



**CHALMERS**  
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# Preparing BIM Models for Construction

Challenges and Requirements

Master's thesis in Design and Construction Project Management

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CHALMERS UNIVERSITY OF TECHNOLOGY

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MASTER'S THESIS ACEX30

# **Preparing BIM Models for Construction**

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Göteborg, Sweden 2025

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## **Abstract**

As the construction industry shifts toward increased digitalization, model-based design delivery is gaining attention as an alternative to traditional 2D documentation. While drawings remain the main form of design communication, a growing number of projects are beginning to adopt model-based deliveries. This uncovers a research gap in focus on the design phase, and how specifications, interoperability, and trust are understood and applied in model-based practices, particularly when models lack the visual cues and scale typically found in 2D drawings.

This thesis explores how the absence of scale and visual hierarchy in BIM models affects stakeholder interpretation, whether detail and maturity specifications can help address these issues, and why collaboration and adoption challenges persist even in digitally advanced project environments. Further, it investigates how the absence of drawing scale and other visual cues that typically indicate detail or reliability affects the way stakeholders interpret design information in BIM models. This research also investigates barriers to model use on construction sites, including legal constraints, inconsistent use of standards and specifications, limited digital literacy, and lack of trust in model data.

Based on a literature review and twelve semi-structured interviews with professionals across the AEC industry, the findings show that BIM can support more efficient design communication, but these benefits are limited without clear indicators of maturity and reliability. Specifications such as Level of Development and Model-Maturity Index show potential for improving model readiness, but are inconsistently applied and rarely enforced through contracts. By focusing on the design phase, this thesis contributes new insight into how models can be better structured and communicated to support their reliable use in construction, bridging the gap between model-based design delivery and its practical implementation.

Keywords: Model-based Design Delivery, BIM, MMI, LOD, Design Phase Coordination

Förbereda BIM-modeller för byggnation

Utmaningar och krav

Examensarbete inom masterprogrammet Design and Construction Project Management

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## Sammanfattning

I takt med att byggbranschen i större utsträckning rör sig mot digitala arbetssätt får modellbaserad projektering ökad uppmärksamhet som ett alternativ till traditionella arbetssätt. Ritningar i 2D är fortfarande det huvudsakliga kommunikationsmedlet, men vissa projekt har börjat implementera modellbaserade leveranser. Detta visar att det finns en klyfta i hur specifikationer, interoperabilitet och tillit förstås och tillämpas i modellbaserade arbetssätt, speciellt när modeller saknar skalangivelser som är typiska i 2D-ritningar. Denna studie undersöker hur avsaknaden av skala och visuell hierarki i BIM påverkar projektdeltagares tolkning av modellens detaljnivå och informationspålitlighet, huruvida specifikationer kan hjälpa dessa brister, samt varför samverkans- och tillämpningsproblem ofta kvarstår även i projektmiljöer som är digitalt avancerade.

Genom en kombination av litteraturstudie och tolv semistrukturerade intervjuer med verksamma inom byggbranschen undersöker studien hur frånvaron av skala och andra visuella indikatorer som normalt signalerar detaljnivå eller informationssäkerhet påverkar tolkningen av designinformation i BIM. Studien behandlar även hinder för modellanvändning på byggarbetsplatser. Däribland förekommer juridiska begränsningar, inkonsekvent användning av standarder och specifikationer, begränsad digital kompetens samt bristande tillit till modellens informationsinnehåll.

Resultaten visar att BIM kan stödja en mer effektiv designkommunikation, men att dessa fördelar begränsas utan tydliga indikatorer på informationsmognad och tillförlitlighet. Specifikationer såsom Level of Development (LOD) och Model-Maturity Index (MMI) visar potential att stärka modellens användbarhet, men tillämpas ofta inkonsekvent och sällan med kontraktsmässig förankring. Genom att fokusera på projekteringsskedet bidrar denna studie med nya insikter om hur modeller kan struktureras och kommuniceras bättre för att säkerställa deras tillförlitliga användning i produktion, och därmed fylla gapet mellan modellbaserad projektering och dess praktiska tillämpning.

Nyckelord: Model-Based Design Delivery, BIM, MMI, LOD, Samverkan i projekteringsfase

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# Preface

This thesis has been shaped as much by questions as by answers. As the construction industry navigates digitalisation, we found ourselves fascinated by what technology enables, and by what it leaves unresolved. Throughout this process, we have been driven by a desire to understand not just how model-based workflows function, but why they sometimes fail to reach their potential. Writing this thesis has allowed us to engage with professionals, literature, and ideas that challenge ourselves, but also assumptions we had before starting this study.

We would like to thank each and every one of our respondents for their contribution and time throughout this study. This work would not have been possible without their openness and expertise. Furthermore, we would like to give some extra kudos to our supervisor and examiner, Oliver Disney and Dilek Ulutas Duman, for challenging us throughout the process and continuously providing constructive feedback.

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## Abbreviations

BIM - Building Information Modelling

MBDD - Model-Based Design Delivery

LOD - Level of Development

MMI - Model Maturity Index

AEC - Architecture, Engineering, and Construction

CAD - Computer-Aided Design

CDE - Common Data Environment

IFC - Industry Foundation Classes

LOIN - Level of Information Needed

BIP - Building Information Properties

MEP – Mechanical, Electrical, and Plumbing

# 1. Introduction

The construction industry is undergoing significant digital transformation, driven by advancements in technology and the increasing demand for more efficient and collaborative project delivery methods. An emerging narrative supporting digitalization of the construction industry in Scandinavia is the elimination of drawings from design and construction practices and their replacement by Model-Based Design Delivery (MBDD). MBDD workflows are based on Building Information Modelling (BIM), which has been extensively studied due to its potential to improve visualization, coordination, and information management in the Architecture, Engineering and Construction (AEC) industry (Sacks et al., 2018; Volk et al., 2014).

However, an upcoming challenge connected to this shift is the interpretation of scale and detail in models. Previously, design information was communicated through 2D drawings with scales and textual information, such as design phase or revision, that indicated their level of detail and reliability. In BIM, users can zoom in and out on any part of the model indefinitely, which can lead to misunderstandings if the elements being observed are not clearly explained through additional metadata (i.e., data embedded in the elements, such as completeness or approval status) (Blanchard, 2022). Consequently, this has also raised concerns about trust in the model data, as visual precision does not always reflect the actual development of model elements, nor whether the design team or the client approved them for construction. These challenges become even more critical as the industry explores model-based construction, the direct use of BIM on construction sites for planning, coordination, and execution. This highlights the need to better understand how models are prepared during the design process, before they are handed over for construction use.

To address the challenges of interpreting model detail and ensuring model reliability, the industry has introduced specifications such as Level of Development (LOD) and Model Maturity Index (MMI). These specifications aim to define the necessary model content and indicate the maturity of elements, making it easier to know when a model component is ready to be used for specific purposes, such as quantity take-offs, coordination, or on-site construction (Abualdenien & Borrmann, 2022). However, the construction industry still faces challenges in consistently applying these specifications and ensuring that models meet the standards required for confident use in construction.

At the same time, digital collaboration platforms that enable real-time communication, data sharing, and model coordination (like BIM 360 or Dalux) are changing how stakeholders interact, offering faster and more integrated communication. Yet, successful collaboration depends not only on digital tools but also on the existence of clear processes, training of personnel, and a shared understanding among project participants, factors that are not always in place (Volk et al., 2014; Azhar et al., 2012). Model-based workflows are seen as a promising step forward, as they could improve coordination, reduce on-site collisions and rework, support

more dynamic decision-making, and eliminate the time-consuming process of drawing production, which also introduces translation errors (Disney et al., 2022).

Despite this, most projects continue to rely on traditional 2D drawings as legal documents, even when detailed models exist (Disney et al., 2022). One reason for this reliance is that models are rarely developed to a level that would allow contractors to use them with confidence. Some recent examples, presented by Disney et al. (2022), show that it is possible to build directly from a model without using drawings, for instance, by using tablets on-site to access up-to-date 3D models with embedded information for measurements and element specifications. These cases demonstrate that when models are sufficiently detailed and trustworthy, they can replace traditional 2D documentation on construction sites. However, few studies have examined what needs to happen during the design phase to make models truly construction-ready. Understanding and improving the design-phase processes is, therefore, a critical step in supporting the transition to fully model-based construction workflows.

This thesis addresses that gap by identifying some challenges in MBDD that contribute to the continued reliance on traditional methods rather than supporting model-based workflows on construction sites. By exploring how models should be developed, structured, and managed during the design phase, the study aims to highlight a few potential improvements of MBBB processes supporting the communication of levels of maturity and reliability for downstream use that could make models more construction-ready.

## 1.1. Aim and Problem Statement

The aim of this study is to investigate how model-based design delivery (MBDD) should be structured during the design phase to ensure that BIM models are suitable for effective use in the construction phase.

To achieve this aim, the study addresses the following four objectives:

1. To examine how the absence of drawing scales in BIM influences the interpretation of model detail and design maturity.
2. To investigate whether specifications such as Level of Development (LOD) and Model Maturity Index (MMI) can help address challenges in interpreting model detail and reliability in the absence of drawing scales.
3. To examine the communication and collaboration challenges that persist in using MBDD, despite its potential to improve interdisciplinary coordination.
4. To investigate how limitations in current MBDD practices may contribute to the underutilization of BIM models on construction sites.

By addressing these objectives, the study contributes to the ongoing digitalization of the construction industry and supports the broader adoption of model-based design and construction practices.

### 1.3. Delimitations

This study focuses on exploring the requirements for MBDD to support the future implementation of model-based construction. The research is limited to the design phase and does not directly evaluate construction site practices or the full execution of model-based workflows on-site.

Finally, the study's findings are based on qualitative data gathered through semi-structured interviews and analyzed using thematic analysis. As such, the results reflect the subjective experiences, interpretations, and perspectives of the participants. This means that individual biases or differences in professional background may have influenced how certain challenges or practices were described. To reduce the risk of these biases, participants were selected from a wider range of roles and different companies, and the analysis focused on identifying repeating patterns across multiple interviews rather than drawing conclusions from isolated opinions.

## 2. Method

This chapter presents the research method used to study the role of Model-Based Design Delivery (MBDD) and its impact on the industry. Given the focus of the research questions and the growing interest in model-based workflows across the Swedish construction industry, a qualitative research design was selected as the most suitable approach.

### 2.1 Research design

To explore how MBDD is understood and applied in practice, this study used a qualitative research approach. Qualitative methods are suitable for investigating complex, content-dependent processes where meaning, perception, and experience play a large role (Braun & Clarke, 2013). This research strategy was chosen to support a detailed exploration of how practitioners experience and interpret MBDD. Quantitative methods were considered less appropriate, as relatively few projects have adopted these workflows, and companies may be cautious about sharing detailed operational data in surveys or other means of quantitative data collection. By combining a literature review with semi-structured interviews, the qualitative approach provided a deeper understanding of the topic, grounded in participants' insights and open to new themes that emerged during the study. Given that the interviews aimed to capture experience-based insights from professionals working in the industry, semi-structured interviews were chosen as the primary data collection method, as they offer a flexible but focused approach, allowing us to cover predefined themes while also enabling our respondents to elaborate on issues they consider important (Braun & Clarke, 2013).

As with many qualitative research projects, this study evolved as new insights surfaced during the early stages of data collection. Initially, the research was framed around model-based construction to examine the implementation of Building Information Modelling (BIM) models as the main project document.

However, after conducting the first round of interviews, it became clear that the insights we were gathering primarily related to MBDD. Recognizing this change, we paused to reassess the theoretical framing of this study. Parts of the literature review were then revised to better fit the new theme focused on MBDD, and the second and the third round of interview questions were redesigned to better explore the specifics of this theme.

As a result, the thesis has shifted its central focus from model-based construction workflows on-site to the concept of MBDD in construction projects. This change not only aligns more accurately with the data collected but also enables the thesis to contribute more meaningfully to the academic discussion, where we identified a gap regarding MBDD.

## 2.2 Data gathering

The data gathering process consisted of two main methods: a literature review and semi-structured interviews.

### 2.2.1 Literature review

The literature review was conducted using academic databases such as Google Scholar and the digital Chalmers University Library. Search terms included “model-based design delivery,” “BIM models,” “BIM,” “Level of Development,” “Model Maturity Index,” “digital construction practices,” and “on-site integration challenges.” Additionally, relevant publications, industry reports, and guidelines from professional organizations were reviewed to develop a solid understanding of the technical and practical aspects of delivering BIM models in projects.

Several papers were also identified through citation chaining (also known as citation snowballing), which involves reviewing the reference lists of used papers to locate additional relevant sources. This helped broaden the literature base and covers how we, the authors, gathered some of the literature.

Some of the literature was also provided by the academic supervisor, whose experience in model-based workflows helped guide the review toward material with strong relevance to industry practice.

An initial literature review was carried out to establish a foundation regarding MBDD and closely related subjects. The insights gained from this review helped create the first round of interview questions and provided a broader context for analysing, interpreting, and discussing the study’s findings.

### 2.2.3 Semi-structured interviews

Semi-structured interviews were used as the main data collection method to get hold of experience-based perspectives from industry professionals. A total of twelve interviews were held with eleven respondents (Respondent 2 was interviewed twice, in the first and the second rounds).

The interview process occurred in three rounds:

1. First round: four interviews, February 2025:

Focused on model-based construction practices broadly. Interview questions were structured around the initial research aim, which was model-based construction. The first round revealed that respondents had highlighted Model-Based Design Delivery rather than Model-Based Construction practices. This led us to switch the focus of the research aim towards model-based design delivery because it seemed more common to our interviewees, and the first round helped us identify an interesting gap in the research and industry knowledge.

2. Second round, three interviews, March/April 2025:  
Based on the insights gained from the first round of interviews, questions were refined to focus specifically on Model-Based Design Delivery and collaboration between stakeholders using model-based workflows.
  
3. Third round, five interviews, April/May 2025:  
Based on insights from the second round of interviews, questions were refined to focus more in-depth on the data already found to better support our findings. For example, this round of interviews examined the contractual and legal status of BIM more in depth and examined the Model Maturity Index (MMI) and its application in an infrastructure project.

Participants were selected using purposeful sampling, targeting professionals with experience in BIM, the coordination of BIM, and model-based workflows. Methods included reaching out to earlier contacts from university courses, LinkedIn networking, and direct e-mail communication with professionals known to work with above named categories.

### 2.2.4 Respondents

The participants interviewed in this study represent a mix of professionals from the Architecture, Engineering, and Construction (AEC) industry with relevant experience in BIM and digital workflows. They were selected based on their engagement with model-based practices.

The participants were asked to evaluate themselves or their companies on the BIM Maturity Level according to the model presented by Bew & Richards (2008). *Figure 1* below shows the levels. If the bar spans across two levels, it means that BIM Maturity is dependent on specific projects.

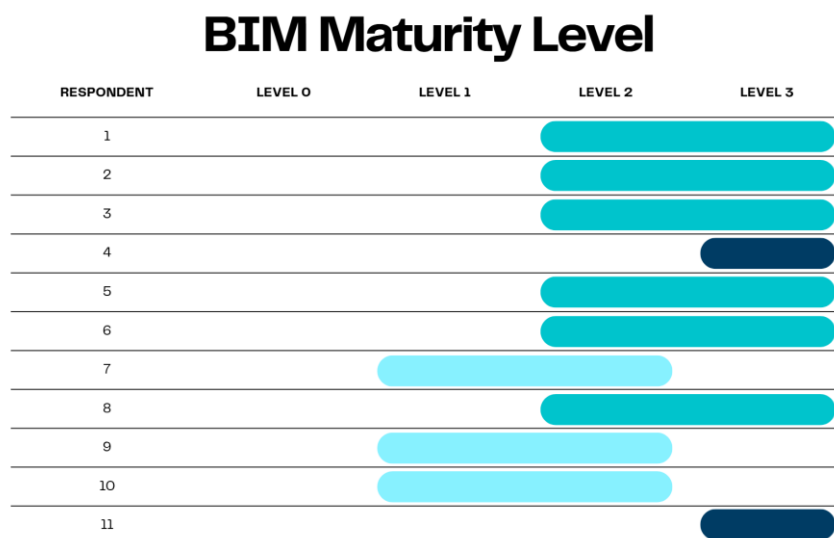


Figure 1. Respondents' own evaluation of their BIM Maturity Levels (Authors' own creation)

Compared to the study by Lidelöw et al. (2023), which shows BIM Maturity Levels across the Nordic construction industry, the sample in this study shows higher maturity. This study benefits from the expertise of its participants; however, it does not therefore reflect the situation across the whole industry.

Their roles of the respondents span from architecture and structural engineering to BIM coordination and strategic development of digital workflows. While all respondents are anonymized and assigned an ID in this thesis, brief profiles are provided below in *Table 1* to contextualize their perspectives and present the width of professional experience contributing to this research.

*Table 1. A brief overview of the respondents involved in this study*

ID	Role	Discipline	Approximate years of experience	Specialization	Length of interview
First Round					
1	Senior digital strategist in an architectural office.	Architect	20 years	Integrating digital design strategies across teams and projects.	1h 27min
2	BIM coordinator/digital construction leader at a large contractor	Structural engineer	10 years	Digital construction platforms (ACC), coordination and implementation of BIM workflows across projects.	1h 25min
3	BIM strategist/team manager in a consultancy firm	Engineer	15 years	BIM adoption and guiding internal workflows based on model-centric processes.	1h 17min
4	BIM Developer in a consulting firm	IT / Civil Engineer	10 years	Aligning construction processes with up-and-coming digital tools. (Experienced with fully integrated model-based construction)	1h 18min
Second Round					
2	Second interview with Respondent 2				20min
5	Digital workflows and BIM developer in a consulting firm	Civil Engineer / Architect	7 years	Collaborative aspects of BIM, developing digital processes that improve efficiency and communication across disciplines.	Through e-mail

6	BIM strategist in a consulting firm	Civil Engineer / Architect	7 years	Development of digital workflows in construction projects, with extra focus on improving model integration and usability.	Through e-mail
Third Round					
7	Construction engineer in a construction firm	Site Engineer	7 years	On-site contractual and project engineering reflects the practical realities of handling, interpreting, and applying BIM in field conditions	50min
8	VDC/BIM Engineer on an infrastructure site	Infrastructure designer	4 years	Responsible for maintaining models on site, planning and scheduling, 4D BIM (construction sequencing)	78min
9	Project manager with insights on contractual and legal questions	Civil engineer	3 years	Responsible for contractual questions regarding projects using precast elements	47min
10	Structural engineer at a precast firm	Structural engineer	3 years	Creation of models and validation of BIM before delivery	43min
11	Specialist in computational design for structural engineering projects	Bridges and special construction design	15 years	Developing and promoting parametric and computational design tools for Structural Design projects, integration of BIM into all project stages	1h 19min

The interviews were conducted during 2025 and mainly via digital platforms, except for three, which were either held at the respondent's office or through e-mail communication. The interviews were mainly conducted in English with a few exceptions, where the interviews instead were held in Swedish due to the respondents feeling more confident in their native language. One respondent did not want to be recorded or transcribed due to security reasons. In this case, we took notes during the interview and received the respondent's written answers after the interview. The length of the interview varied across the data-gathering process. Early interviews tended to be longer, as they were more explanatory and aimed to broadly map out the experiences and data. As the research progressed and patterns were clearer, the following interviews became more focused and targeted. This led to shorter, more structured interview sessions later in the study. This aligns with the flexible and adaptive form of semi-structured interviews, where later interviews can be shaped by the insights gained from earlier ones.

