenges

While KAJ 16 was pushing boundaries by fully implementing MBC, external authorities created counterproductive challenges by insisting on traditional drawings for building permits and approval purposes, creating a fundamental challenge for the project. The challenge becomes clearer when considering authorities maintain decades of city system data in legacy formats and complete digitization of these archives proves extraordinarily difficult, making project-level adaptation to existing workflows more practical than systemic overhaul. As Sacks et al. (2018) document, public institutions face unique technology adoption barriers due to slow regulatory evolution, though some progressive entities have begun updating contract terms for BIM collaboration. This institutional inertia leads to partial acceptance of model-based submissions, forcing KAJ 16 project to maintain dual delivery systems (both BIM and traditional drawings). Sacks et al. (2018) stress that comprehensive BIM adoption ultimately requires contractual and legal reforms to overcome these systemic barriers. Until such fundamental changes occur - and given the authorities' reluctance to operate parallel systems - these challenges will persist indefinitely.

The implementation of MBC in KAJ 16 faces another major challenge: the lack of clear legal standards. While contracts mandated model usage, they provided no specific strategies, leaving teams to develop workflows through trial and error. This ambiguity originated from a fundamental knowledge gap as neither designers nor clients fully understood MBC requirements, including necessary deliverables or quality control procedures. With even clients uncertain about expected workflows, teams were forced to improvise, resulting in excessive revisions, prolonged discussions, and repeated modifications to satisfy unclear expectations. Designers bore burdens, constantly adjusting their work without defined acceptance criteria. These findings corroborate Alshorafa and Ergen's (2019) research, which identifies a persistent disconnect between BIM mandates and practical execution. Clients often lack the experience to specify critical parameters like scope, BIM applications, Level of Detail (LOD), or standardized protocols, causing project delays. Contractors, equally inexperienced, frequently depend on external specialists to fulfil requirements. Supporting this view, Brooks et al. (2022) contend that MBC requires entirely new contractual frameworks and standardized practices to establish clear responsibilities, workflows, and quality benchmarks, as traditional contracts prove inadequate for this evolving methodology.

The KAJ 16 project's pursuit of full MBC implementation aiming for a "paper-free" site with the model as the "single source of truth" revealed significant practical complexities during stakeholder interviews. The research uncovered a fundamental divide in perspectives among participants. One camp strongly advocates modeling every project element, viewing this as essential to fulfilling MBC's core promise of a comprehensive digital representation. These stakeholders emphasize the theoretical benefits of having all information centralized in a single authoritative model. However, other interviewees present compelling practical counterarguments. They question both the feasibility and value of exhaustive modeling, noting that certain details don't warrant the required effort. These practitioners argue that overloading models with unused data actually diminishes efficiency rather than enhancing it, creating unnecessary complexity without corresponding benefits.

This tension raises three critical implementation questions that currently lack consensus: how to define the appropriate modeling scope "everything", what information truly needs inclusion, and who should make these determinations. The findings suggest these aren't merely technical decisions to be resolved through discussion, but rather structural issues requiring formal legal frameworks and governance structures to enable effective MBC adoption.

5.3 Implementation of model-based construction

Several interviewees in the KAJ 16 project noted that MBC is more suitable for large-scale projects, where the complexity and coordination needs justify the extra modelling effort. In smaller projects, they warned that design-phase costs could nearly double, making MBC less cost-effective compared to traditional methods.

While the literature studies as Disney et al. (2024) and Brooks et al. (2023) do not explicitly compare MBC across project sizes, their case studies implicitly focus on large public-sector and infrastructure projects, where model-based workflows are more viable due to complexity and stakeholder alignment. Similarly, Lidelöw et al. (2023) note that smaller firms and projects often lack the resources or incentive to adopt MBC unless it is mandated through contracts or client demands. Moreover, Sacks et al. (2018) stated that for larger and more complex projects, BIM's ability to integrate data and facilitate collaboration becomes invaluable, but this is extensive to BIM applications not just to MBC.

Given the current maturity of model-based practices, MBC appears more practical and cost-effective for large projects. However, as standards evolve and tools become more accessible, the additional design costs associated with MBC may diminish. In such a scenario, smaller projects could benefit from MBC in the same way large projects do today, particularly in terms of improved information flow, reduced errors, and simplified coordination.

