infrastructures

MDPI

Article

Navigating the Adoption of 5D Building Information Modeling: Insights from Norway

Haidar Hosamo Hosamo [1,2,*], Christian Nordahl Rolfsen [1], Florent Zeka [1], Sigurd Sandbeck [1], Sami Said [1] and Morten André Sætre [1]

[1] Department of Built Environment, Oslo Metropolitan University, St. Olavs Plass, P.O. Box 4, NO-0130 Oslo, Norway; crolfsen@oslomet.no (C.N.R.)
[2] SALab Sustainable Architecture Lab, Department of Architecture, Prince Sultan University, Riyadh 12435, Saudi Arabia
* Correspondence: haidarho@oslomet.no

Abstract: Exploring the integration of 5D Building Information Modeling (BIM) within the Norwegian construction sector, this study examines its transformative impact on cost estimation and project management, highlighting technological and skill-based adoption challenges. Through methodical case studies and interviews with industry experts, it is revealed that 5D BIM significantly enhances the precision of cost estimations and effectively reduces financial overruns in complex construction projects, indicating an industry shift towards its broader acceptance. The research sets out to explore current challenges and opportunities in 5D BIM, assess the usability and integration of software tools, and understand systemic barriers and skill gaps hindering further progress. These objectives lead to a detailed understanding of 5D BIM's role in improving economic and procedural efficiencies in construction. Suggesting its pivotal role in the evolving construction management realm, the study contributes important insights into 5D BIM's transformative potential and underscores its importance in advancing the construction industry's digital transformation.

Keywords: 5D BIM adoption; construction industry digitalization; cost estimation precision; Norway construction sector; skill-based challenges

Citation: Hosamo, H.H.; Rolfsen, C.N.; Zeka, F.; Sandbeck, S.; Said, S.; Sætre, M.A. Navigating the Adoption of 5D Building Information Modeling: Insights from Norway. *Infrastructures* **2024**, *9*, 75. https://doi.org/10.3390/infrastructures9040075

Academic Editor: Kay Smarsly

Received: 1 February 2024
Revised: 29 March 2024
Accepted: 5 April 2024
Published: 18 April 2024

1. Introduction

Building Information Modeling (BIM) is a comprehensive process that utilizes digital technologies to represent the physical characteristics of building projects [1–3]. Tracing its origins back to the 1970s, BIM evolved from the early concepts of computer-aided design (CAD) [4]. It was during this period that the foundational ideas of digitally representing buildings were conceived. Over the decades, BIM has transformed into a comprehensive digital representation technique, far surpassing traditional drawing or modeling [5]. It encapsulates not only the physical but also the functional characteristics of a building, providing a multidimensional view of construction projects [6].

The evolution of BIM is marked by the addition of various dimensions that enhance its utility and complexity. Researchers investigate the evolution of BIM from CAD systems, examining its history, technology, and philosophy while proposing a periodization based on idea, approach, and organizational culture, exploring BIM's dual nature as both a tool and a philosophy, reflecting on its developmental stages and future directions [7]. Starting with the initial three dimensions (3D) covering geometric aspects [8], BIM has expanded to include time management (4D) [9], cost estimation (5D) [10], sustainability analysis (6D) [11], and facility management (7D) [12]. Each dimension adds a new layer to BIM, enriching the process and offering a holistic approach to building design, construction, and management.

International open standards for digital data sharing have been pivotal in this transformation [13]. Such standards assist business owners, architects, engineers, contractors, and operators in becoming global industry leaders, reducing risks, saving time, and cutting costs [14,15]. A key player in this domain is buildingSMART, an open, neutral, and international non-profit organization [16]. It fosters improved information sharing throughout the building industry's lifecycle by dismantling information silos, thereby enabling better collaboration across different software platforms. The technical cornerstone of buildingSMART's efforts is the Industry Foundation Classes (IFC), which achieved ISO certification in 2013. In this context, it is crucial to recognize that the IFC is one among several standards being developed and refined by buildingSMART. This broader perspective underscores the comprehensive approach buildingSMART adopts in facilitating digital transformation in the construction industry. Alongside IFC, buildingSMART also develops other standards such as BIM Collaboration Format (BCF) for issue tracking [17] and Information Delivery Manual (IDM) for defining processes and data requirements [18]. These standards collectively contribute to a more integrated and seamless digital workflow in the industry.

The IFC schema was created to define a wide range of building information representations, supporting software interoperability within the construction industry [19]. IFC was developed to be an extensive framework for modeling across disciplines, providing a broad and general definition of objects and data to enable more accessible data exchange and detailed, task-specific modeling [19].