## 2.3 Method discussion

The choice of semi-structured interviews was based on the need to capture experience-based insights from professionals in the industry. This method allowed for both comparability and flexibility, enabling respondents to reflect on the different aspects they had experienced and discuss what they think is relevant regarding MBDD.

By focusing on the respondents already engaged in digital workflows, the study includes MBDD familiar perspectives but may have excluded views from organisations less familiar with MBDD.

An additional strength of the study lies in not basing the investigation on a single case study. While case studies can offer rich detail, they often lock findings to a specific organisational context. In contrast, this study draws from multiple projects and roles, providing a broader perspective more suited to the research aim of identifying general challenges and limitations in MBDD implementation.

The data collection also included a mix of face-to-face, digital, and e-mail-based interviews. While in-person and video interviews followed a conventional semi-structured format, the email interview was conducted back and forth. This format allowed the respondents to reflect more in depth on the questions, often resulting in precise and thought-through answers. Since the email dialogue was ongoing, there was also room for follow-up questions, which reintroduces the depth and flexibility that typically comes from semi-structured interviews. As noted by Opdenakker (2006), email interviews offer participants more time for reflection, often leading to more deliberate and considered responses, despite the absence of immediate interaction.

The email interviews were considered a complementary method in cases where respondents were not able to schedule a face-to-face or digital interview. As supported by Dahlin (2021), email interviews are a possibility in settings where respondents are limited by their time availability. They allow respondents to reflect on their answers, respond at their own pace, and avoid scheduling conflicts. For this thesis, some respondents could not schedule time for an interview, and to ensure that their contributions would not be missed, they were interviewed by email. Email interviews helped us preserve clarity, as the responses were already transcribed. This flexibility in interview methods still aligns with the study's main method of semi-structured interviews.

## 2.4 Data analysis

Before the interviews, several initial themes were identified based on research questions and existing literature. These predefined themes guided the development of the semi-structured interview and were used as an early foundation for assuming possible emerging themes. However, the analysis remained open to new insights, allowing themes to emerge inductively

from the data as well. Which was one of the reasons the aim and scope changed from model-based construction to MBDD.

The interview transcripts were analyzed following a thematic analysis approach from Braun & Clarke (2006). Our process included the following steps: (1) We became acquainted with the interview data. (2) During this phase, preliminary reflections were written down, and segments of the text relevant to emerging or predefined themes were highlighted using color coding. (3) We organized the codes from phase 2 into the predefined themes and created potential new themes that emerged and could be relevant. (4) We reviewed and refined the themes, checking if they accurately represent our gathered data. (5) We defined themes. For example, *How does this theme relate to our research? What is the essence of this theme?* (6) We created narratives of the themes to support the upcoming result and discussion chapters. Quotes are extracted and included in the result to illustrate themes (Braun & Clarke, 2006).

To enable comparison and interpretation, the material was organized by category (e.g., discipline), then by theme, and finally by individual respondents. This gave us an overview of how different perspectives aligned or contradicted each other across professional roles and/or experience. By doing this, the work of choosing what to include and what not to include concerning the aim of our study was clear. The themes then formed the structure for the results chapter and were supported by representative quotes from the interviews. Throughout this process, both authors worked with each transcript and, by themselves, identified themes and sorted data by relevance. After both of us had done this, we compared and discussed the themes identified and how they would relate to the results part.

## 2.5 Ethical Considerations

This study followed the ethical principles for business research as outlined by Bell et al. (2018), which include avoiding harm to participants, ensuring informed consent, respecting privacy, and avoiding deception.

Before each interview, participants were informed about the purpose of the study, their voluntary involvement, and their right to withdraw at any time without any consequences. All participants gave verbal consent to participate. The majority of interviews were recorded with the participants' permission, and the recordings were used solely by the authors for transcription and analysis.

To protect participant privacy and encourage open responses, all interview data were anonymized. Each participant was assigned an ID number (e.g., Respondent 1, Respondent 2), and no identifying information, such as company names or personal details, has been disclosed. Role descriptions have been kept as reported; however, minor adjustments have been made to job titles or descriptions in order to protect individual identities. This anonymization was done to minimize any risk of harm or unintended consequences from participation.

Additionally, a copy of the thesis, along with a detailed list of quotes used from each participant, was sent to all participants for final review. This allowed participants to approve the way their contributions were cited, ensuring transparency and mutual agreement before the presentation of their input.

No form of deception was used during the study. Participants were clearly informed about the scope of the research, and the purpose of the interviews remained consistent throughout the process. All data collected has been handled confidentially, and the results have been reported honestly and transparently, without misrepresentation or selective reporting.

## 2.6 Sustainability

While the primary focus of MBDD may lie in improving coordination and information management, it also holds implications for sustainability, particularly in terms of economic and environmental factors. By enabling more precise planning and coordination, MBDD can reduce the amount of rework needed, which contributes to more resource-efficient projects. This can lower material consumption and save both time and labor, supporting both environmental and economic sustainability.

In connection with the UN Sustainable Development goals, this aligns with Goal 9: Build resilient infrastructure, promote inclusive and sustainable industrialization, and foster innovation. (United Nations, n.d.) MBDD supports innovation by introducing more efficient and digitalized workflows into construction practice.

MBDD also connects to Goal 11: Make cities and human settlements inclusive, safe, resilient, and sustainable. Improved collaboration and transparency support more integrative planning (Target 11.3), while fewer errors and less waste contribute to more sustainable and affordable urban development (Target 11.1) (United Nations, n.d.).

Furthermore, Goal 12: Ensure sustainable consumption and production patterns is supported through the potential of models to improve life cycle assessments (Target 12.2). High-quality models can enable better tracking of materials, support refurbishment planning, and allow for more informed decisions about reuse and deconstruction (United Nations, n.d.).

Although social sustainability is less addressed, MBDD may support healthier working relationships and transparency by improving communication and reducing uncertainties, making collaboration more inclusive.

## 2.7 Usage of AI tools

In the making of this thesis, AI tools were used to support the writing and clarification process. We used OpenAI's ChatGPT to:

1. Clarify academic phrasing and restructure some sections for improved coherence.

2. Explore alternative formulations of definitions and background information related to the subject.
3. Receive suggestions for improving the flow and structure of specific sections, such as the methodology chapter.
4. Reflect on how to present findings more clearly in academic language.

At no point did we rely on AI tools for generating original content, interpreting our interview data, or performing any core research tasks. All analytical conclusions, data interpretations, and structure decisions were made by us, the authors. The interview materials, coding of themes, and the creation of our findings were manually reviewed without AI involvement.

We are fully responsible for the content, quality, and academic integrity of this thesis. AI suggestions were always reviewed and, where appropriate, edited or rejected. No AI-generated content was included without thorough review, and we ensured that no sensitive information was shared with the AI tools.

We have followed the ethical guidelines provided by Chalmers University and have not used AI tools to process company data or information that could compromise participant confidentiality. With this section, the use of AI becomes transparent and always under our final control.

## 3. Literature study

To understand the challenges and opportunities associated with adopting Model-Based Design Delivery (MBDD), this chapter provides a brief overview of the historical development that led to the emergence of MBDD in the construction industry, reviews certain standards and specifications that exist to support the implementation of model-based practices, evaluates the effect of MBDD on stakeholders' collaboration, and highlights a few challenges in integrating model-based workflows to construction sites. This reflects the increasing role of model-based working not just as design tools, but as central communicative and contractual elements in construction projects. By grounding the study in this literature, we aim to contextualize the interviews and findings that follow and clarify the broader transformation affecting the Architecture, Engineering, and Construction (AEC) industry today.

### 3.1 Foundations of Model-Based Design and Construction

The transformation from traditional drawing-based design and construction practices to model-based methodologies marks one of the most significant shifts in the AEC industry (Sacks et al., 2018). Historically, architectural and engineering documentation relied on two-dimensional drawings, which, despite their technical precision, introduced limitations in visualization, coordination, and error detection. The usage of digital modeling, primarily through Building Information Modelling (BIM), has the potential to change how projects are conceived, planned, and executed. BIM functions both as a process and a tool, enabling a structured digital representation of a building's physical and functional characteristics that support collaborative workflows (Succar, 2009). BIM as a tool serves primarily as a digital information system that provides a centralized storage for project data, enhances visualization, automates information retrieval, and integrates different functions of construction management (Succar, 2009). It can be used for clash detection, quantity take-offs, scheduling (4D), and cost estimation (5D), which enhances efficiency in managing construction workflows (Porier et al., 2017). On the other hand, BIM as a process can be explained as a collaborative framework that integrates multiple disciplines, unifies workflows, and fosters better communication among project stakeholders (Sacks et al., 2018). By establishing a common data environment (CDE), BIM as a process reduces the excess of data, streamlines decision-making, and ensures that all participants work with up-to-date information (Porier et al., 2017). Despite its potential, the practical implementation of BIM varies significantly across projects due to differences in technological capabilities, adoption strategies, and industry standards (Lidelöw et al., 2023).

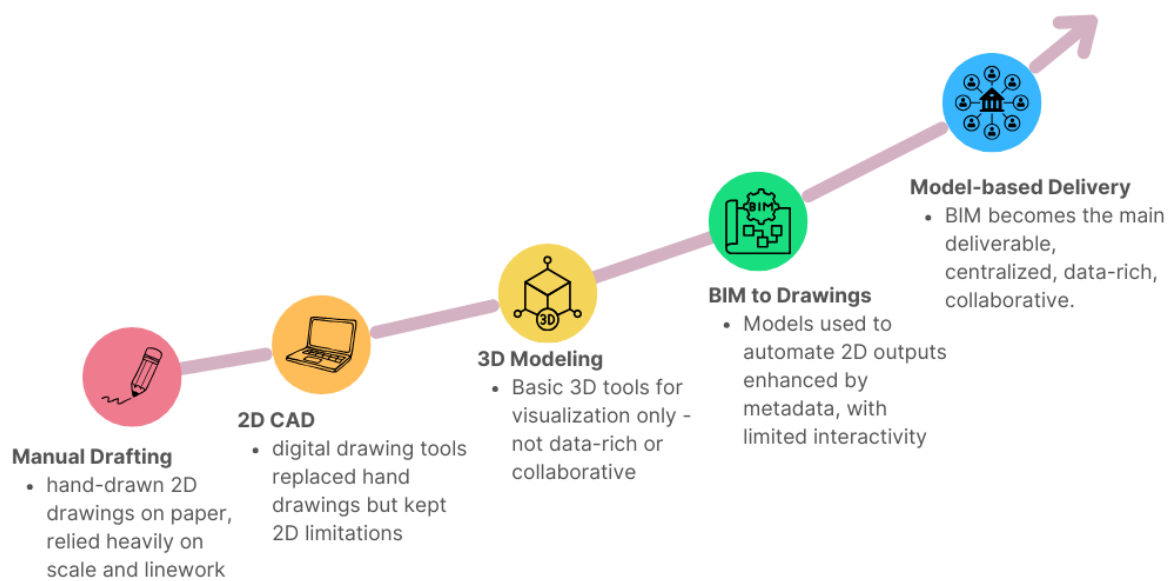
#### 3.1.1 Historical development of architectural drawings

By the 20th century, technical drawings had become somewhat more standardized, allowing for greater precision and consistency in communication. However, the fundamental constraints of 2D documentation, especially in large-scale projects, became evident as designs grew more complex. Errors arising from misinterpretations, disjointed workflows, and difficulties in maintaining version control led to inefficiencies, cost overruns, and disputes among

stakeholders (Volk et al., 2014). The introduction of Computer-Aided Design (CAD) in the 1980s improved drafting efficiency by digitizing the drawing process, but it did not fundamentally change the nature of construction documentation; CAD remained primarily a digital replication of manual drafting (Sacks et al., 2018).

### 3.1.2 Evolution of Project Documentation

A summary of the evolution of project documentation in the construction industry is presented in *Figure 2*, followed by paragraphs explaining each stage of the process.



*Figure 2. A visual presentation of the evolution of project documentation (Authors' own creation)*

#### Paper-based workflows to CAD

The initial step in digitalization was the adoption of CAD, which replaced manual drafting with vector-based digital drawing tools. Despite increasing efficiency, CAD remained a two-dimensional toolset replicating paper-based workflows in digital format (Sacks et al., 2018). Designers created digital drawings that were ultimately printed and shared as static paper documents. Coordination, revisions, and clash detection remained manual and error-prone, as these 2D outputs lacked embedded data and spatial relationships.

#### 3D Modeling to paper-based output

Before the full emergence of BIM, 3D modelling tools were used primarily for form making and visualization in construction. These tools allowed designers to create three-dimensional representations of buildings. However, these models were largely geometric and lacked the semantic data added to the elements. As a result, their use was limited to generating static visual outputs, often exported to paper drawings or rendered images for presentations, planning approvals, or construction documentation (Melendez, 2019). Outputs were typically flattened into PDFs or images, which reintroduced interpretation risks and did not facilitate automation or cross-disciplinary collaboration. As such, while 3D modeling marked a step forward in

representation, it remained disconnected from the lifecycle and informational richness that BIM would later provide (Schreyer, 2023).

### **BIM to paper-based outputs**

The introduction of BIM brought depth to the models by embedding data within graphical representations. However, in many projects, BIM has been used primarily to automate the production of 2D drawings, underutilizing its full capacity as a collaborative and data-rich environment (Aibinu & Papadonikolaki, 2020). The model often functions as a back-end tool to generate traditional deliverables, rather than as a central communication platform during the design and construction process (Kim et al., 2022). This tendency is driven by long-standing legal frameworks, contractual norms, and client expectations that prioritize 2D documentation, even when a comprehensive digital model exists. As a result, the benefits of BIM are frequently sidelined in favor of conventional workflows.

### **BIM to digital drawing sets**

A partial departure from printed documentation was achieved through the delivery of digital 2D drawings (e.g., PDFs or DWGs) extracted from BIM models (Aibinu & Papadonikolaki, 2020). Although this approach reduced printing and allowed for digital review and markup, it maintained the separation between object data and communication tools. Even though some platforms allow for the object data to be integrated in the exports, this potential is often underutilized. These digital drawings, while more accessible, continued to fall short in conveying the full richness and context embedded in the model, limiting opportunities for automation and real-time collaboration (Ahmed, 2022). Furthermore, this strengthens a broader transformation discussed by Whyte (2019), who argues that despite increased digital maturity, many project environments still rely on document-based processes, which constrain the shift to more dynamic and integrated processes that BIM seems to provide.

### **Model-based design delivery**

The current evolution of project documentation is moving toward a full MBDD, where BIM itself is the primary source of information throughout the project lifecycle. In this workflow, the model, not the drawings, carries all relevant information, from geometry to specifications to scheduling data (Brooks et al., 2022). Projects employing this method utilize the model directly for coordination, quantity takeoffs, and on-site decision-making, often eliminating the need for separate 2D drawing sets. Cloud platforms and CDEs facilitate real-time access, and digital views are customized directly within the model, enhancing efficiency and reducing misinterpretation (Disney et al., 2023).

This shift aligns closely with the principles of MBDD, where digital models are used not just as a design tool, but as a contractual and communicative tool across disciplines. By embedding structured data and aligning with standards such as ISO 19650 and Industry Foundation Classes (IFC), models become interoperable, verifiable, and actionable for “downstream” users, including contractors, manufacturers, and facility managers (Swedish Standards Institute, 2024; Nour El-Din et al., 2022).

### Implications for design practice

The evolution from CAD to full BIM-based delivery has implications for the design process. Model authorship extends beyond graphical representation to include data structuring, version control, and compliance with specifications of model readiness (e.g., Level of Development (LOD), Model Maturity Index (MMI)) (Garcia, 2017). The design model becomes a live iterative product that responds to input from multiple disciplines, allowing for earlier clash detection, better informed decisions, and increased coordination (Volk et al., 2014).

However, this transition is not without its challenges. As Disney et al. (2022) note, many professionals still rely on 2D drawings because of legacy workflows, contractual requirements, and software limitations. Confidence in using the model as the single source of data remains an issue in some organizations; barriers must be addressed through training, technological investment, and cultural change.

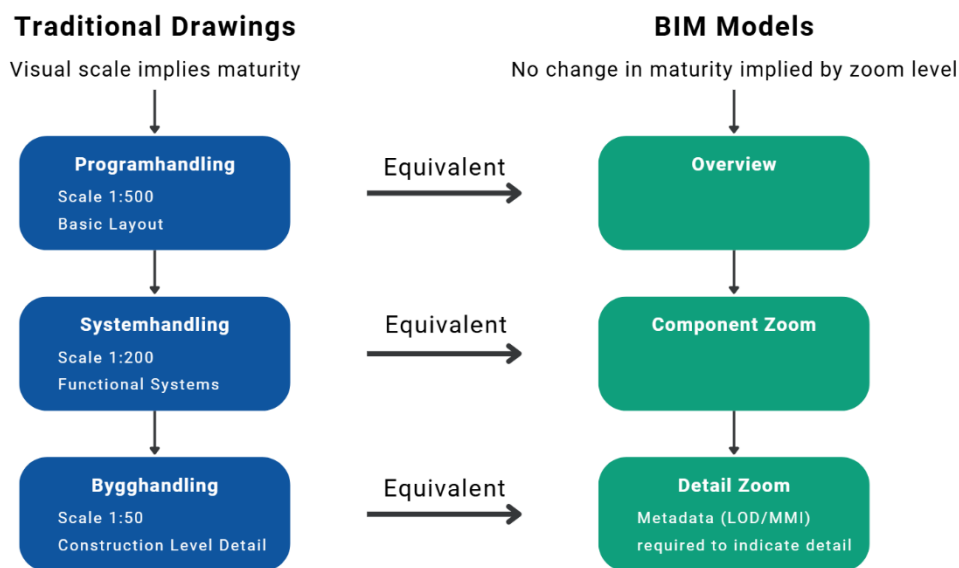
### 3.1.3 Challenges with scale and representation of detail in BIM

One of the challenges associated with MBDD is the interpretation of scale in the BIM models. In traditional architectural representation, drawing scale acts as an implicit control mechanism and allows us to structure the documentation in representational hierarchies governing the type of information presented and the level of trust a viewer places. (Evans, 1995) A floor plan at 1:100 is understood to communicate spatial layout and general design intent, while a 1:5 detail is associated with fabrication-level resolution. This hierarchical structure allows drawings to serve not only as geometric references but also as communicative filters that constrain the viewer's interpretation according to representational intent (Bayhan et al., 2023).

An example of how scale and representational detail are managed in traditional drawing-based workflows is found in the Swedish planning and design process, which is structured around three phases: *Programhandling*, *Systemhandling* & *Bygghandling* (SIS, 1990). While this structure originates from the drawing-based standards outlined in *Bygghandlingar 90* in SIS (1990), it continues to influence expectations today. The scale is adapted to the different phases of the project, where drawings need more detail and therefore a lower scale. Each of these phases carries expectations regarding the detail, reliability, and completeness in the project documentation, typically communicated through the drawing scale. For instance, early-stage drawings (Programhandling) might be produced at 1:1000 or 1:500, to communicate general layout and functional relationships, while more developed drawings, systemhandlingar, usually use 1:200. Finally, construction documentation (Bygghandling) would be expected at 1:50 or finer, showing high resolution and construction-ready elements.