The implementation of MBC leads to a redefinition of professional roles, particularly by increasing the interaction between design and construction teams. Designers are now required to participate in on-site processes to ensure that the model is constructible and aligns with real-world conditions. Likewise, site engineers must engage earlier during the design phase to inform the model with practical execution knowledge. This narrowing gap reflects a structural transformation in project delivery. Additionally, the shift places new demands on site workers, many of whom must adapt to using 3D models for data extraction and task execution. While this transition poses challenges for older workers, it is expected to ease over time as younger, digitally fluent generations enter the workforce and digital tools become more intuitive and widely adopted.

This is supported by academic studies, which highlight the need for designers to develop practical, execution-oriented knowledge when the model becomes the legally binding and primary reference for construction. The academic literature emphasizes that MBC shifts the responsibility of checking constructability and completeness earlier in the process, requiring more interdisciplinary collaboration and more integrated planning. Scholars also underline that this shift demands organizational and cultural adaptation, particularly in how teams communicate and align responsibilities, as shown in the findings by Disney et al. (2022).

Our findings support this perspective, showing that the narrowing gap between design and construction roles under MBC reflects a structural transformation. Designers can no longer focus solely on form and compliance; they must now account for exact execution needs within the model. Their involvement in site processes is necessary to make the model not just accurate but buildable. This leads to the necessity for designers to develop more site-oriented thinking and collaborate continuously with site teams.

In addition to the change in professional roles, the interviews also point to the growing need for on-site workers to acquire skills in navigating and extracting information from 3D models. Traditionally accustomed to working with 2D drawings, many workers now face the challenge of understanding and using digital tools such as tablets and BIM viewers. The interviews suggest that while this transition may be difficult, particularly for older generations, practical training could help overcome initial resistance.

Academic sources reinforce this observation, acknowledging that the adoption of 3D model-based workflows on site requires significant training efforts, particularly for older workers who often face challenges due to limited digital literacy. However, studies also show that younger, digitally native professionals adapt more readily to model-based practices, indicating that generational turnover will gradually ease this transition (Duman & Gustafsson, 2025).

Our interpretation aligns with this, suggesting that while the initial implementation of MBC may require focused training and adaptation strategies for site workers, especially those with less IT experience, this challenge is transitional. As more digitally fluent generations enter the workforce, the need for extensive training will diminish. The integration of 3D models into daily construction tasks will gradually become the norm, supported by intuitive tools and increased digital readiness across the industry. Therefore, while the current transformation requires active management and cultural change, future implementation will likely be smoother and with less effort needed.

Clear LOD and MMI definitions, as discussed in section 5.2.2, are crucial to avoid confusion when using the model for execution on site. This is consistent with findings by Brooks et al. (2023) and Disney et al. (2024), who highlight that precise model specifications makes the shift from MBDD to fully operational MBC smoother.

Model reliability also remains critical. Our findings showed that contractors sometimes rebuild models to extract trustworthy data, reflecting insufficient validation practices, a challenge similarly noted by Whyte (2019) and Lobo & Whyte (2017).

Finally, effective MBC further depends on live feedback from the construction site to keep the model current. Without this, discrepancies may grow, weakening the model's role as the primary information source, an issue that was underlined also by Aibinu & Papadonikolaki (2023).

5.4 Strategies and recommendations for successful MBC implementation

The success implementation of MBC in the KAJ 16 is driven by the client's mandate to use BIM as the single source of truth and defining Revit for modeling and StreamBIM as a platform from early stages of the project and conclude all these requirements in the contract conditions. Additionally, while the stakeholders were afraid to risk with a new method, the financial support of the client was crucial for the project's continuity. Accordingly, due to novelty of the MBC, the success relied on strong stakeholder early engagement, collaboration, and education efforts done to increase the stakeholders' digital skills.

Effective implementation of MBC depends on a set of enabling conditions and strategic choices. This section explores the factors that contributed to or hindered success in the KAJ 16 project. It discusses the role of client leadership, the importance of early standard setting (e.g., LOD, MMI), training strategies, and team selection. These insights provide guidance for future projects aiming to adopt MBC in a more structured and scalable way.

5.4.1 Lessons from KAJ 16: strategies that enabled success

Making information extraction easier for users

As discussed earlier, subcontractors had difficulties navigating the model due to missing filters, over-detailed content, and limited digital skills. Future MBC projects should address this by including predefined trade-specific views, better object tagging, and early onboarding tailored to subcontractor needs.