Currently, IFC is commonly used for information exchange between parties in specific business transactions. It also serves as a tool for archiving project information, either progressively during various project phases or as a comprehensive "as-built" collection of data for long-term preservation and operational purposes [20]. The necessity for updating IFC is acknowledged, with IFC 2x3 being the most common version currently in use and IFC 4 emerging as an updated, improved version addressing the limitations of the earlier version [21]. While the future clearly leans towards IFC4, the extensive market penetration of IFC2x3 means that this certification remains relevant, especially for applications introduced later in the project lifecycle [16].

The objective of this study is to explore the challenges and opportunities associated with the adoption and implementation of 5D Building Information Modeling (BIM) in the construction industry. As BIM has evolved from its origins in computer-aided design (CAD) to a comprehensive process encapsulating various dimensions, including geometric representation, time management, cost estimation, sustainability analysis, and facility management, its potential to transform the construction process has grown exponentially. This study seeks to understand how the incorporation of cost estimation into BIM (5D BIM) can enhance the efficiency, accuracy, and overall management of construction projects. To achieve this, we have employed a multifaceted research approach that includes a detailed case study and in-depth interviews with industry professionals.

The case study provides a practical examination of the use of Industry Foundation Class (IFC) files across different construction software platforms, highlighting the technical and procedural challenges encountered in implementing 5D BIM. This hands-on exploration serves as a foundation for understanding the complexities of integrating 5D BIM into current construction practices. Complementing the case study, interviews with professionals from various roles within the construction sector offer insights into the real-world application, perceptions, and recommendations for the effective implementation of 5D BIM. These interviews not only reveal the benefits and hurdles of 5D BIM adoption from a diverse range of perspectives but also connect the theoretical advancements in BIM to the practical realities faced by practitioners.

Together, the case study and interviews are integral to fulfilling the study's objective, providing a comprehensive view of the current state of 5D BIM in the construction industry. They highlight the need for standards like IFC to facilitate interoperability and collaboration across different BIM software, addressing both the potential and the limitations of current practices. Through this approach, the research aims to contribute valuable insights into advancing the application of 5D BIM, ultimately supporting the construction industry's digital transformation and enhancing project outcomes.

2. Background

2.1. Traditional Methods in Construction Cost Management

Cost management encompasses more than mere cost estimation; it involves applying management accounting principles, data collection, analysis, and presentation to effectively plan, monitor, and control project costs [22]. The Project Management Institute (PMI) has been instrumental in setting global standards for project management across various industries, as detailed in their Guide to the Project Management Body of Knowledge [23]. Similar efforts have been made by associations in the UK, Australia, and the USA, all aiming to standardize cost management across different project phases [24]. Specifically in construction, the project lifecycle is divided into pre-construction, construction, and maintenance and operation phases, each with distinct stages like briefing, building, commissioning, and eventual operation or end-of-life [25].

The cost management plan is a foundational process occurring at a project's inception or key mileston33es [26,27]. It dictates the methodologies and tools to be utilized for estimating costs, budgeting, and managing expenses throughout the project's lifespan. This plan is critical for early stage decision making, refining both project development and associated cost information [28].Cost estimation is a crucial step allowing stakeholders to project the financial resources needed based on a detailed assessment of project constraints, risks, and potential cost ranges. Estimates can be either conceptual or detailed, with traditional methods involving manual calculations based on 2D CAD documents [29].

Budget determination, which sets the financial baseline for a project, typically occurs early in the lifecycle or at specific milestones [30]. In construction, budgeting and cost estimation are often intertwined, necessitating frequent updates during the early design stages [31]. However, this constant revision can impact cost performance, especially with design changes and extra work. In addition, lifecycle cost analysis (LCCA) evaluates all costs from design to project completion [32], aiding in investment decisions and design option selection.

2.2. D-BIM

Five-Dimensional Building Information Modeling (5D BIM) represents a significant evolution in construction project management, adding time (4D) and cost (5D) dimensions to traditional 3D BIM [33,34]. It enables real-time cost estimation and effective budget management throughout a project's lifecycle by incorporating financial data into the digital project model [35,36]. This approach provides dynamic visualizations of financial impacts for each design and construction decision, transforming cost perception and management. In 5D BIM, each building component is linked to its cost, allowing precise expense tracking and early detection of potential over-runs crucial for exploring cost-saving opportunities and maintaining financial discipline. Cost estimation, a key focus in construction management research, involves the systematic calculation of project costs, which is crucial for financial control and future insights. This research categorizes costs into variable, fixed, direct, and indirect [37], each with specific implications for budgeting in construction projects.

The 5D BIM framework we proposed to show the 5D BIM concept depicted in Figure 1 represents the method for integrating multidimensional information into the construction management process. At its core, the model enhances the traditional 3D BIM with two additional dimensions, cost and time—hence the term '5D'. These two dimensions enable a comprehensive view of the project lifecycle, facilitating more effective decision making.