In contrast, BIM models are flexible in scale and are devoid of these scale-based boundaries. Users are free to zoom into any part of the model, regardless of the actual maturity of its content, often without semantic cues to indicate whether a given component has been developed to a schematic or detailed level (Blanchard, 2022). The author observes that BIM's

adjustable zoom “destabilizes the visual hierarchy” traditionally enforced by scale, opening the model to misinterpretation and premature reliance. This condition is intensified in federated models, where contributions from different teams may vary in maturity, and visual detail is often mistaken for completeness unless clearly annotated through metadata or linked documentation (Abualdenien & Borrmann, 2022). In *Figure 3*, an example of how to interpret maturity in traditional drawings vs. BIM is shown. Additional illustrations are included in the *Appendix*, featuring real-world examples comparing traditional 2D drawings with their BIM counterparts. These visualizations help clarify how apparent visual detail in BIM can be misleading when not accompanied by explicit maturity indicators.



*Figure 3. A visual interpretation of how scale implies maturity in the Swedish design process vs. BIM (Authors' own creation)*

The challenge of interpreting model maturity becomes more critical as models grow in visual detail (Abualdenien & Borrmann, 2022). Current BIM visualizations often appear precise, even in early stages, leading users to mistakenly treat placeholders as finalized content. Beyond the visual accuracy that BIM offers, one challenge lies in its inability to continuously differentiate between provisional and finalized design data (Abualdenien & Borrmann, 2022). Unlike traditional 2D drawings, where line weights, annotations, and scale hierarchy communicate implicit expectations, BIM's 1:1 scale could lead to over-interpretation of immature elements. The authors demonstrate that visualizing vagueness and maturity in BIM models remains an unsolved problem.

At a strategic level, BIM implementation frameworks often fail to articulate representational expectations across different LODs (Garcia, 2017). This gap leads to inconsistent interpretations of LODs by different project stakeholders, increasing the risk of miscommunication during interdisciplinary collaboration.

## 3.2 Standardizing BIM: Specifications, Models, and Implementation

As BIM adoption increases, the establishment of technical standards and definitions is essential for ensuring consistency and interoperability across projects. Various industry organizations and regulatory bodies have developed specifications, guidelines, and best practices to standardize how BIM is implemented. These include the IFC, LOD, Level of Information Need (LOIN), MMI, and BIM maturity models. The evolution of these technical definitions has played a role in guiding the digital transformation of construction practices (Becerik-Gerber & Kensek, 2010).

The effective implementation of MBDD relies on well-defined technical standards and specifications that guide industry interoperability, data consistency and project coordination. BIM standardization efforts aim to provide a common language and that enables collaboration across different disciplines, platforms and environments (Poljanšek, 2017).

One of the most widely adopted BIM standardization frameworks is ISO 19650, which establishes guidelines for information management in projects. It aligns closely with IFC, which enables interoperability between different BIM tools (i.e., open BIM) (Nour El-Din et al., 2022). This chapter explores some of the frameworks and specifications addressing the challenges connected to the interpretation of detail and model maturity in BIM deliverables.

### 3.2.1 BIM Maturity models and adoption

Several BIM maturity models have been developed to assess the degree of BIM integration in organizations and projects. Among the most widely used is the Bew and Richards BIM Maturity Model, which categorizes BIM adoption into four levels (Bew & Richards, 2008):

- Level 0: Reliance on manual processes and 2D CAD drawings with no collaborative data sharing.
- Level 1: Partial collaboration with 3D modeling used in some disciplines, but without standardized data exchange.
- Level 2: Object-based 3D modeling with coordinated workflows and structured data-sharing through formats such as IFC.
- Level 3: Full integration with real-time collaboration across disciplines using a CDE and fully digital workflows.





Similarly, BIM maturity could be described based on collaboration levels, where Level 3 represents real-time, interdisciplinary integration (Bensalah et al., 2018, as cited in Ahmed, 2022). According to Succar (2009), the use of maturity models is essential for measuring BIM performance, guiding decision-making, and ensuring that organizations can fully realize the benefits of BIM at scale. Higher BIM maturity levels correlate with cost reductions, efficiency gains, and improved project coordination, but achieving higher levels of BIM integration requires significant investments in training, workflow restructuring, and infrastructure upgrades (Lidelöw et al., 2023).

### 3.2.2 Level of Development (LOD)

LOD is a standardized specification that defines the completeness and reliability of BIM model elements at different stages of a project (Sacks et al., 2018). It serves as a specification for assessing the level of geometrical detail and information in BIM. Rather than focusing solely on the graphical accuracy of a model, LOD evaluates how well the data represents real-world conditions. It helps project teams and stakeholders define expectations at various stages of a project, guiding contractual agreements and ensuring clarity on deliverables. (Garcia, 2017). For instance, while an engineering team may not require a highly detailed visual representation of a piece of equipment, they do need essential specifications such as its manufacturer, model number, and dimensions to facilitate procurement and installation.

Originally developed by the American Institute of Architects (AIA), the LOD specification ensures that BIM components have the necessary graphical and non-graphical information required for different phases of design, construction, and operation (BuildingSMART International, 2021). By definitions from BIMForum (2024), the LOD system consists of six incremental levels, an example of which can be observed in *Table 2*:

*Table 2. Explanation of different LODs in BIM models*

LOD Level	Description	Use Case	Graphical example from BIMForum (2024), structural column
LOD 100	Symbolic model elements or placeholders. No detailed geometry.	Early concept design, feasibility	Symbol
LOD 200	Approximate geometry with basic size, shape, and location info.	Schematic design, massing studies	
LOD 300	Accurate geometry and essential non-graphical data for coordination.	Design development, quantity takeoffs	
LOD 350	Includes interfaces and accurate connections with other building elements.	Trade coordination, clash detection	
LOD 400	Detailed enough for fabrication and installation (like shop drawings).	Prefabrication, construction	
LOD 500	As-built condition verified in field. Final, accurate representation.	Operations, facility management	As-built model

These levels help standardize BIM expectations across project phases, ensuring that stakeholders understand the LOD required at each stage. The application of LOD is critical in ensuring model consistency, interoperability, and usability across design, construction, and maintenance workflows (Sacks et al., 2018).

Despite its usefulness, LOD presents several challenges when applied in practice. According to Garcia (2017), some major issues are its emphasis on the presence of information rather than the quality or approval status of that data, which makes it difficult to ensure that models reflect accurate and validated inputs at different project phases. Additionally, LOD does not clearly define responsibilities among various disciplines, often leading to confusion regarding ownership of different modeling elements. Another limitation is the level of granularity required for tracking, as the Unifomat classification system necessitates monitoring progress at the individual component level, making implementation time-consuming. (Garcia, 2017)

As a reaction to the existing limitations of LOD, recent developments have introduced the concept of LOIN, as defined in ISO 7817-1:2024. LOIN ensures that only the required information is delivered at the right time and for the right purpose, preventing excessive or unnecessary data (Swedish Standards Institute, 2024). This framework consists of geometrical information, alphanumeric information, and documentation. Together, this defines the necessary data granularity for a given project stage. The definition of LOIN highlights the necessity of structuring data, delivering milestones, and defining the required information granularity for different project stages, enabling efficient information exchange. Lindholm et al. (2025) further show that integrating LOIN with construction production planning through CDEs can enable real-time verification of information deliveries, enhance collaboration, and enable sufficient data-centric workflows in projects.

### 3.2.3 The Model Maturity Index (MMI)

To address the shortcomings of the LOD specification, the research from Garcia (2017) proposes the MMI as an alternative approach to tracking progress in model-based engineering. Unlike LOD, which primarily focuses on graphical representation and available information, MMI incorporates both visual and non-visual data, allowing for a more comprehensive assessment of model maturity. The paper also notes that the existence of multiple LOD-based workflows across different industries and regions has contributed to inconsistency and confusion. MMI aims to streamline this process by offering a clearer, more structured methodology, particularly for measuring engineering productivity and ensuring accurate tracking of modeling progress. MMI provides a more comprehensive approach to assessing BIM completeness, data richness, and usability (Garcia, 2017).

Garcia (2017) introduces the MMI as a structured coding system for evaluating the progression and quality of model-based engineering. Unlike conventional percentage-based tracking methods, with 30%, 60%, 90% of completion, which leave a lot of room for interpretation and misunderstanding, MMI offers discrete levels (MMI 100-600) to define the maturity of modeled components across disciplines. This system enhances the clarity and consistency of model review processes by integrating both graphical and non-graphical data into the assessment.

The MMI specification categorizes model maturity into seven defined levels: MMI 100, 200, 300, 350, 400, 500, and 600. Each level represents an increasing degree of detail, validation, and approval of modeled components. It integrates data quality, interdependencies between disciplines, and verification stages as key factors in assessing model readiness (Garcia, 2017). This ensures that progress in model-based engineering is not merely measured by visual detail but by the completeness, accuracy, and usability of engineering information.

Figure 4 offers a visual comparison of LOD, MMI, and LOIN:

Criteria	LOD	MMI	LOIN
Main focus	Graphical + informational level	Readiness+ verification level	Delivering only the information needed
Structure	LOD 100-500	MMI 100-600	Geometry + data + documentation
Driven by	Visual & data detail level	Verification + status	Use case based requirement
Strength	Easy to apply in project phases	Tracks readiness & approvals	Prevents info overload and unnecessary data
Limitation	Does not track quality or usage responsibility	Not widely adopted or standardized	Requires well-defined metadata and intended use
Best used for	Defining expectations during design and development	Model publishing, internal validation, and progress tracking	Targeted data delivery (e.g. for facility management, or bids)

Figure 4. A visual comparison of LOD, MMI, and LOIN (Authors' own creation)

### 3.2.4 Challenges in the implementation of the specifications

The implementation of BIM standards and definitions is not without challenges. While specifications like LOD, MMI, and BIM maturity models provide clear guidelines, their real-world application varies across projects and organizations (Becerik-Gerber & Kensek, 2010). Key barriers to the standardization of BIM include:

- Lack of industry-wide agreement on BIM definitions and workflows, leading to inconsistencies in model development.
- Challenges in achieving full interoperability between different BIM software due to proprietary formats and data exchange limitations (Afsari et al., 2017).ch
- The need for extensive training and skill development, as many professionals still lack the expertise required to work with advanced BIM models (Gu & London, 2010).

The apparent solutions to some of the challenges in the standardization of BIM, especially regarding communication of model development and maturity, lie in specifications like LOD and MMI. However, they come with their implementation challenges. In a case study performed by Hooper (2015), the following errors with LOD were identified:

- First, an excessive amount of irrelevant, outdated, or incorrect information clutters models, making it difficult to distinguish essential details from unnecessary content.
- Second, the use of overly versatile objects, intended to accommodate all possible scenarios, often results in cumbersome, impractical elements that hinder usability rather than enhancing it.
- Third, the absence of standardized industry-wide solutions leads to a reliance on quick-fix, reactive measures to meet deadlines, which compromise efficiency and model quality over time.
- Finally, while individual checklists help streamline personal workflows, the lack of standardized routines, processes, and data formats prevents the full benefits of BIM from being realized, limiting opportunities for knowledge reuse and digital integration.

The standardization of BIM data through standards like IFC and open BIM standards has played a crucial role in enhancing interoperability (Gu & London, 2010). IFC, developed by buildingSMART International, allows for the exchange of model information across different BIM platforms, ensuring compatibility between software such as Autodesk Revit, Bentley Systems, and ArchiCAD (BuildingSMART International, 2021). Furthermore, the Swedish Transport Administration (STA) has adopted IFC (ISO 16739-1) as the central standard for exchanging data about physical infrastructure, aligning with its long-term goal of machine-readable data and automated quality control (Nordic Road and Rail BIM Collaboration, 2022).

Another aspect that challenges the wider adoption of BIM workflows is that, in most cases, BIM is not a legally recognized documentation form. Disney et al. (2022) mentioned projects where, even though the process of producing 2D drawings is deemed inefficient, it is still a legally binding document. In this case, the benefits of BIM are invalidated by the need to produce 2D drawings and the additional labor spent on it. "Indeed, currently most designers create 3D data models rich in information that do not reach the construction site." (Disney et al., 2022)

### 3.2.5 BEAst delivery requirements

The purpose of "BEAst BIM" is to create a structure of how to handle data and information when working with BIM. Information provided by BEAst was created through collaboration with the construction industry in Sweden. In the early stages, BEAst outlines guidelines for delivering BIM models during early project phases. The models should be provided as an integrated part of the tendering documentation and must include all relevant building bodies. Deliverables should be in the original CAD file format, IFC format (version 2x3 or 4), and PDF according to specific guidelines established by BEAst. IFC models should include the correct property sets, notably Building Information Properties (BIP) and base quantities (BEAst, 2023).

Quality assurance of the delivery involves ensuring models are free from internal clashes, duplicated elements, and unwanted items. Material layers must be exported as solid objects,

and all required object information as specified by the guidelines must be carefully verified before submission (BEAst, 2023).

Export requirements specify the correct use of IFC entities according to the applicable IFC standards for enabling consistency in geometries or object parameters. Specific building components have corresponding IFC entities; for example, slabs use IfcSlab, walls use IfcWall, and doors use IfcDoor (BEAst, 2023).

### 3.2.6 AB 25

In Sweden, at the time of writing this thesis, the Swedish Construction Contracts Committee (BKK) launched proposals for new standard contracts intended to replace AB 04 and ABT 06 (Byggandets Kontraktskommitté, 2024). The proposed contracts have been named AB 25 and ABPU 25. These contracts are currently subject to a public consultation period lasting until Spring 2025, to present final versions by the summer of 2025. One of the key updates in the proposed new standard contract is a clear focus on digitalisation (Söderström, 2024). The key preliminary suggestion is to put the digital model above drawings and documents in the hierarchy of legal compliance. Furthermore, AB 25 introduces new regulations regarding the use of digital models and rules for how these should be managed throughout the entire construction process. It is not just about providing digital documents, but also ensuring that they are accessible, traceable, and used by all parties. This is a step forward from AB 04, which lacked this type of specific regulation for digital information flow.

## 3.3 Stakeholder collaboration

BIM significantly enhances stakeholder collaboration, communication, and project coordination by centralizing project data and enabling real-time updates. However, its successful implementation requires overcoming challenges such as interoperability issues, training gaps, legal uncertainties, and resistance to change. This section explores how BIM influences interdisciplinary collaboration, the shifts in stakeholder roles, and the key challenges affecting its successful implementation.

While full integration of BIM across the construction industry could be seen as an aspiration, its adoption in specific projects has reshaped collaboration, especially among design disciplines (Linné, 2019). Traditional AEC workflows were often characterized by fragmented communication, with stakeholders operating in silos using disconnected information (Succar, 2009). BIM adoption alters stakeholder roles, workflows, and responsibilities, necessitating new approaches to project management and collaboration (Azhar et al., 2012). Moreover, BIM introduces a centralized, real-time data sharing environment that enables better coordination. In some projects, BIM was not just a technical tool but also a process for new stakeholder collaboration and integrated work practices (Linné, 2019). The case highlighted by Linné (2019) shows BIM's potential to change how key project stakeholders interact, especially during the design and planning phase. Even if its broader industry-wide change remains uneven

(Volk et al., 2014), it shows that there is literature supporting BIM and its role in positively affecting collaboration between stakeholders (Linné, 2019).

### 3.3.1 Digital collaboration and communication

BIM adoption has reshaped stakeholder roles by enabling centralized data sharing platforms and improving interdisciplinary collaboration (Zakeri et al., 2023). However, research suggests that resistance to digital transformation remains a significant barrier, especially among construction professionals accustomed to 2D documentation (Okakpu et al., 2022). Studies indicate that early-phase stakeholder engagement is crucial for reducing miscommunication risks and optimizing workflow efficiency (Wang et al., 2022).

BIM enhances interdisciplinary communication by serving as a shared knowledge resource, reducing the risk of “data silos” created for separate disciplines and enabling real-time collaboration (Linné, 2019). Traditional project management relied on 2D static drawings and isolated document exchanges, which often led to misinterpretations and coordination errors (Poirier et al., 2017). BIM offers the possibility of using cloud-based collaboration platforms that, if used correctly, can integrate project data into a unified model, ensuring that all stakeholders work with the latest information (Azhar et al., 2012).

Through BIM collaboration environments such as CDEs, stakeholders can simultaneously update and review models, ensuring that decisions are made based on the most current project data (Volk et al., 2014). These platforms also reduce the need for redundant manual inputs, streamlining workflows and improving decision-making processes (Succar, 2009). Research has shown that early stakeholder involvement in BIM projects leads to more effective collaboration, as teams align their expectations, workflows, and deliverables from the project’s outset (Poirier et al., 2017). However, some challenges persist, including reluctance to share proprietary information, concerns over intellectual property rights, and the need for standardized data formats to facilitate seamless interoperability (Azhar et al., 2012).

### 3.3.2 Shifts in stakeholder roles and responsibilities

The transition to BIM reshapes the traditional roles of stakeholders in construction projects. Historically, architects focused primarily on design intent, engineers worked in discipline-specific silos, and contractors interpreted drawings with limited integration across disciplines (Azhar et al., 2012). BIM fosters greater interdependency between stakeholders, requiring a more collaborative approach to project execution (Volk et al., 2014).

Architects and designers must now create parametric 3D models that integrate structural, mechanical, and environmental data if the models are going to be used as the main delivery document. (Sacks et al., 2018) Their role extends beyond drafting, requiring a proactive approach to model coordination. Engineers increasingly use BIM for real-time clash detection, simulations, and performance analysis such as energy modeling and structural integrity testing

(Poirier et al., 2017). This expands their role in data-driven decision-making, moving beyond traditional calculations to ensure model accuracy. Contractors and construction managers rely on 4D scheduling for time simulation and 5D cost estimation, making their involvement in model coordination crucial (Azhar et al., 2012). BIM enables virtual construction planning, reducing waste and optimizing logistics before materials reach the site (Volk et al., 2014). Facility managers utilize BIM models post-construction for facility management, maintenance, and lifecycle monitoring, ensuring that operational teams have access to accurate as-built information (Succar, 2009). This assists in asset tracking, predictive maintenance, and renovation planning.

Despite these improvements, the shift in roles requires significant training and process adaptation. Many industry professionals lack the digital skills necessary to fully leverage BIM capabilities, highlighting the need for ongoing professional development and education initiatives (Poirier et al., 2017).

### 3.3.3 Barriers and challenges in BIM collaboration

While BIM can improve stakeholder collaboration, several barriers and enablers affect its successful integration into AEC projects. Interoperability issues persist due to different stakeholders using various BIM software platforms, leading to data exchange limitations (Succar, 2009). Many construction professionals are accustomed to traditional workflows, making it difficult to transition to fully digital BIM workflows (Volk et al., 2014). This is particularly evident among smaller firms with limited resources for training.