Strategic role of the client, client's leadership and vision

The client in KAJ 16 initiated and sustained the MBC process by mandating BIM as the legal source of information, selecting specific tools, and embedding these requirements in contracts. Without such leadership, MBC would not have been adopted. This aligns with several directions in the literature. Disney et al. (2022) showed that Total BIM was only possible due to strong client enforcement. Whyte (2019) emphasized that digital delivery transformation begins with client-side intent and structure. Similarly, Aibinu and Papadonikolaki (2020) noted that MBC adoption rarely occurs without contractual or regulatory push.
MBC is not just a technical implementation; it is a strategic shift. The client's role as a digital sponsor, with clear intent, contractual tools, and financial commitment is essential. Without this, even capable teams are likely to revert to hybrid or traditional processes, unless MBC becomes legally mandated in construction.

Structured training for all project members

Although many participants stated that they received structured training in KAJ 16, several others mentioned a lack of such training - especially for subcontractors and non-design roles - which led to confusion and limited the effective use of the model during construction. Training was mainly focused on designers. This supports Gaunt (2017), who found that limited model review skills delayed workflows. Duman and Gustafsson

(2025) also showed that in both Slussen and Celsius, training and internal learning processes were critical for enabling stakeholders to adapt to model-based work. Without training, model use tends to remain superficial or revert to 2D.
Training must include all project actors, not only designers, to ensure that MBC is used consistently from design to site. A certain level of digital literacy, particularly in extracting data from 3D platforms, should be required to ensure that workers can fully engage with the model.

5.4.2 Recommendation strategies for future MBC project

In KAJ 16, the absence of clearly defined standards and processes at the start led to misunderstandings and inconsistent modelling outputs across teams. Participants emphasized the need to define LOD, MMI, and structured workflows early to avoid delays and rework. This aligns with Whyte (2019), who argues that early-stage digital planning is essential for coherent project delivery. Disney et al. (2022) showed that early definition of MMI helped synchronize model content with on-site use. Without this, teams often revert to traditional outputs due to uncertainty.

This is one of the most important points suggested to facilitate easier implementation of MBC, as early standardization creates alignment between disciplines, supports model usability throughout the project, and makes the overall goals more achievable. In parallel, a clear quality control system should be integrated with the modelling standards to continuously check accuracy, completeness, and discipline-specific compliance. Without this, even well-defined standards may fail during execution, especially when multiple teams contribute to the same model environment.

In KAJ 16, participants emphasized that the late introduction of MMI and LOD caused confusion about whether model elements were finalized or still under development. This led to uncertainty and miscommunication during on-site execution, which could have been avoided with early definition of model maturity levels. This aligns with literature findings that highlights that early clarification of modeling tasks and dependencies is essential to avoid misaligned workflows and inefficiencies. Without clear definitions of what is expected in each stage of the model, different teams interpret the model's readiness differently, leading to coordination issues.

Introducing MMI and LOD from the start ensures that stakeholders understand the status of model elements and how they can be used. This builds trust in the model, reduces rework, and supports consistent use across the project lifecycle.

6 CONCLUSION

This research sought to explore the practical implementation of Model-Based Construction (MBC), investigating how stakeholders interpret, adopt, and respond to MBC processes through an in-depth case study of the KAJ 16 project in Gothenburg. The primary objectives were to examine how different stakeholders understand the concept of MBC, identify the organizational, technical, financial, and legal challenges encountered during its implementation, and extract lessons that can inform future adoption of model-based construction methodologies.

The study revealed that MBC is understood variably across disciplines: some stakeholders viewed it mainly as a digital tool to replace 2D drawings, while others perceived it as a transformative methodological shift demanding organizational and contractual realignment. Empirical findings demonstrated that MBC has clear benefits in enhancing collaboration, information flow, cost estimation reliability, and sustainability tracking. However, the transition to MBC also showed deep-rooted challenges. Organizationally, resistance to change and skill gaps, particularly among older site workers, emerged as significant barriers. Technically, difficulties were linked to model complexity, software and hardware limitations, and persistent interoperability concerns. Financially, while large projects like KAJ 16 could absorb the increased design-phase costs, smaller projects might find MBC economically prohibitive. Legally, the lack of standardized frameworks meant that projects still needed to maintain traditional documentation to satisfy authorities, undercutting the aim of fully model-based delivery. Through this detailed examination, the study confirmed that while the technical infrastructure for MBC exists, its success depends predominantly on human factors, proactive leadership, and clear, early establishment of standards and expectations.