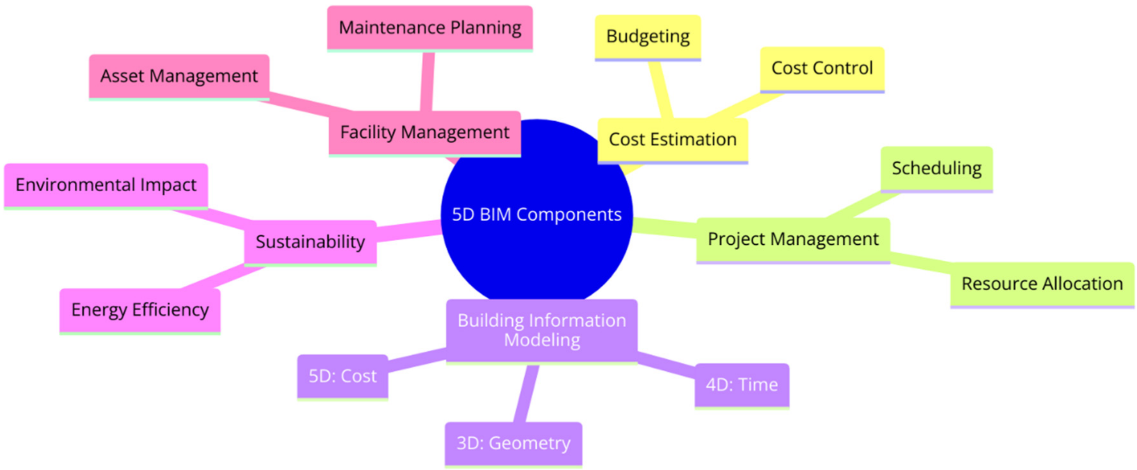


Figure 1. Illustrates the multifaceted components of the Five-Dimensional Building Information Modeling (5D BIM) framework. Central to the diagram is the 'Building Information Modeling' node, underscored by the pivotal dimensions: Geometry (3D), Time (4D), and Cost (5D). The surrounding nodes, delineated by a color scheme, denote the integrated processes and outcomes: yellow for management activities (e.g., Budgeting, Cost Estimation, Scheduling), blue for objectives (e.g., Sustainability, Energy Efficiency), and purple for the core BIM dimensions.

The central components of 5D BIM include 3D geometry, site context, and building components, which are the backbone of any BIM model, allowing for detailed visualizations of the physical space. Surrounding these core elements are critical management and operational aspects: maintenance planning, budgeting, cost estimation, scheduling, project management, and resource allocation. These elements are interconnected, signifying that changes in one aspect can dynamically update related information. For instance, modifications in the 3D model can automatically adjust the schedule and budget. This interconnectedness ensures that stakeholders have access to real-time, actionable data for asset management, facility management, environmental impact, sustainability, and energy efficiency.

In construction management, this framework is significant as it allows for meticulous planning, efficient resource allocation, and proactive cost control. It also promotes sustainability by enabling the simulation of energy performance and assessment of environmental impact throughout the building's lifecycle. Ultimately, 5D BIM supports stakeholders in making informed decisions that lead to cost savings, time optimization, and improved quality of the built environment.

2.2.1. Integrated Quantity Takeoff and Cost Estimating

The integration of quantity takeoff and cost estimating in 5D Building Information Modeling (BIM) has significantly transformed the accuracy and efficiency of material scheduling and cost predictions. Researchers indicate that BIM models expedite the production of material schedules, provided they contain the necessary information [38]. Nadeem et al. [39] highlight that combining bills of quantities with 3D visualizations enhances both the accuracy of the bill and project visualization. However, other researchers found that not all quantities can be directly extracted from BIM models, necessitating manual intervention by estimators and surveyors to supplement or validate the data [40]. The ability to integrate quantity takeoff tools with external cost databases enhances the precision of cost estimates, allowing estimators to link quantities to costs efficiently [41].

2.2.2. Advanced Cost Budgeting and Control Mechanisms

Additionally, 5D BIM enables estimators to rapidly evaluate cost and resource alternatives, thereby enhancing client understanding and value management [42]. This process is particularly useful in calculating the cost impacts of design changes early in the project lifecycle, thereby optimizing overall project management [43]. Moreover, integrating subcontractors' pricing information into the model facilitates real-time budget performance and forecasting [44]. For cost control, automated cash flow analyses and complex payment modeling enable precise and early-stage cash flow forecasting. Additionally, linking the model to contractor rates enables quick evaluations of costs-to-date, facilitating the assessment of budget variances and final cost predictions [45].

2.2.3. Enhancing Procurement, Change Orders, and Progress Payment Processes

The capabilities of 5D BIM tools extend to procurement processes, with the possibility of purchasing directly from the model, leveraging manufacturer-developed models for detailed specifications [46]. The dynamic link between the model and costing information significantly streamlines change order management. It allows professionals to quickly assess the cost implications of changes, enabling accurate simulations before construction [47]. This approach has led to reduced change orders in some projects. Furthermore, 5D BIM facilitates the validation of contractor progress payments by allowing users to select specific time periods, verify completed elements, and correlate these with their costs [48].