Legal and contractual uncertainty is another challenge, as the collaborative nature of BIM introduces questions about intellectual property, liability, and data ownership (Azhar et al., 2012). There is often uncertainty about who is responsible for errors in a shared BIM model. Implementation costs can also be a prohibitive factor. The initial investment in BIM software, training, and infrastructure can be significant (Poirier et al., 2017). While the long-term benefits outweigh these costs, many organizations struggle with the upfront financial burden. Since BIM involves cloud-based collaboration, concerns over data security, cyber threats, and unauthorized access remain significant (Gu & London, 2010). Ensuring secure data-sharing mechanisms is essential for widespread adoption.

### 3.3.4 Strategies for effective BIM collaboration

A case study on a hospital construction project in Norway provides valuable insights into the factors enabling effective digital collaboration in BIM projects (Merschbrock & Munkvold, 2015). The study revealed that a well-defined BIM infrastructure played a crucial role in enabling collaboration. The establishment of digital collaboration frameworks, supported by shared protocols for data management and communication, allowed project stakeholders to easily interact with BIM models. The implementation of a CDE provided a centralized archive of information, which enabled real-time updates across disciplines and minimized data

inconsistencies. Another key enabler was the integration of BIM-specific contractual agreements. Traditional construction contracts often fail to reflect the collaborative nature of BIM workflows, which could lead to doubts about model ownership and information exchange. The case study highlighted the significance of contracts that explicitly define responsibilities, data sharing protocols, and decision-making processes. By establishing “legal clarity” on these aspects from the start, project teams were able to mitigate delays, reduce liability concerns, and prevent coordination bottlenecks.

Furthermore, enabling a “BIM learning culture” was a critical component in ensuring effective collaboration (Merschbrock & Munkvold, 2015). The project underscored the importance of continuous training, digital learning platforms, and cross-disciplinary coordination meetings to promote knowledge sharing and adoption of best practices. Their findings illustrate that effective BIM collaboration requires an alignment of technical, contractual, and educational elements. A combination of structured BIM infrastructure, clearly defined contract models, and continuous professional development ensures efficient model coordination.

### 3.3.5 LOD as a collaboration tool

The LOD specification plays a crucial role in enhancing collaboration and communication among stakeholders in a BIM-enabled construction project. “LOD also determines the reliability of the geometric and alphanumeric information stored in the model element. This meta-information is an important basis for collaborating with other planning disciplines and for the assessment of the planning progress by the client and the construction companies.” (Abualdenien & Borrmann, 2022) One of the key challenges in collaborative environments is ensuring that all parties accurately interpret model information. The LOD specification addresses this issue by establishing a standardized method to define the development and reliability of different model elements, mitigating misinterpretations and enhancing coordination (BIMForum, 2024).

During the design and construction phases, project elements evolve from conceptual ideas to detailed specifications. Without a clear indicator of where the elements are along the path, different stakeholders may make assumptions about the accuracy and usability of model data, potentially leading to errors. The LOD specification lowers the possibility for misinterpretation by providing a structured classification for elements at various stages of development, ensuring that all users understand the intent and reliability of the presented data. (BIMForum, 2024) An article evaluating real-life case studies by Alshorafa & Ergen (2021) provides examples of why defining the appropriate LOD from the start is essential, as unclear or inconsistent definitions can lead to misunderstandings, rework, and increased costs, arguing for the need for a structured classification system that ensures stakeholders interpret data accurately.

Moreover, the visual consistency of BIM models can create misleading perceptions of precision. Unlike traditional hand-drawn schematics, where the level of detail is often inferred from the drawing style, in BIM models, incomplete or approximate elements might look

exactly like finalized components. (BIMForum, 2024) The LOD specification clarifies these distinctions, enabling stakeholders to differentiate between elements that are conceptual, approximate, or finalized. This explicit definition enhances decision-making and reduces the risks of miscommunication. (BIMForum, 2024)

Another significant advantage of LOD is its ability to prevent the premature extraction of unreliable information. “It is possible to infer or extract information from BIM that the author doesn’t intend - unconfirmed dimensions can be measured with precision, assembly information often exists before it’s been finalized.” (BIMForum, 2024) Traditional disclaimers argue against reliance on BIM data, often creating confusion and hindering trust in the model. By contrast, LOD allows model authors to specify exactly what aspects of the model can be relied upon, fostering greater transparency and accountability in collaboration (BIMForum, 2024).

Additionally, in collaborative environments where multiple stakeholders rely on the BIM model to guide their workflows, the timing of information availability becomes critical. The LOD specification supports structured project planning by defining when different levels of model detail will be available. (BIMForum, 2024) This enables architects, engineers, and contractors to align their schedules, accordingly, streamlining project coordination and reducing inefficiencies. The case studies executed by Hooper (2015) observed this effect of LOD specifications in real-life practice. In his conclusion, Hooper (2015) states that: “The main contribution is insight into how LOD can be applied expediently and awareness of the need to structure digital content to facilitate real-time cross-checking with scheduled deliverables. This knowledge is important to enable BIM information authors to align information deliveries or data drops with the expectations of downstream users.”

By standardizing the interpretation and use of BIM data, LOD significantly enhances interdisciplinary communication, ensuring that all stakeholders have a shared understanding of model reliability. This structured approach minimizes errors, optimizes workflow integration, and facilitates a more transparent and efficient collaboration process throughout the construction lifecycle (BIMForum, 2024).

### 3.4 Integration of BIM into construction sites

Integrating BIM into on-site construction practices presents various challenges. These include technical issues, organizational factors, and human-centered obstacles that affect implementation efficiency. The transition from traditional methods to BIM-based workflows requires adaptations in how models are handled, displayed, and interpreted on construction sites (Ghaffarianhoseini et al., 2017). Understanding these challenges is crucial to ensuring that BIM technology translates into practical improvements in project execution.

### 3.4.1 Handling and interpretation of digital models in on-site environments

One of the primary challenges in BIM adoption on construction sites is the practical handling and visualization of digital models. Unlike office-based environments, construction sites require real-time access to BIM models under conditions that are often dynamic and unpredictable (Pan & Zhang, 2021). Many construction teams rely on mobile devices such as tablets and AR tools to access BIM data, yet several limitations hinder their effective use.

Beyond technical constraints, digital literacy among on-site workers also affects BIM adoption. Many experienced professionals have developed expertise in traditional workflows and may struggle to transition to fully digital methods (Ghaffarianhoseini et al., 2017). Printed drawings continue to be used alongside digital models, creating potential inconsistencies between different sources of information. To ease these challenges, Ghaffarianhoseini et al. (2017) suggest that companies invest in training programs tailored to construction site teams, ensuring that workers understand how to interpret and interact with BIM models in real-world conditions.

### 3.4.2 Real-time model updates and synchronization

For BIM to be effective on-site, real-time updates must be reliably synchronized between different project stakeholders. However, maintaining up-to-date model information is challenging due to unreliable internet access, slow data transfer speeds, and limitations in cloud-based storage infrastructure (Pan & Zhang, 2021). Disruptions in synchronization can result in construction teams working with outdated model information, increasing the risk of rework, delays, and errors.

Recent advancements in 5G technology and improved cloud computing infrastructure offer potential solutions to enhance real-time model accessibility. Automated updating systems have also been developed to improve synchronization, ensuring that construction workers always have access to the most current project data (Wang et al., 2024). In addition, AI-driven anomaly detection tools are increasingly being integrated into BIM workflows to show inconsistencies between planned designs and on-site progress, allowing for proactive error resolution. Despite these innovations, the effectiveness of digital updates remains dependent on seamless integration with construction site workflows and the ability of teams to quickly adapt to evolving data.

### 3.4.3 User interface design and accessibility challenges

The complexity of BIM software interfaces presents another significant obstacle in its practical application on-site. Many BIM platforms were originally designed for use by architects and engineers in office environments, requiring technical expertise that site workers and field engineers may not have received (Ghaffarianhoseini et al., 2017). Traditional BIM applications often include a broad range of functionalities, making them unintuitive for non-expert users.

This complexity reduces overall efficiency in digital model interactions and can lead to reluctance in adopting BIM tools.

The software usage and interoperability are other aspects that complicate the adoption of BIM on construction sites. Many construction workers struggle with BIM software designed for advanced users, and they often lack the necessary training and on-site support to help them navigate the tools effectively. Consequently, these limitations in software and hardware lead to workers relying on printed drawings rather than interacting with the models dynamically on mobile devices, reducing the benefits of real-time access to information. (Disney et al., 2023) Supporting this argument are Disney et al. (2022) and the example from the Celsius project that showed that contractors needed a dedicated on-site VDC/BIM support team to help them adapt to the Total BIM workflows.

To overcome these barriers, several strategies have been proposed to improve BIM integration on construction sites. The development of more intuitive and user-friendly BIM interfaces tailored for on-site use is a crucial step in increasing adoption. Simplified mobile applications that prioritize essential functions such as model navigation, real-time updates, and clash detection reduce the learning curve for construction teams (Pan & Zhang, 2021).

#### 3.4.4 Training, skill development, and workforce adaption

A key factor in the successful implementation of BIM on construction sites is workforce adaptation. Many construction professionals, particularly those with extensive experience in traditional methods, exhibit resistance to digital tools (Gu & London, 2010). The shift to BIM requires not only technological infrastructure but also structured professional development programs tailored to different levels of expertise.

Studies show that companies that implement structured BIM training programs report faster adaptation rates and higher competency levels among site workers (Ghaffarianhoseini et al., 2017). Training methods such as gamification-based learning and VR training simulations have been shown to increase engagement in BIM-related education, helping construction teams gain confidence in digital workflows (Wang et al., 2024). Additionally, integrating BIM-related knowledge into construction management courses ensures that future professionals enter the workforce with a foundational understanding of digital construction methodologies.

Using BIM as the primary construction document eliminates conflicting information from multiple sources. As all data is stored in the cloud, the site workers can generate their own production views and measurements from the model, deeming 2D PDFs to only serve as a supplement for complex details. This gives workers the freedom to generate views relevant to their work tasks and reduces unnecessary drawings, which improves efficiency. Additionally, by centralizing all data, BIM enhances transparency and cross-disciplinary coordination among subcontractors, fostering better collaboration on-site. (Disney et al. 2022)

### 3.4.5 Model-based project delivery

A practical example of Model-based design delivery can be seen in the Tideway East project in London, where model-based design delivery was implemented with the goal of eliminating traditional 2D drawings delivery in the design phase. This led to a reduction in inefficiencies stemming from redundant workflows and enabled a model-centric assurance process for reviewing and approving design milestones (Gaunt, 2017). Design reviews were conducted directly in the model environment, facilitating interdisciplinary collaboration and reducing design iteration cycles. Gaunt (2017) further notes that reliance on the model as a contractual deliverable incentivized higher-quality model development, though it also required elevated levels of technical competency among project participants.

Brooks et al. (2022) examine the broader UK shift toward model-based construction and highlight both the potential and the challenges of moving beyond traditional documentation. The authors identify key advantages such as time savings due to the elimination of 2D production, improved coordination from a unified information source, and enhanced construction accuracy. However, they also point to significant barriers, including legal ambiguities, high software and hardware demands, and gaps in digital literacy across the workforce. The study's findings underscore that while model-based construction extends beyond model-based delivery, understanding the implications of this evolution is essential for contextualizing the design phase's transformation. Some of the key benefits and risks of implementing model-based construction, according to Brooks et al. (2022), are listed in *Table 3*, below:

*Table 3. Summary of benefits and risks in model-based workflows. (Adapted from Brooks et al. (2022))*

Adapted from Brooks et al. (2022)	Benefits	Risks
Time efficiency and resource allocation	It can save time both by eliminating the need to create 2D drawings and by improving efficiency during on-site construction.	Significant time investment required to develop models to a sufficient level of detail for practical use on-site.
Collaboration and competency	Improved coordination through a centralized information source enhances communication efficiency across disciplines.	Effective model use requires training, as navigating models can be complex for untrained project participants.
On-site execution and workforce integration	Improved construction accuracy, enhanced quality control on-site, and more reliable as-built documentation.	Unrealistic expectations can result in workarounds, and skilled site workers without BIM competence risk being excluded.
Scalability of workflows and inclusivity in the industry	Industry-wide efficiency gains are possible when model-based workflows become standard practice.	Smaller firms may struggle to adopt model-based workflows due to limited resources, while drawings remain necessary for legal and procurement purposes.

In the Swedish context, Duman and Gustafsson (2025) report that model-based delivery has progressed from experimental to operational status in selected projects, including New Slussen and Celsius. These initiatives marked a departure from traditional documentation by establishing the BIM model as the legally binding source of information. Organizational adaptations, such as early contractor involvement, clear role definitions, and comprehensive digital training programs, were central to the implementation. The Celsius project demonstrated effective model-based workflows across procurement, logistics, and on-site coordination, and was completed on time and under budget (Disney et al., 2022). Critical success factors identified by Disney et al. (2022) include legal recognition of BIM, cloud-based model environments, intuitive mobile viewing tools, and strong leadership to drive cultural and procedural changes. These success factors, in the context of MBDD, could be seen as goals on what to deliver and what the models you deliver should be able to do.

While much of the literature focuses on models as deliverables, Whyte (2019) offers a broader view of the digital transformation of construction delivery systems. She highlights the increasing significance of data-centric workflows that extend beyond BIM, emphasizing how digital platforms, analytics, and cloud infrastructure are reshaping stakeholder relationships, governance mechanisms, and operational practices. Her work suggests that model-based delivery should be considered within the larger context of digital delivery evolution, where models are one element in a wider ecosystem of integrated digital tools and processes.

## 4. Results from the Interview Study

In this chapter, the results from the interview study conducted are presented. The structure is as follows: (4.1) Interpretation of Building Information Modelling (BIM) and the challenge of understanding detail without scale, (4.2) Usage and perception of supporting specifications such as Level of Development (LOD) and Model Maturity Index (MMI), (4.3) The impact of Model-Based Design Delivery (MBDD) on collaboration and communication between stakeholders, and (4.4) How design-phase issues affect the implementation of model-based workflows on construction sites. This structure follows the research objectives and presents findings connected to them.

### 4.1 Interpretation of detail and maturity in the absence of scale

This section presents findings from the interview study related to the first research question. It is divided into two subsections. The first explores how BIM models are interpreted differently from 2D drawings, particularly in terms of accessibility, communication, and visualization. This helps contextualize how the shift to model-based workflows changes expectations. The second subsection presents challenges related to interpreting scale and model detail, a recurring issue that emerged in the absence of traditional drawing conventions like scale.

#### 4.1.1 Differences between interpretation of BIM models and 2D drawings

Model-based workflows, according to one of our respondents, came to be a response to inefficiencies associated with traditional workflows. A key driver for this transition was the recognition of repeating the same mistakes from project to project, and the frustration that stemmed from it. Model-based workflows are therefore not only adopted as a technological advancement, but also to address the recurring inefficiencies in information transfer and traditional project execution. When asked about driving factors of working model-based, Respondent 4 answered the following:

*"One big driver was curiosity, and there was so much frustration with the current way of working. The same mistakes were made project after project because the information that we got from the early stage was always the same." - Resp. 4*

In today's project, BIM models are gaining more recognition and are considered the main design delivery, with drawings only fulfilling the function of additional detailing, as mentioned by Respondent 6, when asked about the necessity of delivering drawings along with models:

*"In most projects today, drawings are becoming more of a complement used for detailing rather than the main deliverable." - Resp. 6*

The interview study provided several distinctions between BIM models and traditional drawings in terms of storing and conveying design information. BIM models were described by Respondent 3 as a shift in how construction projects manage and communicate information

when using model-based design, emphasizing that BIM models are more than just an improved version of scaled drawings; they alter the way professionals interact with project data.

The transition from 2D drawings to BIM models was often described by interviewees as a shift from an experience or knowledge-demanding task to a more intuitive experience. While 2D drawings require specialized knowledge to interpret the design intent, BIM models reduce the need to mentally translate the design from multiple 2D views into a 3D image, making the information more accessible. Other respondents emphasized how experience is needed to navigate 2D plans, especially when filtering relevant information. In contrast, models allow users to view and control information more easily. These interpretive differences are illustrated in *Figure 5* below.

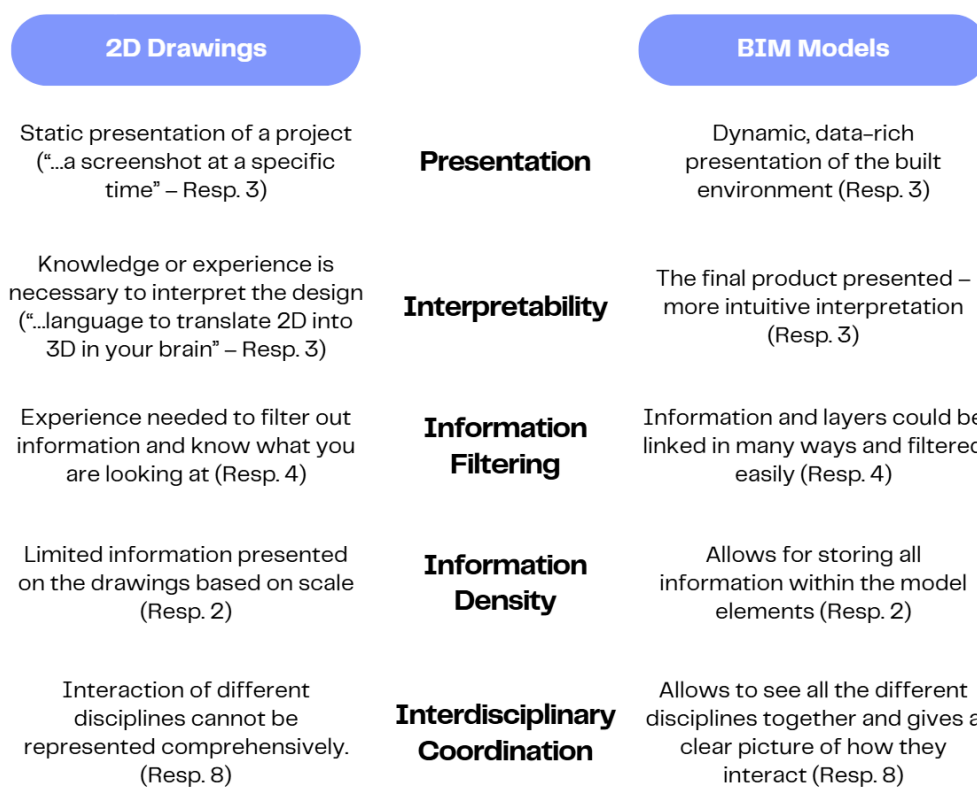


Figure 5. Respondent’s interpretation differences between 2D drawings and BIM (Authors’ own creation)

In addition to being easier to interpret, BIM models provide the possibility for a more integrated and automated approach to handling project information, reducing the reliance on fragmented sources. As opposed to 2D drawings, which are limited by scale and scope, BIM models offer a way to centralize and manage data throughout a project’s lifecycle. Respondents further noted that models allow better coordination across disciplines and a clearer understanding of the final product. As such, BIM was not only seen as a design tool but as a dynamic, data-rich representation of the built environment that enables decision-making and communication across different project stages.