Contributions to knowledge

This research contributes to both theoretical and practical understandings of digital transformation in construction, particularly within the context of BIM adoption and MBC.

On the theoretical level, the study offers nuanced insights into the transition from Model-Based Design Delivery (MBDD) to MBC, illustrating that the move is not merely a linear technological progression but involves complex shifts in responsibilities, workflows, and stakeholder relationships. The findings reinforce and expand on existing theories such as those by Disney et al., 2024; Brooks et al., 2023.... by showing how the reuse of MBDD practices, though often criticized, can pragmatically provide gradual transformation for early MBC implementation in the absence of mature standards.

Practically, the case study of KAJ 16 provides a contemporary, real-world benchmark of MBC application, offering detailed empirical evidence on the benefits, obstacles, and critical success factors of fully model-based delivery. It highlights actionable lessons on the importance of client leadership, early contractual clarity on digital expectations, early engagement of stockholders, inclusive training programs, and iterative learning processes that adapt standards and practices over time.

Limitations of the study

The study's main limitation is the focus on a single case within the Swedish construction industry, which may restrict the transferability of findings to other contexts or project types. Additionally, the absence of perspectives from some disciplines limits the breadth of insights. Language translation from Swedish to English also risks subtle meaning loss. Lastly, the study's exploratory nature led to an evolving thematic focus, introducing elements of iterative framing.

Recommendations for practice

Practitioners aiming to adopt MBC should establish clear modelling standards early, invest in training across all roles, and ensure strong client leadership to drive adoption. Starting with simpler projects can help organizations build experience before tackling complex builds. Finally, improving software usability and field-specific tools will be essential to support on-site implementation.

Future research suggestions:

- Examine how MBC impacts project budgets over time, considering both the higher initial design costs and potential long-term savings in construction and operations.
- Investigate how digital transformation can be extended to include external and governmental authorities, which still largely rely on traditional documentation and processes.
- Explore whether it is practical or necessary to digitalize existing legacy data, or if efforts should mainly focus on new projects going forward.
- Include a wider representation of site roles, such as foremen, craftsmen, and subcontractors, in future studies to better understand their needs and challenges with MBC.
- Study how MBC can be adapted and made feasible for small and medium-sized organizations, which may face different financial and resource constraints.

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8 Appendix

The main points mentioned during the interviews concern understanding

MBC understanding:	Qty	Int 01	Int 02	Int 03	Int 04	Int 05	Int 06	Int 07	Int 08	Int 09	Int 10	Int 11	Int 12
Model is the single source of truth	6	☑	☐	☐	☑	☑	☑	☐	☑	☑	☐	☐	☐
Paperless	7	☐	☐	☐	☐	☑	☑	☑	☑	☑	☐	☑	☑
Might include printed papers	8	☑	☑	☐	☐	☑	☑	☑	☑	☑	☑	☐	☐
Tool	5	☑	☑	☐	☐	☐	☑	☐	☐	☐	☑	☑	☐
Methodology	3	☐	☐	☑	☐	☐	☐	☐	☐	☐	☑	☑	☐
MBC as an extension to MBDD	3	☐	☑	☐	☐	☐	☐	☐	☑	☑	☐	☐	☐
MBC understanding varies by discipline	8	☑	☐	☐	☑	☑	☐	☑	☑	☑	☑	☑	☐
It is Stream BIM	3	☐	☑	☐	☐	☐	☑	☐	☐	☐	☐	☐	☑
Plattform for sharing knowledege	12	☑	☑	☑	☑	☑	☑	☑	☑	☑	☑	☑	☑

The main points mentioned during the interviews concern Organizational challenges