This integrated approach to cost management in 5D BIM, encompassing quantity takeoff, cost estimating, budgeting, and control, reflects a paradigm shift in construction project management. It offers a more precise, efficient, and dynamic process, addressing traditional challenges while opening new avenues for cost optimization and project control.

2.3. Software Used in 5D Building Information Modeling (5D BIM)

The integration of 5D Building Information Modeling (5D BIM) into construction projects significantly depends on a suite of specialized software programs. Each program is designed with unique capabilities that are vital for the successful adoption of 5D BIM, encompassing aspects from design and visualization to cost estimation and project management. For professionals in the construction industry, understanding and leveraging these tools is fundamental to harnessing the full benefits of 5D BIM.

Table 1 provides an overview of key software programs utilized in 5D BIM, detailing their features and applications. It is crucial to recognize that the mere availability of these sophisticated tools does not guarantee the realization of 5D BIM's full potential. The effectiveness of these tools is deeply influenced by several factors, including their integration into existing workflows, the level of user training and adaptation to project-specific requirements, and the overall management of the 5D BIM process.

The distinction between the theoretical capabilities of these software tools and their practical application in real-world projects is substantial. For instance, while Autodesk Revit offers comprehensive solutions for design, visualization, and data management, its optimal use in a 5D BIM context requires a well-structured implementation strategy that addresses technical and organizational challenges. Similarly, tools like BEXEL Manager, with its focus on 5D cost estimation, demonstrate significant cost-saving potentials, yet their benefits are fully realized only when tailored to the specific needs of a project and when users are adequately trained.

As we transition to discussing the challenges in 5D BIM implementation (Section 2.4), it becomes apparent that achieving the efficiencies, precision, control, and visualization promised by 5D BIM involves more than selecting the right software. It necessitates a comprehensive approach to overcoming barriers to integration, including the development of a conducive environment for innovation and learning transfer. The subsequent section will explore these challenges in greater detail, underscoring the critical need for a strategic framework that guides the selection, customization, and application of 5D BIM software in the construction industry.

Table 1. Building Information Modeling (BIM) software tools.

Software	Description
Autodesk Revit 2023 [49]	A leading tool in BIM for designing, visualizing, and coordinating building projects. It enables efficient data management and integrates changes across the model. Revit supports all building disciplines, facilitating collaboration, and offering 3D visualization, film, and VR capabilities.
Graphisoft Archicad 26 [50]	Known as the first tool for creating 3D models, initially developed in the 1980s for designing nuclear power plants, Archicad has a leading role in buildingSMART and is renowned for its modeling capabilities.
Solibri v9.12 [51]	A tool for analyzing, visualizing, quality assuring, and communicating in BIM. It uses the IFC open format for compatibility with all BIM tools, making it an essential tool for advanced model checking and quality assurance in BIM projects.
Sparkel v1.4 [52]	A relatively new, web-based platform that allows for quantity extraction from IFC files and creating custom measurement forms within models. It offers the ability to share links to quantities and add multiple models to a project. Sparkel continuously updates, including recent features for querying AI (GPT-4) for quantities and information from design documents.
BEXEL Manager v3.9.2 [25]	A BIM software integrating dimensions up to 6D, simplifying cost and time estimation. It offers cloud-based solutions and facilitates project monitoring, including using the EVM method and the critical path method for time management. The focus of this study is on the 5D cost estimation aspect of BEXEL Manager, known for significant cost-saving potentials.
Autodesk Navisworks Manager 2023 [53]	4D and 5D—Owned by Autodesk, Navisworks Manager supports both automatic and manual linking of schedule data from various timeline applications. It also allows for quantity takeoffs and model rendering, making it a versatile tool in 4D and 5D BIM contexts.
iTwo v2021 [54]	5D—iTwo is a software focused on delivering data for 5D BIM. It enables functionalities such as estimation, tendering, planning, subcontractor management, cost control, and billing processes, making it a comprehensive tool for 5D implementation.
Trimble Vico Office v2022 [55]	5D and 4D—Owned by Trimble, Vico Office offers model reviewing, quantity takeoff and estimation, planning, and project control. In its 4D capabilities, it provides a comparison between planned and actual scheduling with 4D visualization, enhancing project management and timeline tracking.

2.4. Addressing Research Gaps and Current Challenges in 5D BIM

The integration of 5D Building Information Modeling (BIM) into construction cost management heralds a transformative potential, promising enhanced efficiency, precision, control, and visualization. However, despite these recognized benefits, the practical application of 5D BIM remains in its nascent stages, with its full scope and limitations yet to be fully understood or realized in the industry.