#### 4.1.2 Interpretation of scale and model detail in BIM models

While the previous section highlighted benefits BIM models offer when it comes to the representation and interpretation of the design, a common theme that occurred during the interviews was mistakenly identifying elements as finished, since they looked finished when zoomed out in the model. This indicates that while BIM models offer significant improvements in accessibility and clarity, they introduce new challenges due to losing the drawing scale as a tool to communicate what detail can be expected from a given delivery. The model scale was often described as flexible and solely dependent on how far you zoom in or out in the model. Interviewee 11, who is working on bridge structures, highlighted this description:

*“There is no scale you need to worry about, because what is modelled is there, so the level of detail involved depends on how far you zoom in, because we are doing every single nut and bolt.” - Resp.11*

Even though detailed models can reduce uncertainties and provide a clearer representation of the design than 2D drawings, they can also cause unintended risks if stakeholders misinterpret elements that are still under development:

*“More detailed models can reduce uncertainty, but also risk people interpreting something as finalized when it’s still under development.” - Resp. 6*

An example of the challenges caused by the disappearance of scale from model-based workflows is over-modelling, as noted by interviewee 6:

*“In 2D delivery, detail is guided by drawing scale - show only what's necessary. In model-based delivery, there’s no scale limitation, making it easy to over-model.” - Resp. 6*

Further concerns about this problem were expressed in multiple interviews, mentioning that incorrect interpretations of the modeled detail can lead to premature extraction of data for measurements or calculations (Resp. 5), or, on the other hand, incorrect definition of necessary detail can lead to cluttering the model with unnecessary information (Resp. 4). Our interviewees stressed the necessity to define the required detail early on, based on different factors - purpose (who will use the model for what?), project goals, model maturity of the recipient (client, contractor), etc (Resp. 6 and 8). Interviewee 6 highlights the need for balance:

*“It’s always a balancing act - include enough to create value but not waste time and resources on modeling things nobody will use.” - Resp. 6*

An example of how to find this balance was presented by Respondent 1, who explained that the ambition in their architectural company is to “correctly” model everything that would traditionally be shown on a drawing in 1:50 scale, with the same level of detail. Specific building parts that require a higher level of detail, which vary from project to project, are either modeled in the level of detail that would be shown on a 1:20 drawing or supplemented with a 2D drawing, depending on what seems to be more efficient to fulfill the specific requirements.

*“Our aim is to model everything that we would traditionally represent in a scale 1:50 drawing; we will model correctly in 3D.” - Resp. 1*

The discussion of fulfilling specific requirements resonated with multiple interviews. Therefore, identifying the correct balance seems to depend on many factors that are often project-specific. The factors mentioned by the interviewees (Resp. 5, 6, and 8) are combined in *Figure 6* below.



*Figure 6. Project specific requirements for defining the necessary LOD (Authors' own creation)*

When asked about who should be responsible for defining these project-specific factors, Respondent 8 noted that, as a contractor, they do not always have a say in what LOD the models should be delivered, and then the responsibility falls onto the designer:

*“We often only see the product after it is designed, when it is delivered to the site. Then it is a mixture of different requirements put together for each unique project. The definition of what level of detail is necessary is the responsibility of the designers in this case.” - Resp. 8*

Other interviewees agreed that model detail is driven by the functional needs and project type. An interesting discussion followed about what is the most detailed or smallest thing they usually model. Examples were grouped by discipline and are presented in *Table 4*:

*Table 4. Most detailed elements by discipline according to the respondents*

<b><u>Discipline</u></b>	<b><u>Most detailed elements</u></b>	<b><u>Respondent</u></b>
Architects (including interior design)	Custom furniture, screws, trims	1, 5, 6
Structural engineers	Steel profiles, structural connections	2, 10
Bridge designer	Nuts, bolts, and detailed steel components	11

These project-specific conversations about what needs to be detailed to a high level and what can be accepted at a lower detail point to a lack of standardized understanding about levels of detail in the industry. This situation seems to lead companies to independently find their own way to define what the model needs to contain at what stage, and to increase efficiency and

reduce errors, the data in the model must be verified to ensure correct extraction, as explained by Respondent 1:

*“It’s important to have really good quality control of your models. When looking at a model digitally, you can always zoom in, no matter what scale or how big it is. Everything is going to look nice and crisp, but if the model isn’t modeled as it should be built, there’s still a risk of losing information.” - Resp. 1*

These findings point to a broader issue in MBDD: the absence of scale and standardized maturity definitions leaves significant room for misinterpretation and inefficiency. Without common expectations for what model elements should represent at different stages, project teams rely on their own interpretations, increasing the risk of over-modeling, missing information, or misaligned deliverables.

## 4.2 Usage of LOD and MMI in Model-Based Design Delivery

The interviews showed that while many practitioners are aware of LOD and MMI specifications, their implementation remains inconsistent and often adapted to specific project or company needs. This section presents how these specifications are currently used in practice, what challenges they bring, and how modeling requirements are defined based on context.

### 4.2.1 Company-Specific Practices and Benefits of LOD & MMI

The general sentiment shared across the interviews about these standardized specifications was that while they are a good idea, it seems difficult to implement them under current circumstances, with a few project-specific exceptions. Most of the interviewees said their companies had their own internal methods of specifying necessary detail and monitoring data readiness of model elements that resembled LOD and MMI specifications but were adapted to the needs and habits of the company. An example of how LOD was adopted as an internal standard is provided by Respondent 2:

*“Instead of just relying on the standard, we have a management document that states a lot of the requirements for different project stages. We have connected them to the LOD numbers, but we’ve based our document on LOD and then implemented it in a way that includes our additional requirements.” - Resp. 2*

The popularity of using LOD, MMI, LOIN, or internally developed equivalents among the respondents is summarized in *Figure 7*, showing a graphical representation as well as the number of respondents for each option.

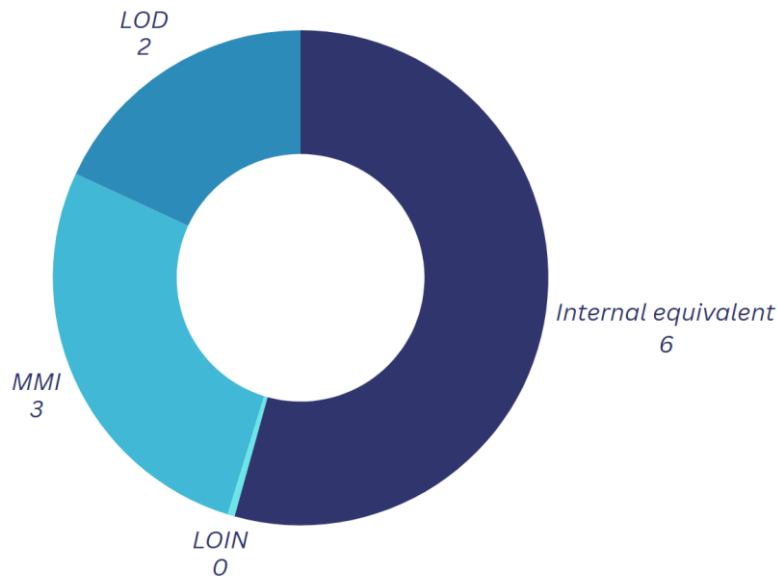


Figure 7. Graphical representation of the preference for LOD, LOIN, MMI, or Internal Equivalents (Authors' own creation)

Many interviewees agreed that this structured tracking allows for better project management and ensures that all changes are documented in a clear and traceable manner. It also helps maintain data integrity, reducing the risk of outdated or conflicting information within the model.

*"At one project, we are working with MMI, and it's my first project where 100% of the requirements are model-based. Without a status measurement on objects, it would be impossible to manage MMI is key in model-based design and construction. It's not just about approval status, but about trust in data maturity and cross-disciplinary accountability, which enables automated delivery control and robust digital twins." - Resp. 3*

This indicates that as the industry moves toward model-based workflows, the use of specifications like MMI becomes a necessity rather than an option. Some apparent benefits were discussed, mentioning that these specifications help define the responsibilities of different stakeholders in the design process, and prevent premature or incorrect use of design data, improving project reliability and reducing coordination errors. Interviewee 3 provided the following example:

*"For example, as a ventilation designer, you model your voids in the structure. But is the structural engineer allowed to use that information to create openings in the concrete walls? MMI allows designers to formally approve when their models are ready to be used by others." - Resp. 3*

An example of full integration of MMI across all project disciplines was presented by respondent 11 with experience from an infrastructural project in Norway. The project included several different structures, such as tunnels, bridges, and retaining walls, stored within a single federated model shared through a Common Data Environment (CDE). The respondent expressed a very positive attitude towards MMI, highlighting its benefits in simplification of

the complex project and improved communication through the model, thanks to everyone using the same specification. The following quote provides an example of these benefits:

*“All those hundreds of structures have to work to the same matrix, which is good for me because when I am designing a wall, the road next to it is using the same standard. So, if my wall is developed to MMI 350 and the road is only MMI 100, I directly see the problem and know where to address my questions.” - Resp. 11*

In this case, the definitions of what was expected from all the different MMI levels were developed before the beginning of the design phase in collaboration between the client and the design team.

#### 4.2.2 Challenges and Misconceptions Related to LOD

Interviewees also highlighted several challenges and misconceptions. One of our interviewees discussed a challenge with the use of LOD in model-based design, cautioning against the misconception that all components must be highly detailed. This sentiment was shared across the interviews. An example is provided in the quote below:

*“One of the biggest misconceptions in the industry is asking for an LOD 400 model for everything. It’s unfeasible. A concrete wall won’t have more detail at LOD 400 than at LOD 200. The information side might be more detailed, but not necessarily the geometry.” - Resp. 1*

Respondent 2 mentioned that the digital competences of the manufacturer play a role in deciding the appropriate level of detail of certain elements, expressing that some specialists often only need a basic level of detail, as they design the elements themselves before manufacturing (for example, window producers):

*“Some elements we know will be refined later on, so we can keep them basic and leave the design to others. While some things, like steel columns, need a higher level of detail because they’re going straight to delivery.” - Resp. 2*

Another respondent said that some objects take more time to model in 3D than to build in reality, and then there are cases where high detailing of elements or objects is not necessary at all:

*“Some objects are just unnecessary to model since they come already done and take a lot of time to model, for example, water mixers.” - Resp. 3*

Furthermore, interviewee 5 questioned the usefulness of LOD, especially in renovation projects, drawing on experience where too much detail, inconsistent with the existing structure, caused the construction team to lose trust in the model:

*“The usefulness of LOD goes to a certain point. When you're designing, you don't have the full truth. Too much detail that might be incorrect can cause the construction team to not trust the model. This is especially true in renovation projects.” - Resp. 5*

These statements challenge that higher LOD is what makes better models and emphasize that higher detail might even be incorrect and lead to a loss of trust in the model data. Interviewee 1 then highlighted the risks of excessive element complexity, sharing an example of a past project.

*“One project had a shower mixer taken from the manufacturer’s website, modeled at 96,000 polygons each. The entire project had 300 apartments, and this single component caused the model to completely break down.” - Resp. 1*

This case demonstrates how excessive graphical detail can negatively impact model performance, making it difficult to work on a practical level. Optimizing model complexity is critical to maintaining efficiency while still capturing necessary information for construction. This issue, however, is not only relevant to the graphical level of detail, but also the information richness the element requires, as mentioned by interviewee 4.

*“If you don’t clearly define what’s required at the object level, you end up with unnecessary information or non-reviewed data that gets inserted into the model.” - Resp. 4*

This underscores the importance of establishing clear standards for what BIM models are supposed to include. Without proper guidelines, digital models can become cluttered with unreliable data, which can lead to errors and inefficiencies later in the project.

### 4.2.3 Contextual Decision-Making and Stakeholder Needs

In response to the challenges, interviewees emphasized the need to adjust modeling details based on the project’s context, purpose, and users. When asked about what LOD models should be detailed in, another challenge appeared regarding determining the appropriate model detail. The size of the project and its available resources were mentioned as deciding factors by Respondent 2. While high LOD enhances precision and coordination, it also requires more time and effort to produce. On smaller-scale projects, this added investment is often harder to justify, as the construction process can rely more heavily on the builder’s experience, and it is then more economical to shift a greater burden to the construction site. Larger projects, by contrast, are more likely to benefit from and afford detailed modeling, both because of their complexity and their larger design budgets.

*“Having a high LOD is more time-consuming and can be hard to motivate for small-scale projects. So, they tend to try to stay as simple as possible. Bigger projects will often also have a bigger design budget, which can carry the cost of higher LOD.” - Resp. 2*

In addition to project size, defining the right LOD is a continuous negotiation between cost and benefit. Each additional object or piece of information must be justified not only by its usefulness but also by how it interacts with other model components and what it costs. Respondent 2 stated that if an object is not a risk for clashes and does not have a precisely fixed

location in the model, it is not necessary to model it geometrically; it can instead be included as a quantity of elements (i.e., this bathroom needs 2 towel hangers).

*“It is an ongoing process; it is cost vs. benefit. If the object is flexible, it can often be included as a number connected to an apartment, for example.” - Resp. 2*

In addition to balancing the costs and benefits of detailed modeling, considerations must be made about value creation and efficiency. Respondent 6 stressed the importance of defining modeling requirements early in the project:

*“We often define what should be modeled and the level of development early, based on the project’s goals and users’ needs. It’s a balance: enough detail to create value, without wasting resources.” - Resp. 6*

When asked about LOD-related decision making, Respondent 5 shared similar sentiments and highlighted that sometimes details can be included in the room summary; the necessity of modeling, therefore, depends on the intended use of the model.

*“It depends on the project. Many times, details can be described in a room summary, but if you want to use the model for cost estimation or climate analysis, you need to model them anyway to get reliable figures in real time.” - Resp. 5*

This reaffirms the idea that modeling is not a one-size-fits-all process, but rather a strategic and context-dependent activity that must be tailored to the specific needs, scale, and constraints of each project. When asked about alternative ways of specifying the LOD needed to successfully apply MBDD, one of our interviewees argued that defining the LOD for the whole project is not always the best solution and instead argued for defining the necessary LOD to reach MMI 400, which would communicate what elements are ready for production instead.

*“Rather than specifying the LOD of the project, it would be more suitable if people used the MMI to mark something ready for production. That would enable different elements to be modeled to different LODs and still give us the information we need.” - Resp. 1*

These reflections show that misconceptions about LOD - particularly the belief that more detail always equals better quality - can lead to inefficiencies, performance issues, and even a loss of trust in the model. Instead, the interviews show that the details should be aligned with the purpose and context of use in the project.

### 4.3 Impact of MBDD on collaboration and communication among stakeholders

The shift toward MBDD has introduced changes in how project teams collaborate and communicate. Compared to traditional drawing-based workflows, MBDD supports faster feedback cycles, centralized communication, and greater transparency in project development.

This section presents findings from the interview study related to these impacts, focusing first on how digital models enhance communication between stakeholders, and then on the collaboration advantages that shared models bring across disciplines.

### 4.3.1 Benefits and persisting challenges in communication through models

Communication between designers happening through the models and digital collaboration platforms was recognized as one of the biggest positive impacts of MBDD among the respondents in this study. Some of the most commonly mentioned benefits are presented in *Table 5* below:

*Table 5. Benefits in communication in MBDD according to the respondents*

BENEFIT	SUPPORTING QUOTE
<b>Daily communication</b>	<i>"Instead of having coordination meetings where you drop off some information and they will receive it and open the models later, you need to have more daily communication between everyone." - Resp. 4</i>
<b>Faster iteration of changes</b>	<i>"You have to communicate more because those changes will reach the receiving end in minutes instead of two weeks." - Resp. 4</i>
<b>Access to information and traceability</b>	<i>"Reviews, issue management, and questions are handled directly in the platform, so everyone has access to the same information and everything becomes traceable." - Resp. 6</i>
<b>Attaching questions and comments directly to model elements</b>	<i>"You can click on the object and attach the question to that specific object. This increases efficiency and supports location-based issue tracking, which speeds up the question-and-answer process, increases clarity, and mitigates risks in complex projects." - Resp. 3</i>
<b>Client involvement</b>	<i>"With model-based design, clients had a lot more insight into what was really going on, and they could see the project evolve in 3D over time." - Resp. 4</i>

The benefits of daily communication, faster iteration, and immediate access to information on the digital collaboration platforms were mentioned by six respondents (1-4, 8, and 11) and were the most established benefits presented in the interviews. However, even these benefits are still hindered by certain challenges. One of the commonly mentioned prerequisites for these benefits to be harnessed was ensuring the interoperability of software used by different disciplines. Respondent 8 expressed frustration about the lack of standardized formats and their inconsistent use in the following quote:

*"The biggest challenge is the lack of standardized formats across different software. While most software can export IFC files, it's not always consistently used, creating compatibility issues." - Resp. 8*

This challenge was also mentioned by Respondents 1, 2, 3, and 11. Respondent 2 thought the problem was in using outdated formats from the early 2000s and emphasized that: "... the new

*standards are being expanded on, but the old ones are lacking in certain sectors."* Respondents 2, 3 on the other hand mentioned that the cause of this persisting issue lies in varying levels of technological adoption among stakeholders, as the transition to MBDD requiring adapting to new tools and workflows, and designers are at different stages in this digital transformation journey, and might be using software that does not support interoperability. Respondent 11 elaborated on this issue, saying that interoperability issues occur even in technically advanced design teams if they are using software from different providers.

The function allowing for the assignment of comments and issues directly to model elements on digital collaboration platforms was mentioned by Respondents 3, 7, 8, and 11. However, it comes with its own set of implementation challenges, described in the following quote:

*"Sometimes people get tagged in the wrong element, and sometimes people who shouldn't be tagged get tagged in an assignment. That creates some kind of irritation regarding the usage of the BIM model. If the wrong element is tagged, then people get confused because they don't recognize it. If the wrong people get tagged, then they get irritated and feel like their time is wasted. People are sensitive, especially when using 'new' model-based ways of working." - Resp. 7*

As mentioned by Respondents 1 and 4, the introduction of model-based design not only alters the collaboration between designers but also allows for better involvement of the client. While this transparency improves trust and collaboration, it also demands higher accountability from project teams, as clients now have more direct access to evolving project details. Respondent 1 mentioned a challenge connected to this benefit:

*We also have to educate our clients. So in a way, it's not just the architects and electricians... the clients are on a completely different journey." - Resp. 1*

This quote highlights that clients often need to be educated to engage with these digital tools, which creates more work for the design leaders, and this education remains an ongoing challenge.

Overall, while model-based communication brings benefits, it comes with challenges associated with it. When the tools are selected and used correctly, they can make collaboration faster, clearer, and more transparent. But as the interviews show, realizing these benefits depends on how well the tools are adopted, how compatible the software is, and how ready the different stakeholders are to work model based.