Organizational	Qty	Int 01	Int 02	Int 03	Int 04	Int 05	Int 06	Int 07	Int 08	Int 09	Int 10	Int 11	Int 12
Changing people mentality	7	☑	☑	☑	☐	☑	☐	☑	☐	☑	☐	☑	☐
Fear/ they afraid	4	☑	☑	☐	☑	☐	☐	☐	☐	☐	☑	☐	☐
Resistance to MBC / tendancy to traditional way	6	☑	☐	☑	☐	☐	☐	☑	☑	☑	☐	☑	☑
Lack of knowledge	9	☑	☑	☑	☑	☑	☑	☑	☐	☐	☑	☐	☑
Lack of understanding the method	9	☑	☑	☑	☑	☑	☑	☐	☑	☑	☐	☑	☐
Age differences	4	☑	☐	☐	☐	☑	☐	☑	☐	☐	☐	☐	☑
Communication	3	☐	☐	☐	☑	☐	☐	☐	☑	☐	☑	☐	☐
Change management	2	☐	☐	☑	☐	☑	☐	☐	☐	☐	☐	☐	☐
Not commiting to contract	2	☐	☐	☑	☐	☑	☐	☐	☐	☐	☐	☐	☐
User competency /extract of the information	9	☑	☑	☑	☑	☑	☑	☑	☑	☐	☑	☐	☐
Necessity of 2D Information	5	☐	☑	☑	☐	☐	☑	☐	☑	☐	☑	☐	☐
Complex for subcontractors & vendors	5	☐	☑	☐	☐	☐	☐	☑	☑	☐	☑	☑	☐

The main points mentioned during the interviews concern technical challenges

Technical	Qty	Int 01	Int 02	Int 03	Int 04	Int 05	Int 06	Int 07	Int 08	Int 09	Int 10	Int 11	Int 12
Initial difficulty	6	☐	☐	☑	☑	☐	☑	☐	☐	☑	☑	☑	☐
Equipment	2	☐	☐	☐	☑	☐	☐	☑	☐	☐	☐	☐	☐
Internet connection	5	☐	☐	☑	☐	☐	☑	☑	☐	☐	☐	☑	☑
Device usability in challenging site conditions	3	☐	☐	☐	☐	☐	☑	☑	☐	☐	☐	☐	☑
Limited access and security issues	3	☐	☐	☐	☐	☐	☑	☐	☑	☐	☐	☐	☑
Model complexity	9	☑	☑	☑	☐	☑	☐	☑	☑	☑	☑	☑	☐
Model Accuracy	4	☐	☑	☑	☐	☑	☑	☐	☐	☐	☐	☐	☐
You can't model everything	3	☑	☑	☐	☐	☐	☐	☐	☑	☐	☐	☐	☐
Revisions and updates	4	☑	☐	☑	☐	☐	☑	☐	☐	☑	☐	☐	☐
System performance and vulnerability	6	☐	☐	☑	☐	☐	☑	☑	☐	☐	☑	☑	☑
No preset views that could replicate the layout	1	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☑
Graphic quality	2	☐	☐	☑	☐	☐	☐	☐	☐	☐	☐	☐	☑
Technical problems with stream BIM	3	☐	☐	☑	☐	☐	☑	☐	☐	☐	☐	☐	☑

The main points mentioned during the interviews concern financial challenges

Financial	Qty	Int 01	Int 02	Int 03	Int 04	Int 05	Int 06	Int 07	Int 08	Int 09	Int 10	Int 11	Int 12
Time consuming in design phase	6	☐	☑	☐	☑	☑	☐	☐	☑	☑	☑	☐	☐
Software license costs	1	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☑	☐
High initial costs	6	☐	☑	☐	☐	☑	☑	☐	☑	☑	☑	☐	☐
difficult to make cost estimation	4	☐	☐	☐	☐	☑	☐	☐	☑	☐	☑	☑	☐
Higher relative cost for small projects	2	☐	☐	☐	☐	☑	☐	☐	☐	☐	☐	☑	☐

The main points mentioned during the interviews concern legal and contractual challenges

Legal	Qty	Int 01	Int 02	Int 03	Int 04	Int 05	Int 06	Int 07	Int 08	Int 09	Int 10	Int 11	Int 12
Model is not legally binding	2	☐	☐	☐	☐	☑	☐	☐	☑	☐	☐	☐	☐
Model ownership	2	☐	☑	☐	☑	☐	☐	☐	☐	☐	☐	☐	☐
Lack of standard practice	5	☐	☐	☑	☑	☐	☐	☐	☑	☑	☑	☐	☐
Regulatory compliance	3	☐	☑	☐	☐	☐	☐	☐	☑	☐	☐	☑	☐
Client power and requirement	3	☐	☑	☐	☐	☑	☐	☐	☑	☐	☐	☐	☐
Project agreements and relationships	1	☐	☐	☐	☐	☐	☐	☐	☐	☑	☐	☐	☐
What information needed	5	☐	☑	☐	☑	☑	☐	☐	☑	☑	☐	☐	☐