Current research and industry practices highlight a pressing need for clarity on implementing 5D BIM effectively [56,57]. While Section 2.3 outlined the array of software tools available for 5D BIM, achieving the theoretical benefits of these tools in real-world projects requires navigating a series of complex challenges. These challenges range from the technical—such as software integration and data interoperability [58]—to the organizational, including staff training, change management, and adaptation to project-specific needs [59].

The gap in understanding how to leverage 5D BIM effectively is notable. Research tends to focus on isolated case studies or specific software capabilities without providing a comprehensive view of how to fully integrate 5D BIM into traditional cost management practices. This gap reflects the industry's early adoption stage, necessitating an environment that fosters innovation, learning transfer, and the development of best practices [60,61].

The historical shift in the construction industry from accountant-managed costs to the specialized roles of quantity surveyors or cost engineers illustrates a parallel need in today's digital economy. This transition underscores the evolving requirements in cost management and the critical role of specialists in adapting to these [62] As the construction industry progresses towards complete digitalization, identifying suitable 5D BIM solutions becomes imperative. The research aims to frame the development of 5D BIM in a way that resonates with both academic and industry needs, facilitating its integration into the digitalized working environment.

However, the industry faces the challenge of lacking a neutral and comprehensive framework for selecting the most appropriate 5D BIM solutions for specific applications [63,64]. Such a framework would aid practitioners in making informed decisions when integrating BIM into their cost-management processes and implementing 5D BIM software. The development of this decision-making framework is complex as it must encompass a deep understanding of business processes and cost management practices. It is essential to address these gaps to enhance the progress of 5D BIM in the industry and overcome the barriers to its broader adoption.

To address these gaps and overcome barriers to broader adoption, this research aims to contribute to the development of a decision-making framework that encompasses a deep understanding of business processes, cost management practices, and the specific challenges of implementing 5D BIM. By providing clearer guidance on navigating these complexities, the research seeks to facilitate the successful integration of 5D BIM into construction projects, enabling the industry to fully realize its benefits and advance towards complete digitalization.

2.5. Study Objectives and Research Questions Derived from Literature Review

The evolution of Building Information Modeling (BIM) has been a subject of extensive research and debate within the construction industry, with particular attention to the fifth dimension of BIM (5D), which incorporates cost data into traditional 3D models. Despite its innovative potential, 5D BIM presents a series of challenges that hinder its broader implementation. An exhaustive review of scholarly articles, industry reports, and case studies has revealed key themes and gaps in our current understanding of 5D BIM. From this review, the study's objectives have been articulated, aiming to address these gaps through a set of targeted research questions.

Objective 1: To identify and analyze the current challenges and opportunities in the implementation of 5D BIM. This objective is underpinned by the question, "**What are the current challenges for 5D BIM, and what opportunities might be available tomorrow?**" It seeks to dissect the immediate obstacles faced in applying 5D BIM and to forecast potential future advancements.
Objective 2: To evaluate the software tools available for 5D BIM regarding their usability, efficiency, and integration within the broader BIM framework. This objective stems from the question, "**What kind of software can be used in 5D, and how is it used?**" It is formulated based on literature findings highlighting the diversity of software tools for 5D BIM and aims to assess their practical application and efficacy.
Objective 3: To understand the systemic barriers and skill gaps that have prevented the further progression of 5D BIM within the industry. This is encapsulated in the question, "**What are the reasons that 5D BIM has not progressed further in the industry, and what is needed to take it to the next step?**" This question is critical for identifying the underlying issues hindering 5D BIM's advancement and determining the steps necessary for its broader adoption.

The comprehensive literature review has led to the formulation of pivotal research questions, setting the foundation for an in-depth exploration of 5D BIM. This paper aims to address the gaps identified in existing research, thereby contributing significantly to the advancement of BIM technology within the construction industry.

3. Methods

In the methodology section of our research, we present a structured and comprehensive approach that guided our investigation into the practical applications and challenges of 5D Building Information Modeling (BIM) in the construction industry. To provide a clear overview of our research methodology, we have devised a visual flowchart that delineates the key steps and processes involved, as shown in Figure 1. In the following sections, we will elaborate on each step of this methodology, offering a detailed account of our approach to data collection, analysis, and synthesis.

3.1. Literature Review

Figure 1 shows the method flow chart. Prior to formulating the research questions and tasks, a thorough literature review was conducted within the subject matter to understand the potential challenges within the topic. Search engines like Google Scholar and Scopus (Figure 2) were utilized, employing both English and Norwegian keywords.