### 4.3.2 Benefits in collaboration of disciplines

Another aspect that MBDD has significantly improved is the collaboration of all the disciplines involved in the design. As respondent 2 said, *"Collaboration is the biggest positive impact of the models."* By working with cloud-based tools, teams can integrate their designs and resolve conflicts before they reach the construction phase. Another aspect mentioned in the interviews was that traditional 2D drawings can be difficult to interpret across disciplines, which can lead

to misunderstandings and inefficiencies that can occur if a professional in Mechanical, Electrical, and Plumbing (MEP) disciplines does not have the necessary knowledge to interpret a drawing from a structural engineer, for instance:

*"2D drawings are very big in exclusion because it's very hard to understand aspects from other disciplines. An electrical MEP drawing for a structural engineer is a lot harder to understand than seeing model objects in the model." - Resp. 2*

Instead of referring to multiple drawings, federated models allow for seeing the collisions and can highlight them simply by a section box, as mentioned by respondent 1:

*"Previously, coordination required referring to multiple drawings; now with model-based approaches, you just draw a section box in 3D and get the full picture straight away." - Resp. 1*

This ease of visual access allows teams to work more effectively across disciplines and address conflicts before they become costly problems. This shift changes how teams can interact with models from other disciplines. Unlike traditional workflows, which often require cross-referencing multiple documents, model-based design, as earlier stated, provides the possibility of a more efficient process. When asked about what it means to work together on a common model, Resp. 1 said:

*"Previously, there was a lot more about 'this is my area, you don't tell me what to do.' Now, with everyone focused on the model, collaboration has improved." - Resp. 1*

This statement underscores that traditional workflows often encouraged discipline-specific silos, where architects, engineers, and contractors operated independently and then coordinated with each other. By contrast, model-based workflows promote a collaborative environment, where different disciplines work together with a shared model as their central reference point. They are still experts in their own field, but experts together in the collaborative model. However, this transition requires a willingness to adapt and learn new ways of working, as resistance to change can create inefficiencies and gaps in project coordination.

## 4.4 Challenges in extending MBDD to model-based construction

MBDD has the potential to improve construction outcomes significantly, but successful implementation on-site is heavily dependent on decisions made during the design phase. This section explores how issues in early project stages, such as unclear requirements, insufficient verification, or lack of contractual clarity, can limit the use of models during construction.

### 4.4.1 Perceived Benefits and Requirements for On-Site Use

Model-based design delivery can resolve many issues in the design phase and bring advantages to construction sites in terms of reducing rework, improving visualization, and supporting early-stage decision-making during the design phase. While measuring the full scale of the impact of model-based workflows seems impossible, some benefits are clear to notice:

*"It's nearly impossible to measure the success of model-based construction, but from my experience on-site, you will have fewer clashes during construction. But model-based workflows shift the focus to early validation, so we reduce risk proactively rather than reacting to errors downstream." -Resp. 3*

Interviewee 2 expressed belief that even though implementation of MBDD is a costly process and requires initial investments, the investment will return later:

*"We believe in the positive effects of being able to visualize everything and take an early design cost to mitigate late-stage rework. It takes more money and time to create these models, but our mindset is that we think we save money in the end by eliminating missed collisions and issues that we couldn't see before." - Resp. 2*

These responses show that while the benefits of MBDD are hard to quantify, their perceived value in minimizing downstream rework is widely accepted.

Another advantage that BIM models with clearly structured properties bring to the construction site is more efficient scheduling. BIM models allow for location-based planning, therefore mitigating the risks of scheduling two different contractors to work on the same part of the project at the same time. Having correctly defined property sets and filled-in parameters, however, is crucial to enable 4D BIM, as expressed in the following quote:

*"Sequencing the project in 4D BIM allows us to better evaluate whether the design is buildable. However, the requirements and property sets need to be set properly at the start of the project; otherwise, elements are impossible to put into sequence." - Resp. 8*

These reflections illustrate that the effectiveness of MBDD on site depends not only on having models available, but on ensuring that models are well-structured and practically usable. The perceived benefits that well executed MBDD could bring to the construction site and the conditions required to be fulfilled in the design are summarized in *Table 6*.

*Table 6. Benefits of model use on-site vs. Requirements to realize them*

<b>Perceived Benefit</b>	<b>Required Condition</b>	<b>Respondent</b>
Reduced rework through early clash detection	Complete, verified models available early	2, 3, 7
Better 4D sequencing and buildability assessment	Well-defined property sets and scheduling info	8
Improved communication and visualization	Access to the centralized model by all stakeholders	General theme

#### 4.4.2 Trust, Verification, and the Cost of Mistakes

Another issue that was mentioned as a long-standing problem in implementing digital models on site is reliability and trust.

*"One of the biggest problems we have had historically in implementing 3D models has been confidence in the data. I think we've worked with the IFC industry format for a very long time, but we haven't always trusted the models for purchasing and live on-site delivery." - Resp. 2*

This points to the need for verification processes to ensure that BIM models contain accurate and reliable information. Without confidence in the data, companies are hesitant to rely fully on models for procurement and construction. If BIM models are to replace traditional drawings completely, contractors must be assured of their accuracy and consistency.

When asked about the relationship between the on-site office workers and designers regarding the implementation of BIM models delivered to the site, Respondent 7 said the following:

*"The models we've gotten our hands on always have some kind of error in them. Sometimes, the quantities don't match the specifications, sometimes certain data is missing or wrong. That makes us lose 'trust' in the models. Also, it makes it even harder to try getting our on-site workers to use it. If we can't trust it 100%, then why should our people?" - Resp. 7*

This indicates that implementing models on-site is a delicate process and needs to be free of problems. Several respondents indicated the importance of verification, not only for the sake of companies to rely fully on models for procurement and construction, but also for the workers to take the step and use them to the extent they are meant to be used.

When asked about trust in the model on site, one respondent noted that trust exists until it does not. One mistake and most of the trust in the model is lost, further stressing the importance of ensuring quality models are developed in the design stage.

*"In a dream scenario, we would use the models only. But as soon as we spot one single mistake, the trust is completely lost, and we go back to counting by hand or checking things manually. The only thing that's immune to that would be collision controls, we do those either way." - Resp. 7*

This insight shows that trust in models received from the design team is fragile on construction sites. Spotting a small mistake makes the site workers question the data in the model and revert to manual calculations and verification practices instead of the automatic ones that models offer.

When asking the interviewee about the ability to perform automatic calculations on site, the respondent answered the following:

*"One time, I did a quantity take-off on the windows in our project. We had a table from the architects saying there were 498 windows, but when I did the take-off on site, I got 500. And when I did the manual check, unfortunately, two windows were not included, so the real number was 500. That was not good, it made me and my colleagues all double- and triple-check information we got from the model." - Resp. 7*

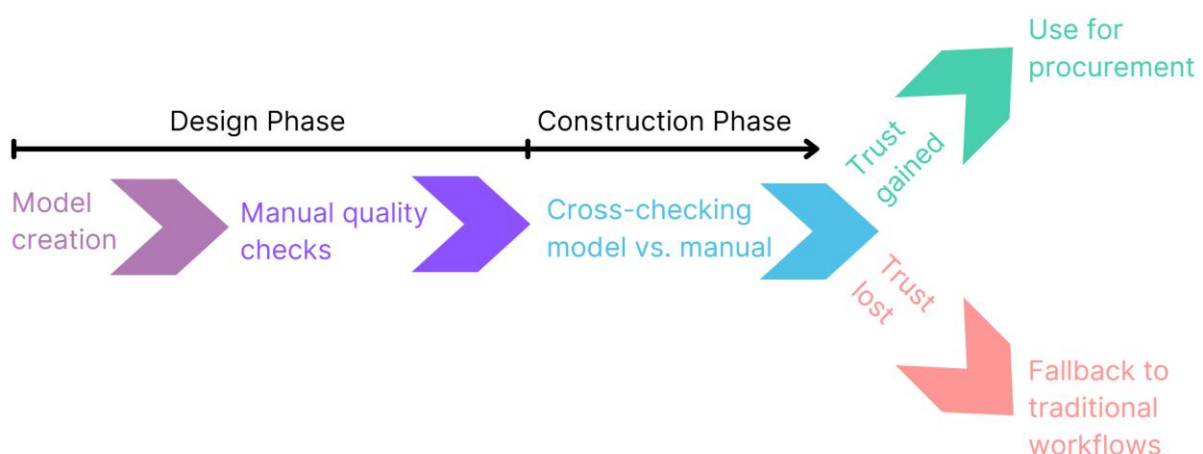
Respondent 2 elaborated on this and said that ordering based on model quantities only happens after the model is verified. Currently, the verification of the data is still done through manual control, as pointed out by Resp. 2:

*“Now I would say that the models are verified manually by doing control checks, comparing takeoffs from models to manually calculated volumes. If the model is consistent with the checks, the people ordering the concrete will start using the volumes from the model to order rather than having to manually calculate everything.” - Resp. 2*

An agreement with the need for manual checks was also expressed by Resp. 8, who mentioned that everyone involved in the project (client, contractor, designers) has their own checklist of expectations from the model that are used to evaluate the completeness of the models and improve trust in the data. However, even if the checklists are fulfilled, the team on site performs manual checks of quantities for some instances in the model. Only if they ensure the data extracted from the model agrees with manual calculations, do they use the models for ordering and scheduling:

*“If everybody follows the checklists agreed upon beforehand, it is safe to trust the model. But we are always double-checking. If the quantities from the model agree with a few manual calculations, then we use the model.” - Resp. 8*

This recurring need for validation suggests that current design practices don't yet support full trust in model-based construction, even when standards are followed. Based on the interview study, *Figure 8* shows the validation and possible outcomes on the construction site, depending on the success of the verification process.



*Figure 8. Model data validation process (Authors' own creation)*

#### 4.4.3 The Role of Contracts, Clients, and Delivery Standards

To take the distinction even further, when asked about the definition of MBDD, one of the respondents mentioned a clear difference needed in contractual agreement. According to Resp. 11:

*“Model-Based Design Delivery for me is when the model is essentially the contract document, so everything you previously had in a drawing now has to be contained within the model ... all the metadata is there.” - Resp. 11*

The same respondent expressed a strong belief in model-based delivery practices to replace the traditional, 2D-based practices. Although acknowledging the slow adoption of changes, typical for the construction industry, Resp. 11 believed in the inevitability of this transformation happening and cautioned companies to start planning for it, saying:

*“I think if you are designing within the built environment and you are not already planning for drawings to disappear, yes, there is a problem.” - Resp. 11*

Furthermore, when asked about the reasons for the slow implementation of MBDD and consequently, model-based construction, and why there are not many projects where the model is the contractually agreed-upon delivery method, Resp. 11 mentioned the key role clients play in the implementation of these new practices:

*“It has to come from the client ... if the client is not pushing it, there is nowhere to go. You cannot sell a product to someone who does not want it.” - Resp. 11*

The same opinion was expressed in the interview with Resp. 9, who admitted they only work with models if it is requested by the client:

*“We work with models, but only when the client has specified it in the contract.” - Resp. 9*

These perspectives could be interpreted as follows: contractual clarity and client leadership are critical factors in enabling model-based delivery workflows. However, even when model-based delivery is contractually required, its success depends on the reliability and usability of the models themselves. To support this, interviewees talked about exploring ways to automate the verification of model quality and readiness, aiming to reduce the burden of manual checks and improve trust in model-based deliverables.

One of the ongoing developments is the use of tools that can assess data consistency within predefined limits. Already existing online tools can analyze Industry Foundation Classes (IFC) models against the delivery goals and provide a percentage of model objects that are developed according to the predefined requirements, as stated by Respondent 2:

*“It gives a percentage of model objects that are up to the predefined limits. This will eliminate the need for manual checks and will give projects even more confidence to use the model for construction. There are more tools like this popping up, so we’ll see what tools will be used in the future.” - Resp. 2*

Another interviewee mentioned their internal attempts to automate the verification process through developing their tool that could detect the MMI in the model and compare it with the

requirement. In case the model was not deemed ‘ready’ by the tool, it would block it from being published and consequently eliminate the occurrence of unverified data in the model.

*“We have an idea of a gatekeeper of IFC models or that blocks models from being published if they’re not the right MMI or have not reached 100% validation yet. This would be a validator and increase the trust in the models.” - Resp. 4*

Another aspect closely tied to model reliability and verification is the way data is managed throughout the project. While tools for automating model checks are being developed to improve trust in model-based deliverables, Respondent 11 pointed out that the foundation for such functions must be established early, through a structured and centralized database. According to Respondent 11, reliable model delivery in a BIM-only workflow is not primarily a modeling issue, but a data issue. They explained that a centralized database can provide better consistency and traceability for model data and can be established before modelling even begins.

*“If you’re in the process of building your model and then you’re assigning data to that model just as you’re building it, you’re already lost. You want all your data in one place. That is actually the biggest thing in a BIM-only project - managing data.” – Resp. 11*

This method supports automation of information management and offers potential for project standardization, at least on a company level. The same respondent described internal efforts to build a reusable database that could be applied across multiple projects and allow the designers to assign predefined metadata at each design stage. The database is also connected to the MMI levels and can automatically fill in information just by switching between them. Respondent 11 explained the connection to MMI in the following quote.

*“You can have a database that allows you to switch between different MMI levels, and it will automatically turn on or off the option to fill in certain details.” – Resp. 11*

The interviews say that even with the right contractual and client conditions in place, reliable automation and quality control remain essential for implementing MBDD. As models increasingly become central to project delivery, ensuring their accuracy in both visual detail and data maturity through clearly defined requirements and technological support is an important factor in realizing the benefits of model-based construction.

## 5. Discussion

This chapter discusses the key findings of the study by analyzing the information from the literature study and the interviews, while reflecting on the research objectives. The discussion is structured according to the four research objectives, each in its own section that follows. These sections focus on how Building Information Modelling (BIM) differs from traditional drawings in terms of information delivery and scale; how specifications like Level of Development (LOD) and Model Maturity Index (MMI) influence model use; how Model-Based Design Delivery (MBDD) affects communication and collaboration; and what challenges in MBDD translate to inefficient implementation of model-based workflows on site.

### 5.1 Information Delivery: BIM vs. Traditional drawings

A consistent theme throughout the interviews was the cognitive difference between working with traditional 2D drawings and BIM. Several participants described 2D drawings as a "language" that requires earlier experience to interpret, especially when trying to visualize complex geometry or integrate fragmented views from multiple sheets. These findings are supported by the research from Volk (2014), who mentioned limitations in traditional 2D documentation, including interpretation and coordination issues. While drawings have long served as the foundation of design communication, they also introduce a barrier to those unfamiliar with their conventions, supporting Sacks et al.'s (2018) arguments on how BIM changes information delivery compared to traditional 2D workflows.

BIM, in contrast, offers an immediate and more intuitive representation of the built environment. Many interviewees emphasized how BIM models remove the need to mentally reconstruct a 2D image to a 3D image, which benefits project participants without design backgrounds. As one interviewee noted: With the model, you don't need the language, you see the product. This aligns with the literature. Volk (2014) described BIM's visual clarity as a way to improve shared understanding, while Poirier (2017) pointed to BIM's ability to enhance communicating information delivery and reducing data silos.

The process of combining multiple 2D views into a 3D picture is exemplified on *Figure 9* below, comparing representation provided by a traditional 2D visualization method and representation provided by a single 3D model.

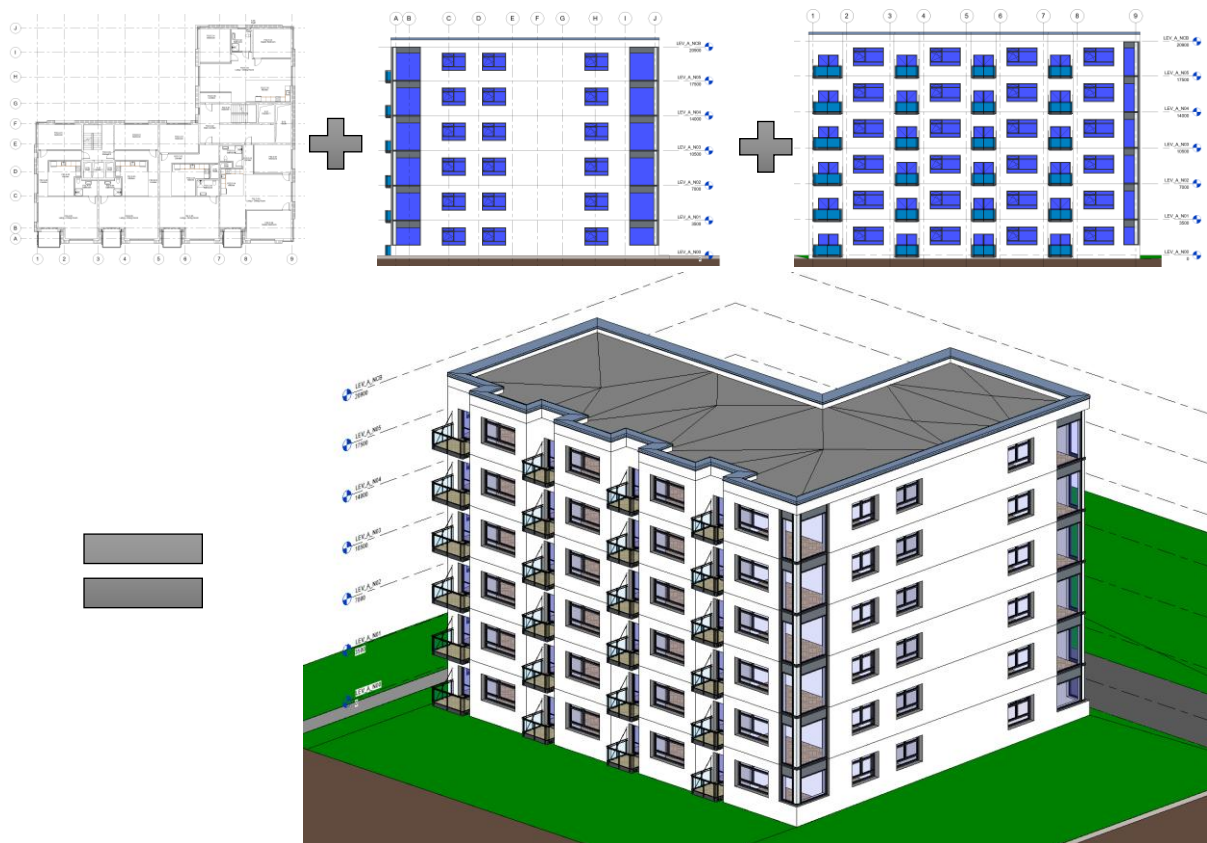


Figure 9. Combining multiple 2D views into a 3D view, comparison of interpretation (Authors' own creation)

However, the visual clarity of BIM models comes with its own risks. Several interviewees warned that zooming into components can give a false sense of precision or completeness, connected to the arguments presented in Section 3.1.3 of the literature study. Unlike traditional drawings, which use scale and annotations to signal a component's maturity, BIM lacks visual cues to distinguish between conceptual and finalized elements. This issue is well described by Blanchard (2022), who argues that the adjustable zoom function disrupts the visual hierarchy that drawings generally have. Similarly, Abualdenien & Borrmann (2022) highlight how a model's polished appearance can lead to overinterpretation of its reliability.