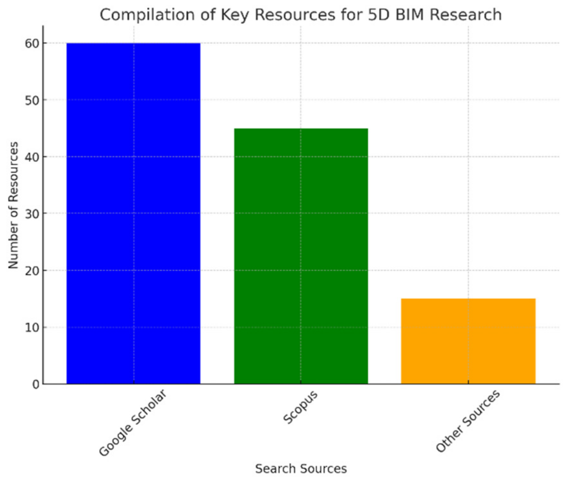


Figure 2. Compilation of key resources for Five-Dimensional Building Information Modeling (5D BIM) research.

In the comprehensive literature review encompassing the domain of 5D Building Information Modeling (5D BIM), a meticulous search strategy was concurrently employed in both Scopus and Google Scholar databases to secure relevant and recent academic literature. The approach was methodically structured, leveraging specific search terms like “5D BIM” and “5D Building Information Modeling” within the TITLE-ABS-KEY field in Scopus and directly in Google Scholar to pinpoint documents where these phrases were significantly present in titles, abstracts, or article bodies. The integration of Boolean operators, particularly in the format (“5D BIM” OR “5D Building Information Modeling”) AND “cost estimation”, was crucial in broadening the research scope to include studies that intersect the technicalities of 5D BIM with its cost estimation implications. Recognizing the fast-paced advancements in this field, the search was tailored to highlight recent developments, using the PUBYEAR > 2015 filter in Scopus and focusing on the most recently dated articles in Google Scholar. This dual-database strategy ensured a thorough and up-to-date collection of scholarly works, which is vital for understanding the current state and future potential of 5D BIM in the construction industry.

The literature search not only provided insights into relevant software for 5D BIM but also led to the discovery of books and articles pertinent to the subject. Additionally, the authors consulted various software websites and received recommendations from an external advisor. The literature search culminated in the compilation of a list of key resources, as presented in Figure 1.

3.2. Case Study

Besides the series of in-depth interviews, a case study is used in this paper. This approach is designed to provide a dual perspective on our subject matter. The case study, illustrated in Figure 3, forms the crux of our initial analysis. It focuses on the practical challenges and advantages inherent in the importation and utilization of Industry Foundation Class (IFC) files across various construction software platforms. The purpose of starting with this case study is to offer readers a foundational understanding of the software's functionality and to shed light on the various challenges encountered during its use. This groundwork is essential before progressing to the interview segment, where we aim to enrich our understanding through expert insights and experiences. To elaborate more, the utilization of a case study in this research is strategically chosen to explore the real-world complexities and challenges of implementing 5D BIM in the construction industry. This methodological approach is instrumental in achieving our second objective: to critically evaluate the usability, efficiency, and integration of 5D BIM software tools within existing construction workflows.