Respondent 11 reflected this concern directly, noting that in the model, there is no scale; it depends on how far you zoom in. Without scale as a reference point, expectations for model completeness become uncertain. As Bayhan et al. (2023) emphasize, scale in traditional drawings uses scale to communicate expected levels of development. The absence of scale in models creates a risk of mistaking placeholders (or not yet fully modelled elements) for finalized elements. This, in a worst-case scenario, can lead to decisions (e.g., planning, procuring, measurements, quantity take-offs) based on immature data. One interviewee described a case where a site clash occurred because the team assumed the model was complete, when it was not, a scenario that aligns with Abualdenien & Borrmann (2022) warning that visual completeness can conceal underdeveloped content. This risk of misinterpreting the current

maturity of the element (or the whole model) becomes problematic in larger multi-disciplinary projects where users approach the model from different perspectives and with different specialities. To ensure the information delivery, when delivering BIM models instead of 2D drawings with included scale, it is important to embed indicators of LOD or metadata about the specific elements' development.

In this way, BIM's core strengths, its detail, interactivity, and scalability, can become liabilities if not carefully managed. These challenges point to a deeper issue, which was touched upon in the paragraph above: the lack of standardized and recurring embedded information in the models. Whether it is design maturity, specifications, or metadata in the elements, it is critical to have a shared method for communicating development status in the models; even a highly advanced model is vulnerable to misinterpretation if there is no shared understanding about what information needs to be included and delivered in the project. Garcia (2017) argues that specifications such as LOD or MMI could serve this function, helping to convey what level of reliability can be expected from each component and preventing premature data use. These specification, and their role in transferring the reliability of information, is discussed further in the next section.

## 5.2 Specifications: LOD, MMI and their role in design delivery

A recurring theme in both interviews and literature is the use, and frequent misuse, of specifications, particularly LOD and MMI. These specifications are intended to clarify what information a model element contains and how reliable it is at different stages of the project. If used as intended, they offer a variant of a standardized way of delivering information across the project, but in practice, their application is often inconsistent, misunderstood, or symbolic.

Multiple interviewees expressed frustration with LOD, describing it as a box-ticking exercise rather than a meaningful indicator of model development. Respondents also described situations where tags were frequently assigned without proper review or validation, reducing their function to symbolic markers. This concern echoes Hooper's (2015) critique of LOD being applied symbolically and Garcia's (2017) argument that LOD emphasized the presence of data over its correctness or approval status. If misused, LOD loses its value as a communication tool for design maturity and increases the risk of misinterpretation.

A shared responsibility gap also exists. Interviewees noted that LOD responsibilities were either assumed by the BIM coordinator or vaguely distributed across disciplines. This lack of process ownership aligns with Garcia's (2017) findings that unclear role definitions undermine the effective use of LOD. When no one owns this process, maturity tracking becomes fragmented and hard, and confidence in the model is lowered. Hence, the responsibilities should be shared and defined.

Another issue is the fragmentation of LOD standards between companies. Several interviewees noted that organisations often adapt variants of LOD definitions and customise them internally

to fit the company context. This conflicts with the structured application described by Sacks et al. (2018) and reflects some challenges identified by Hooper (2015), which are presented in Section 3.2.4. Additionally, interviewees described how large volumes of unstructured or excessive data continue to clutter models, an issue highlighted in section 4.2.3. The context-dependent nature of LOD requirements in projects creates uncertainty around what should be included, when, and by whom, which is something the respondents highlight.

A critical misconception raised during interviews is the assumption that a higher level of detail always equals higher model quality. Examples included excessively detailed elements, like fully detailed reinforcement, or highly polygon dense shower mixers, that caused performance issues and provided little value, this is highlighted in (4.2.2 & 4.2.3). These insights from the interviewees show the need to apply specifications purposefully and in proportion to the use case. Over-modelling not only wastes time and resources but also reflects a lack of coordination between disciplines on what is actually needed in the models.

When comparing LOD with MMI, some interviewees, notably Respondents 3 and 11, expressed a clear preference for the latter. MMI was seen as more useful for tracking maturity in complex models and improved the management and communication between designers. Respondents 2 and 4 reported using custom parameters that resembled MMI more than LOD. In line with Garcia's (2017) suggestion that MMI addresses LOD's shortcomings, interviewees noted that LOD struggles to account for discipline-specific needs, making it harder to define project-wide requirements across the entire model. MMI, by contrast, allows flexibility and tracks (via its levels 0-600) completeness, which several respondents found more practical and easily applicable when actually used in projects.

One noteworthy insight came from Respondent 11, who described a data-driven workflow in which model content was auto-filled from a centralized database based on MMI-defined maturity levels. This reflects Succar's (2009) focus on data management but goes further by directly linking model content to maturity tracking. While this approach was only used in one case, it shows potential for standardizing how maturity specifications are implemented in the industry, where some companies aim for consistency and repeatability. This also strengthens the arguments by Whyte (2019), which highlight the increasing significance of data-driven workflows, emphasizing how digital platforms, analytics, and cloud infrastructure are reshaping operational practices.

Despite the perceived advantages of MMI, awareness and adoption remain low. Respondents familiar with MMI had encountered it only in pilot projects or internal experiments. Most others had little or no experience with it. As Abualdenien & Borrmann (2022) argue, specifications not supported by project frameworks or contracts risk remaining theoretical. Without formal adoption and support, MMI's benefits cannot be fully realized.

The disconnect between specifications and real-world use is reinforced by the broader finding that maturity standards like LOD or MMI are still detached from contractual and organisational

structures, as mentioned before by Garcia (2017) and Hooper (2015). As long as models lack legal weight and specifications are optional, they will continue to be applied inconsistently or ignored entirely. Interviewees repeatedly noted that model expectations are communicated informally or resolved reactively, often after issues appear. This reactive approach reduces trust in model data and contributes to errors downstream. These challenges point to the significance of standard contracts, like AB (Almänna Bestämmelser), and the proposed reforms in AB 25. As stated in the draft by Byggnadets Kontraktskommitté (2024), digital models are no longer supplementary; they are elevated to formal contract deliverables. The proposed draft in AB 25 states that models must be structured, accessible, and usable throughout the delivery process. This, in a way, is an unspoken recognition of the model's status as a core project deliverable. If accepted, AB 25 could pave the way for model-based workflows and thereby the specifications that this study identifies as crucial for supporting model-based design delivery.

The implications are two-fold. First, maturity specifications must be introduced as important parts of project planning, not as optional add-ons, but as parts of the delivery process. Garcia (2017) designed MMI to address approval and verification gaps in LOD, but without structured implementation, neither can fulfill their potential. Hooper (2015) similarly showed that the lack of standard routines when working with LOD undermines the specifications credibility across projects. Second, clients and project owners should lead the way in mandating and embedding these specifications into contracts and workflows. As BEAst (2023) shows, structured digital delivery requirements can be defined early. Without this commitment, even the high-quality models risk being sidelined, which is a pattern observed by Disney et al. (2022). When specifications are supported by contracts and included in the project workflows, they can evolve into additions for quality assurance, delivering information as intended, and supporting MBDD.

Instead, different components require different levels of detail depending on their function. For instance, structural elements such as concrete walls do not require excessive geometric detail but need precise information about dimensions and position for clash detection and construction sequencing. By contrast, interior design elements, such as custom-built furniture, require higher detail for accurate fabrication and visualization. This distinction highlights the importance of balancing model detail with practicality, so over-modeling does not lead to inefficiencies, and under-modeling does not result in missing critical details needed for production.

### 5.3 Collaboration and communication in MBDD projects

MBDD changes how disciplines collaborate by centralizing design development in shared digital environments. Respondents highlighted that cloud based CDEs reduce fragmentation and allow disciplines to work in real time on the same model, thereby minimizing manual coordination and version discrepancies coming from workflows with weekly or monthly file exchanges. This collaborative potential is supported by Porier et al. (2017), who argue that when used correctly, digital platforms help dismantle silos and enhance cross disciplinary transparency.

Collaboration through shared models also changes the traditional separation of design responsibilities. Where traditional workflows follow a sequential path with clear handovers, MBDD introduces overlaps, where multiple participants work on the same evolving model simultaneously. Respondents reported uncertainty around roles, approvals, and ownership of model elements. This aligns with Volk et al. (2014), who identified the uncertainty about roles as a challenge in digital transformation. Without clear procedures for who changes what and when, collaboration risks becoming inefficient despite being digitally enabled. Some interviewees shared promising practices, such as using digital issue tools to assign tasks or responsibilities directly within the model. Respondents 3, 7, and 11 described this as a more structured way of tracking uncertainties and sharing accountability. However, it was also noted that these tools could lead to frustration if used incorrectly, for example, tagging the wrong person or element. In such cases, it may be hard to motivate personnel to keep on using the tools.

The collaborative benefits described also reflect findings by Linné (2019), whose analysis of a project in Sweden emphasized that successful model-based coordination required parallel changes in routines and stakeholder relationships. Collaborative gains must be gathered from the project participants themselves, as they do not simply arise from model usage alone.

While collaboration refers to working together on tasks, communication is about making shared understanding possible. Respondents viewed communication as one of the most improved aspects in MBDD, especially through platforms that allowed traceable comments and discussion within the model environment, and shared visibility into project progress. Design teams and even clients were described as more engaged due to the transparency that models provide, but these benefits come with their own dependencies.

One core issue raised was that even highly interactive tools lose effectiveness if users do not fully understand what they are seeing. Interviewees warned that design elements are often interpreted differently depending on one's discipline, leading to miscommunication, especially when there are no clear indicators of model maturity. This reflects Garcia's (2017) concerns about symbolic LOD use and further supports the relevance of maturity specifications like LOIN as defined in (ISO 7817-1:2024), which clarifies not just what is shown, but how and when it should be used. These communication gaps are amplified by differences in digital literacy. Some interviewees noted that while BIM specialists and coordinators were familiar with these tools, other project participants, especially on-site workers or clients, require training and guidance. This confirms earlier work by Azhar et al. (2012) and later research by Gharrarianhosieni et al. (2017) and Disney et al. (2023), which point to digital competence as a limiting factor in realizing the full communication potential of MBDD.

The issue of trust also appeared as a communication barrier. As one respondent explained, You can have all the tools in the world, but if people do not trust the model or do not know what it means, they will not use it. This behavior reflects a common pattern during high-pressure or stress moments, when individuals revert to PDFs, email threads, or verbal clarification. These

reintroduce traditional workflows and undermine the advantages of MBDD. Ghaffarianhoseini et al. (2017) note that resistance is often cultural, stemming from familiarity with older systems and a lack of support for the digital transformation.

Sitting between communication and collaboration is the issue of interoperability, without which neither can function. Multiple respondents described recurring problems when exchanging models between disciplines using incompatible formats, different software providers, or outdated export standards. These issues resulted in information loss or misalignment. The literature by Afsari et al. (2017) and Succar (2009) emphasizes that interoperability is a persistent barrier in digital collaboration, often rooted in inconsistency rather than software limitations.

The interviewees explained that effective communication and collaboration require not just common tools, but shared protocols. Without agreements on how model data should be structured, what naming conventions to use, and which maturity indicators are in place, digital workflows become just as unclear, *if not worse*, as their traditional predecessors. Specifications like MMI, as highlighted by Garcia (2017), could address this challenge by clarifying what is developed, by whom, and for what purpose.

## 5.4 Practical barriers to on-site implementation

One of the most persistent obstacles raised in both literature and interviews is that BIM models are still rarely recognized as legally binding documents. Even when detailed models are produced, most projects still rely on 2D drawings for legal compliance. As one interviewee put it: We build from the drawings, because that is what the contract says. This reflects Disney et al.'s (2022) critique of outdated document hierarchies that support traditional workflows. The shift in AB 25 toward formally regulating the use of digital models across the entire construction process could challenge the dominance of drawings as the primary contractual reference, which goes in line with what Söderström (2024) explains. By introducing requirements for accessibility, traceability, and structured use of digital models, the draft contract signals a potential notion to challenge the current view of what makes up a valid and enforceable digital deliverable. Whether this shift will gain traction in practice remains to be seen, but for the discussion about MBDD, this is a step in the right direction.

Another issue that raised concerns was digital literacy and usage on-site. While office-based teams are generally more accustomed to working with model-based workflows, site personnel often rely on traditional practices and 2D drawings. This creates a fragmented workflow in which models are maintained in the background, while day-to-day decisions are still made using PDFs or printed drawings. Respondents described this dual system as inefficient, counterproductive, while also undermining confidence in model-based workflows. Some positive examples do, however, exist. Interviewee 4 talked about projects where dedicated VDC or BIM support was present on-site, where the adoption of digital workflows was noticeably smoother. In one case, described in literature by Disney et al. (2023), tailored model

views and on-site training acted as a bridge, filling the gap between model creators and on-site users. This shows that localized BIM support can decrease some of the barriers in on-site implementation. Still, isolated examples are not enough. Legal and cultural dependencies, and uneven training, continue to reinforce the use of 2D documentation, even in digitally mature organisations. For MBDD to succeed on-site, two areas could be addressed: Formal recognition of models as contractual documents, which is described by Disney et al. (2022). Training for on-site personnel is also an area to be addressed. Without progress in these areas, MBDD risks stalling at the office door and being exchanged for traditional workflows.

Respondents noted that on-site personnel often struggle with interpreting models, not just due to unfamiliarity, but because models themselves lack clear indicators of what is construction-ready. Without specifications like MMI, the risk of misinterpreting incomplete elements remains high. As noted in previous sections, LOD is inconsistently applied and can be misleading unless backed by verification. This study argues that an easily validated specification like MMI could reduce uncertainty by clarifying what elements are ready for use in construction and which are not. Using a specification and making sure that it is understood by project participants what it offers them could lead to reducing the risk of falling back on traditional workflows. Several interviewees described forward-looking approaches to improving trust and standardization in model-based workflows. One respondent discussed a data-driven method in which metadata is assigned to model elements easily through a robust centralized database already prepared for what data is supposed to be included and how this project is going to use it. This approach strengthens Whyte's (2019) vision of the digital ecosystem, where structured data and supporting tools guide and enable model development and usage in the background. Instead of manually adding large parts of information, companies can automate and standardize metadata across projects, but then, a robust centralized database and preparations are needed.

On the verification side of models, one respondent described the use of a gatekeeper tool that checks whether model elements meet the required maturity level before allowing them to be published in the model. These tools can act as a safeguard, ensuring that data is not only entered consistently but also validated against the project's predefined requirements. Although still under development, such systems represent an important step forward in quality control, shifting the verification from manual review to an automated process. In doing so, they save time and enable themselves to do other value-adding work, something that could be beneficial for project participants. Furthermore, if the model is verified and without errors, there is a chance that the barriers for on-site implementation of model-based workflows might decrease.

Together, this shows that the gap between MBDD and on-site implementation is not only legal, cultural, or technical. It is also about how information is structured, managed, and communicated.

## 5.5 Broader implications and summary of research objectives

As the previous sections have shown, the challenges surrounding MBDD are not isolated or purely technical; they are set across organizational routines, contracts, and working cultures. Despite the growing availability of digital tools and increasing industry presence around BIM, the actual implementation of MBDD remains split and inconsistent.

A recurring insight from the interviews is the disconnect between the capabilities of current models and the industry's readiness to use them. Models today can be rich in data, capable of supporting real-time collaboration, coordination, and used in planning. Yet they remain widely underutilized, sometimes sidelined due to a lack of shared or individual understanding about their function, maturity, and contractual status. In this sense, the implication is that the limitations of MBDD are not technological, but procedural and cultural. This aligns with arguments made by Volk et al. (2014) and Abualdenien & Borrmann (2022), who emphasize that technological change must be accompanied by structural and operational change.

Another key theme is the trade-off between early investment in model quality and the long-term benefits it may yield. Several interviewees stressed that developing robust BIM models in the design phase requires more time and financial resources. While Merschbrock & Munkvold (2015) do not directly address this trade-off, their emphasis on the need for structured BIM infrastructure before project start implies that early investment is critical for giving MBDD the best shot of succeeding. Many respondents believed the benefits justify the effort and cost by pointing out the reduced clashes or design interpretations. Still, without the whole organization or project being on the same track, the return on that investment might be lost. High-quality models by themselves are not enough, their value depends on how effectively they are embedded within the workflows. MBDD is not a standalone solution, but a part of a wider organizational and industry change.

The interviews describe an industry in transition. There is enthusiasm for using models beyond just visualisation; all respondents spoke positively about all the different possibilities included in model-based workflows. Yet, this enthusiasm often gets put down by the organisations or projects not responding in the same way to the enthusiasm, 2D drawings still dominate legally, specifications are inconsistently applied, and the digital competence varies across different disciplines and teams. The draft AB 25 contract directly addresses many of these points and, in a way, supports the enthusiasts in their view of model-based workflows. This step forward implies that model-based practices and MBDD are beginning to be normalised, which may help resolve or defend against some of the friction with MBDD in this study.

Some frustration raised in the interviews is that BIM is still often used only to produce drawings. This reflects the broader issue identified by Aibinu & Papadonikolaki (2020), who argue that BIM continues to be viewed as a backend documentation tool, rather than the collaborative enabler it could be. This reinforces the finding that, despite existing capabilities, industry norms and legal conventions continue to reinforce traditional workflows.

One of the challenges here is partial adoption. Models may exist, but they are neither fully trusted nor fully used. Yet this also represents an opportunity; many of the remaining barriers are organisational and not technical, meaning they can be changed. This aligns with Porier et al. (2017), who argue that cultural and procedural factors are the most critical to overcome. Interviewees pointed out that better outcomes could be achieved if MBDD is planned early in the project and supported by sufficient environments, such as well-prepared CDEs. Stronger leadership from clients, especially in how they specify deliverables, could also drive more consistent implementation.

Looking beyond project-specific concerns, Whyte (2019) offers a broad perspective. She frames digital workflows as a part of a wider ecosystem of digital delivery, one in which transformation comes from integrating not just models. From this view, MBDD is not the final goal, but a step toward a more connected digital project environment. It also hints at a future where models are connected with predictive planning or management, further increasing the relevance and value of digital project environments.

## 5.6 Reflection on the central challenges of model-based design delivery

Drawing together the insights from previous sections, this part of the discussion emphasizes the main challenges associated with MBDD mentioned in this study. The aim here is not to restate what has already been said, but to reflect on how the identified challenges are interrelated and what they collectively say about the current state of MBDD.

At the foundation lies a shift in how design information is represented and understood. BIM offers clarity and accessibility beyond what traditional drawings can achieve, especially for project participants without formal design training. However, as this study shows, the absence of visual cues such as a drawing scale in models introduces new uncertainties. Without these boundaries, model elements can appear more complete than they are. This creates uncertainty about what can be relied on, especially in the absence of shared standards or specifications to communicate maturity. In short, increased visual accessibility comes with a new demand: to develop standards that define how information should be trusted, interpreted, and acted upon.

This directly connects to the use of specifications like LOD and MMI. While LOD is widely known, its real-world use is often symbolic or inconsistent. Interviewees described a lack of responsibility for defining or validating LOD levels, making the specification more of a label than a reliable indicator or specification. In contrast, MMI was viewed by some as a more structured and actionable system, capable not only of classifying content but of tracking completeness, approval status, and readiness for use. The value of MMI lies in its ability to assign clarity where uncertainty exists, especially in complex, multi-disciplinary projects. Its potential to improve trust, traceability, and coordination makes it a recommended candidate for wider adoption.