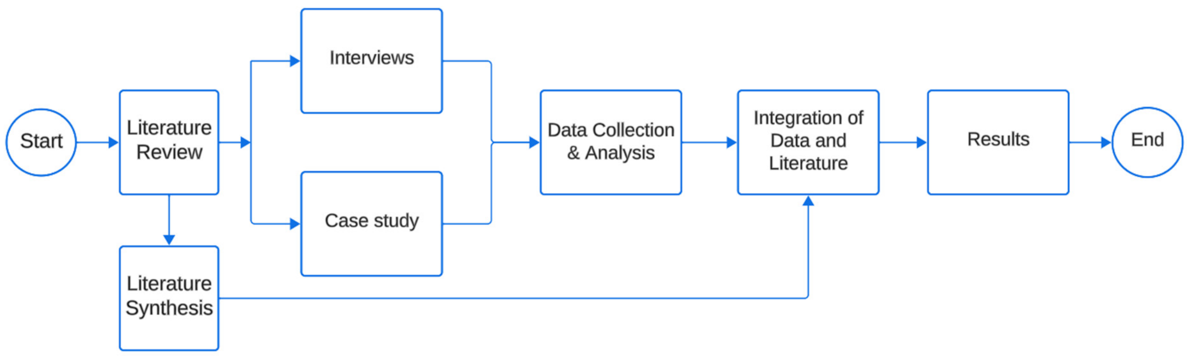
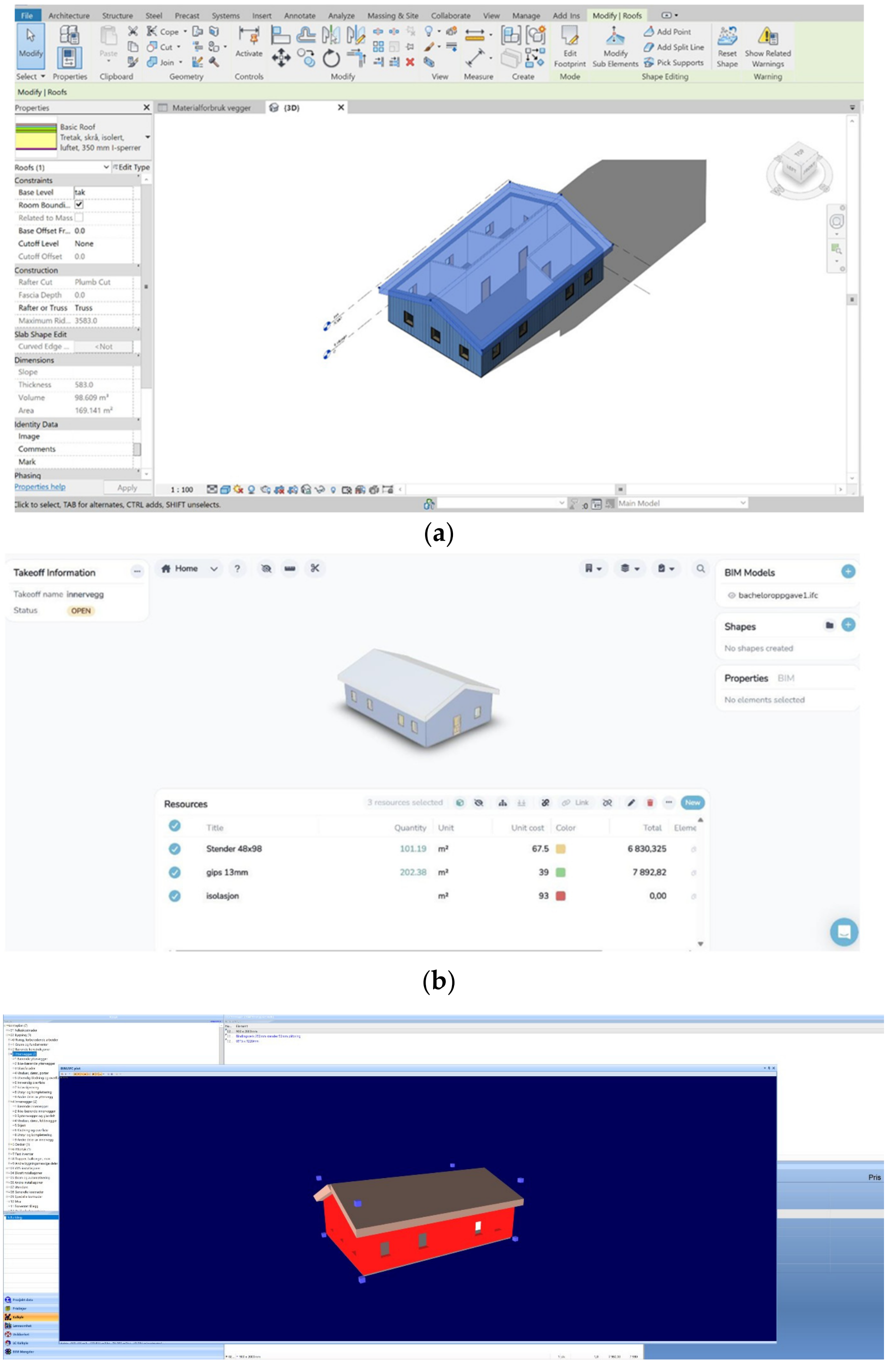


Figure 3. Flowchart of research methodology for Five-Dimensional Building Information Modeling (5D BIM) study.

The genesis of this case study arose from the difficulties frequently encountered in importing IFC files into construction software. To thoroughly investigate these challenges, we developed a basic yet comprehensive model in Revit 2023. This model was specifically designed to test the process of transferring data to three distinct software environments: Sparkel v1.4, Bexel v3.9.2, and ISY Calcus V 7.0. The selection of these particular software platforms was influenced by recommendations from the AF group. They highlighted the prevalent use of ISY Calcus V 7.0 in the industry and brought attention to Sparkel, a new and emerging software firm, suggesting its potential future relevance.

The Revit model (Figure 4) included a variety of structural components, such as doors, windows, interior and exterior walls, roofs, and floors. A critical aspect of this model was the inclusion of detailed construction elements, like wind barriers and insulation, to mirror a realistic construction scenario. In an effort to ensure a level playing field for comparison across all software platforms, uniform pricing was input into each program. This step was vital to guarantee that any variations in outcomes could be attributed to the software's functionality rather than external pricing variables.

The overarching goal of this case study was multi-faceted, aiming to provide a comprehensive evaluation of several critical aspects of software performance in the context of IFC file importation and utilization. Firstly, we sought to assess the ease with which data could be imported into each software environment. This criterion is crucial in understanding how user-friendly and accessible these platforms are for professionals in the construction industry. Additionally, our study aimed to evaluate the efficiency and accuracy with which each software could extract quantities from the model. This aspect is particularly significant in the construction industry, where precise quantity estimations are fundamental to project planning and budgeting.