Communication and collaboration remain critical challenges. While MBDD can enable integrated workflows, it introduces some uncertainty: what does the model mean, who is responsible for it, and when is it reliable? These questions are rarely answered across disciplines or projects. Without shared definitions or structured maturity indicators, teams risk being misaligned, even when using the same model. As several interviewees noted, digital collaboration tools are only as effective as the standards and expectations that surround them.

One of the clearest consequences of this uncertainty is the limited trust in models on-site. Respondents described scenarios where incomplete or unverified models led to hesitation or rework. While manual quality checks are common, automated validation remains rare, but possible and under development. This uncovers another gap: trust in model data is not yet regulated. To fill this gap, the industry should establish clear, enforceable expectations for model quality, starting from early design and continuing through to delivery, supported by specifications like MMI into both workflows and contracts, ensuring that model maturity is not assumed, but actually demonstrated. In summarizing the findings, it becomes clear that the challenge is not whether MBDD works in theory, but whether it is implemented with the necessary alignment, structure, and commitment across the project and its participants. Through every theme explored in this thesis, representation, specification, communication, and implementation, the absence of shared standards remains a limiting factor.

This is where the true promise of MMI becomes clear for us as authors. It not only addresses isolated technical concerns but also offers an easily understood and implemented standard specification: structuring uncertainty, clarifying roles, and providing a common language are among some of the upsides of MMI. It could serve as an enabler, making MBDD operational. While no single specification will solve all challenges, this study suggests that adopting MMI could move the industry closer to model-based practices and MBDD. The most significant obstacle to MBDD is not resistance or complexity, but uncertainty. Without certainty on how models should function as deliverables, teams will continue to rely on familiar tools and informal workarounds. Formalizing model expectation, aligning practices across disciplines, and embedding specifications into workflows are key steps toward making MBDD practical.

## 6. Conclusion

This study finds that while Model-Based Design Delivery (MBDD) is technically feasible, its effective use is still limited by legal constraints, contractual limitations, rigid procedures, and cultural resistance. The gap between the visual clarity of BIM models and the actual reliability or maturity of their content was particularly problematic. Additionally, the absence of a drawing scale, which traditionally helped guide interpretation in 2D deliveries, can make models harder to read when expectations are not clearly defined.

Specifications such as Level of Development (LOD) and Model Maturity Index (MMI) can help manage this issue, but they are often used inconsistently and rarely enforced through contracts. Furthermore, the effective use of LOD is heavily project-dependent, making it difficult to standardize at the company level, let alone across the entire industry. MMI demonstrated greater potential for standardization, at least at the company level, to support maturity tracking, validation, and communication of reliability. It has the potential to replace the function of the scale in 2D; however, to be effective, it needs to be used more widely across projects, implemented early, and followed through on during actual project delivery.

The study also highlights that while MBDD has improved day-to-day collaboration and information sharing between disciplines, challenges remain. Even in projects with high levels of BIM adoption, issues such as uneven digital skills in design, unclear ownership, and reliance on outdated standards, along with a lack of interoperability of software, continue to limit the collaborative potential of model-based workflows. These challenges are made worse when clients do not set clear demands or fail to support the necessary conditions for models to be used with confidence on-site. This reinforces the need for clearer procedures and targeted education on how to use collaborative tools effectively.

Additionally, the continued dominance of drawing-based processes is a major bottleneck. Even when models are information-rich and coordinated, they are often downgraded into 2D deliverables due to a lack of trust, legal requirements, or client expectations. While automated validation processes and real-time synchronization platforms are becoming more accessible, the lack of legal recognition for BIM as a contractual document keeps the workflow mostly traditional.

This thesis contributes to research and industry by bridging the gap between model-based design delivery and the reality of its implementation in design and preparing it for construction phases. By examining the application of maturity specifications, influence of contractual expectations, and digital workflows through the perspective of practitioners, this thesis offers knowledge about some of the challenges that hinder MBDD. For researchers, it provides validation to earlier research and some nuance to existing perspectives of model-based workflows. For industry actors, it offers practice-oriented insights into how specifications like LOD and MMI can be better embedded into the workflows, procurement, and contracts, especially with standards like AB 25 putting more emphasis on digital models. As the industry

continues to transition toward model-based practices, this study identifies where better alignment is needed between technology, contractual structures, and practical workflows. Targeted improvements, such as clearer client requirements, stronger digital competence, and wider adoption of standardized specifications, could help realize the full potential of MBDD and support a broader shift toward more efficient, trusted, and coordinated digital delivery.

## 7. Future research

While this thesis has identified some key challenges and opportunities in transitioning to MBDD, it also shows that more areas require further exploration. Below some suggestions will be presented.

### **Client-led specification enforcement and procurement strategies**

One of the most critical gaps identified in this study is the lack of enforcement of maturity specifications like LOD and MMI. While technically defined, these specifications often remain informal or optional in project delivery. Future research should investigate how public and private clients can put in operation specifications through procurement strategies, standardized contract templates, and digital information delivery requirements. Comparative case studies of clients could offer insight into best practices for embedding model specifications from the start. This includes studying how specifications are interpreted in practice, and whether they create measurable improvements in model trust, quality assurance, or collaboration.

### **Legal recognition of BIM and contractual digital deliverables**

A persistent barrier is the legal precedence of 2D drawings over models, even in digitally mature projects. Despite having verified and detailed models, the industry still goes back to drawings as the legally binding document. Future research could explore how legal frameworks, contract law, and risk allocation can evolve to make BIM the primary contractual deliverable. This includes studying model-based contracting practices and how liabilities are defined when models replace drawings. What legal support might be necessary to support a full shift to model-based workflows? Another area could be identifying the limits of this transition.

### **Organizational capacity and cultural change for model-based workflows**

This thesis suggests that the bottlenecks to MBDD adoption are not always technical, but organizational and cultural. Many project actors still view the model as a supplementary design artifact rather than the central delivery document. Future research could investigate how organizational learning, training programs, and internal change management efforts affect MBDD success. For example, how do project teams respond to cultural resistance?

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## Appendix

### Further examples of traditional drawings and BIM counterparts

The following figures further describe and show visual examples of *Figure 3*.

*NOTE: The drawings shown are not to scale and are included for illustrative purposes only.*

*Source: Professional project visualizations anonymized for academic use only.*

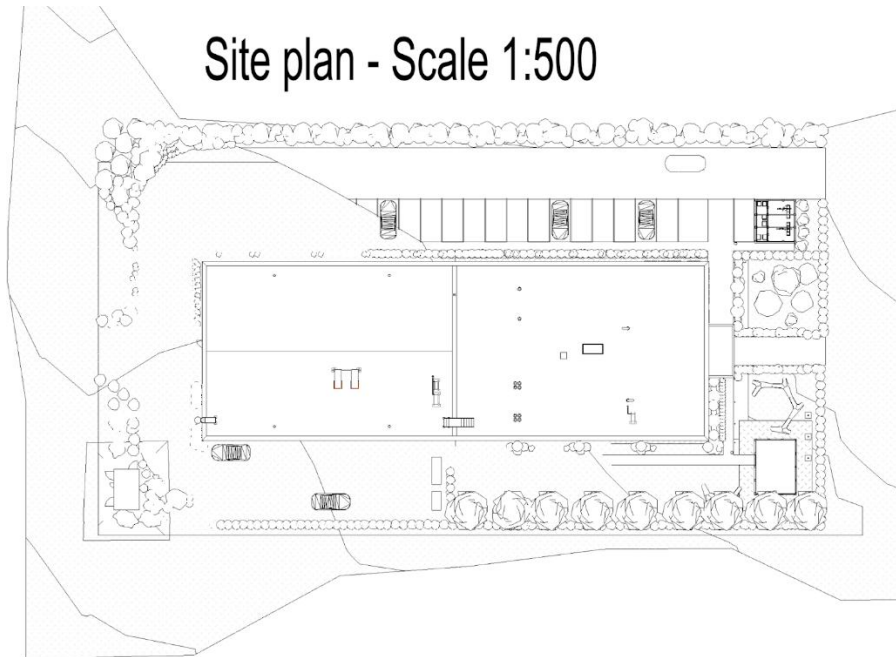


Figure 1. The traditional drawing of a site plan in scale 1:500

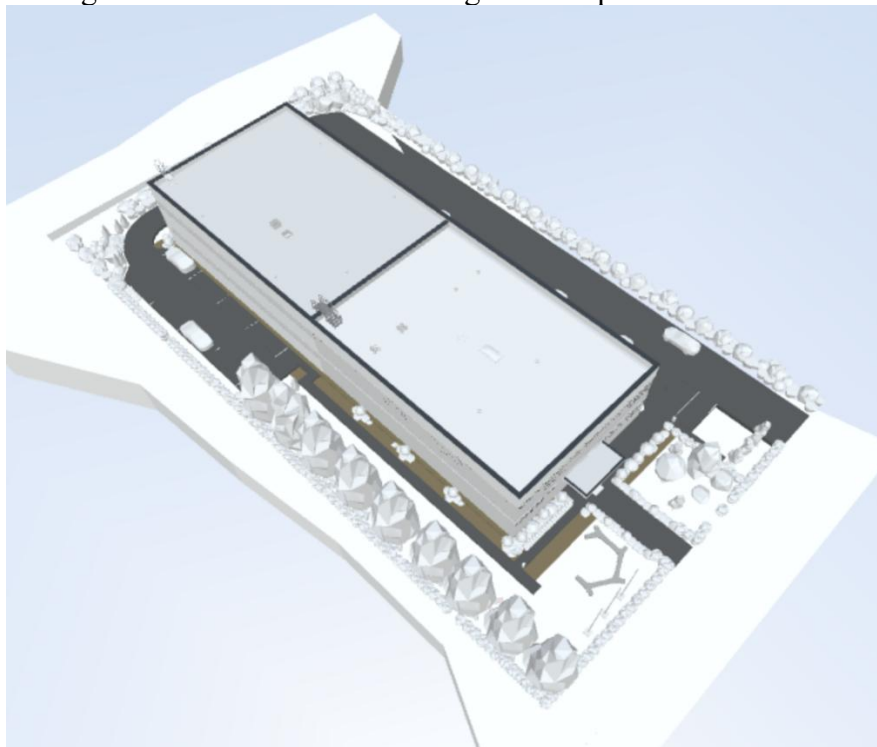


Figure 2. The BIM counterpart of the overview stage

2nd Floor plan - Scale 1:100

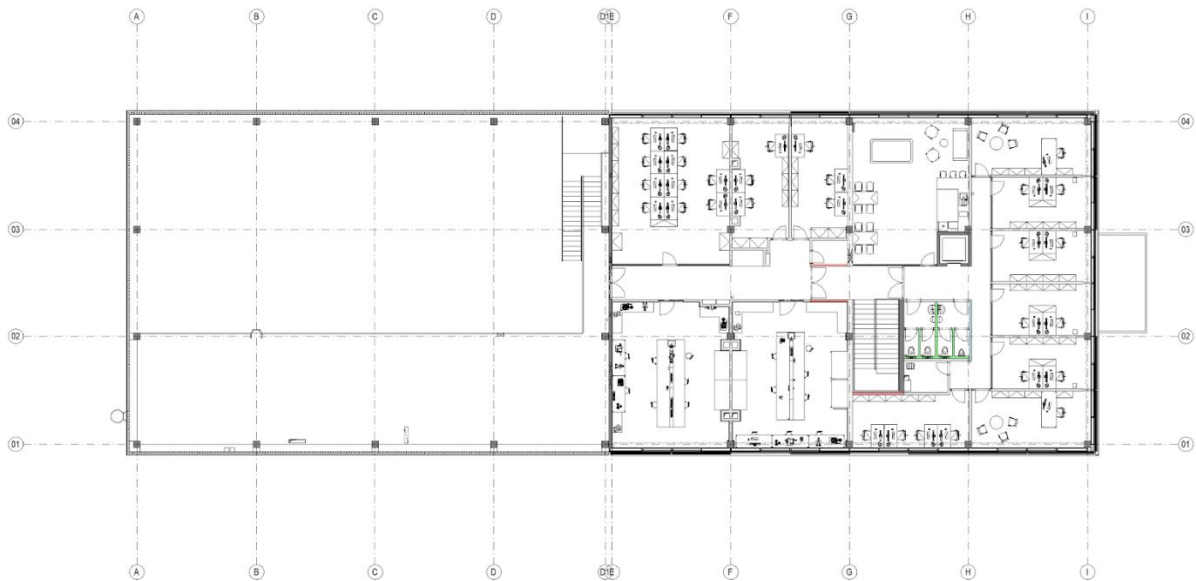


Figure 3. The traditional drawing of a floor plan made in scale 1:100

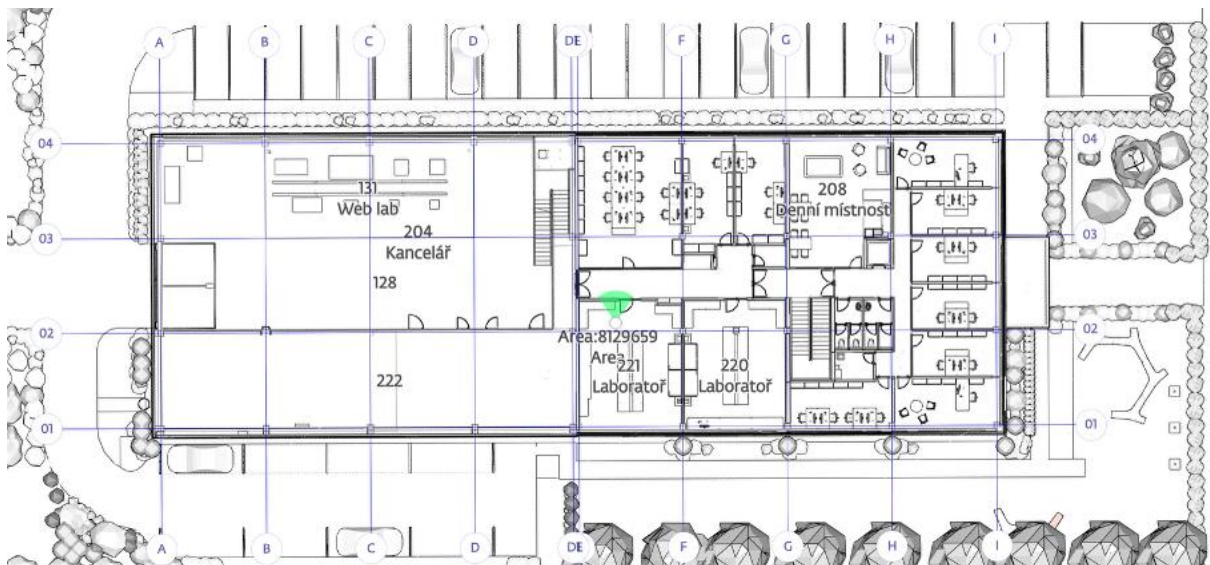


Figure 4. The BIM counterpart of the floor plan without scale

Cabinet Detail - Scale 1:5

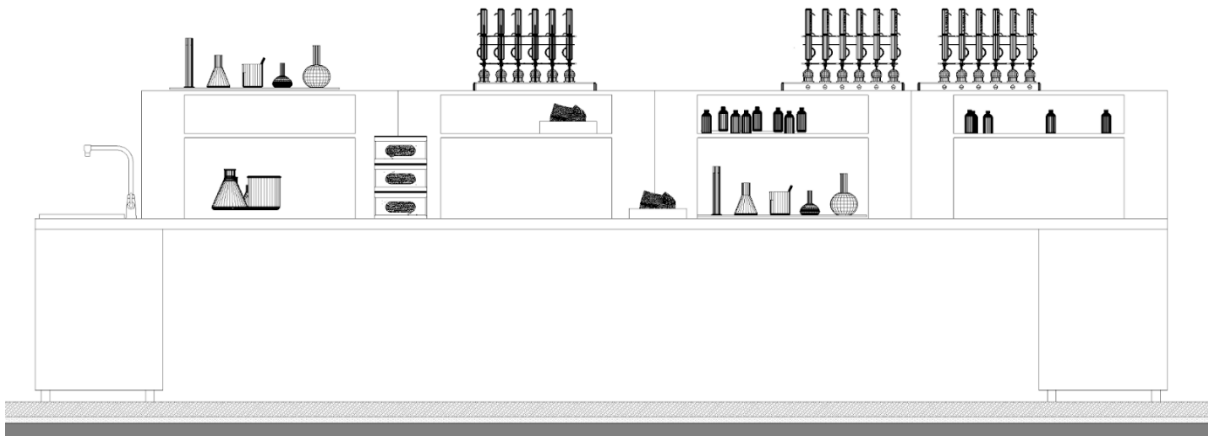


Figure 5. The traditional drawing of a custom-made furniture detail made in scale 1:5

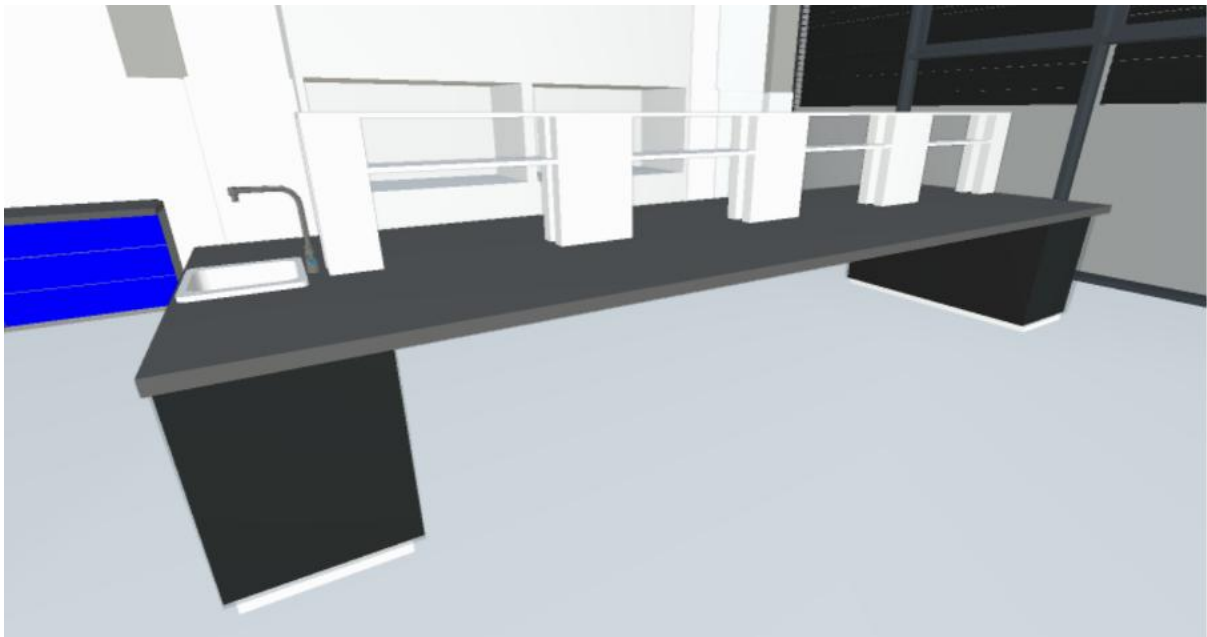


Figure 6. The BIM counterpart of the custom-made furniture detail



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