(**a**)

(**b**)

(**c**)

Figure 4. Demonstration of quantitative control and quality assessment in: (**a**) Revit, with a focus on compliance with design standards; (**b**) Sparkel, highlighting performance specification metrics; and (**c**) ISY Calcus, emphasizing the identification and rectification of errors.

Another critical area of investigation was the integration of pricing within these software platforms. Given the uniform pricing applied across all programs, our study aimed to discern how effectively each software could link this pricing data with the extracted quantities, thereby impacting the overall feasibility and efficiency of project cost estimations. Also, the study was designed to provide insights into the user-friendliness and learning curve associated with each software. In an industry that is often perceived as slow to adopt new technologies, understanding these factors is pivotal. It helps to identify whether the complexity and usability of software act as barriers to their adoption and integration into standard industry practices. This case study, therefore, holds significant importance in both a practical and academic context, contributing valuable insights into the evolving landscape of construction technology.

3.3. Interviews and Data Collection

In our research methodology, we meticulously planned and executed interviews as a central component of data collection. Each interview session had a duration of up to 45 min and was conducted digitally via Teams, with audio recordings captured using the University of Oslo's Dictaphone app. This method allowed us to preserve the content and nuances of the discussions for later analysis.

To ensure a well-rounded perspective on the use of 5D BIM in the construction industry, we strategically selected a diverse group of interview subjects from AF-Gruppen. This selection encompassed various roles within the industry, including an Acquisition Manager, a BIM Technician, an Estimator, a Technology Leader, and a BIM and Digitalization Manager. Additionally, we conducted an interview with a Technology Leader from Sparkel, a new and emerging software firm in the 5D BIM domain. The interview durations varied between 15 and 27 min, reflecting the diverse expertise and backgrounds of the participants.

This approach aimed to extract rich, multi-faceted insights into the application and perception of 5D BIM in professional settings. Prior to the interviews, an extensive process was undertaken to draft, refine, and validate a set of pertinent questions. These questions were designed not only to be relevant and capable of eliciting in-depth responses but also to maintain a natural conversation flow. Importantly, we ensured that the questions did not breach confidentiality constraints, given the public nature of the research. This meticulous planning and diverse selection of interview subjects were instrumental in providing a comprehensive understanding of the practical applications and challenges of 5D BIM in the construction industry.

The selection of interview subjects and the methodology employed in our research were guided by best practices in qualitative research. We ensured that our interviews covered a spectrum of roles and perspectives within the construction industry to obtain a well-rounded view of 5D BIM's impact. This approach is consistent with the principles of qualitative research, which emphasize the importance of diversity in participant selection to enhance the validity and generalizability of findings [65].

Additionally, the collaboration with AF-Gruppen and the assistance of their BIM and Digitalization Manager in facilitating access to interview subjects contributed to the reliability and comprehensiveness of our research. This approach aligns with the principles of qualitative research that advocate for obtaining data from multiple sources to attain a balanced and holistic understanding of the phenomenon under investigation [66].

Furthermore, the interview with the Chief Technology Officer (CTO) from Sparkel provided a unique perspective on the development of 5D BIM and cost estimation software. This insight is crucial as it sheds light on the evolving landscape of 5D BIM technologies, particularly from the viewpoint of a software firm at the forefront of innovation. Such diverse perspectives enhance the credibility and depth of our [65].

Table 2 outlines the diversity of roles represented in the interviews, along with the varying durations of each interview session. It provides a clear snapshot of the demographic characteristics of the interviewees, ensuring transparency and completeness in our research documentation.

Table 2. Demographic overview of interviewees.

Interviewee	Role	Interview Duration (min)
1	Acquisition Manager	23
2	BIM Technician	15
3	Estimator	27
4	Technology Leader	19
5	BIM and Digitalization Manager	26
6	Technology Leader (Sparkel)	22

3.4. Sample Size and Justification

The selection of interviewees for our research was guided by a purposive sampling approach. Purposive sampling, also known as judgmental or selective sampling, involves deliberately choosing participants who possess specific knowledge or experiences relevant to the research objectives [65]. In our case, we aimed to capture a diverse range of perspectives within the construction industry regarding the use of 5D BIM. Therefore, we carefully selected individuals with various roles, including an Acquisition Manager, a BIM Technician, an Estimator, a Technology Leader, and a BIM and Digitalization Manager from AF-Gruppen. Additionally, we conducted an interview with a Technology Leader from Sparkel to gain insights from a software firm's perspective.

The sample size of six interviewees was considered appropriate for our research objectives for several reasons. Firstly, qualitative research, such as in-depth interviews, often involves smaller sample sizes compared to quantitative studies, as the emphasis is on depth of understanding rather than statistical [67]. Secondly, the diverse roles and backgrounds of the interviewees provided a rich and multifaceted perspective on 5D BIM in the construction industry. This aligns with the principles of qualitative research, which prioritize obtaining comprehensive insights from a limited number of participants [66].

To ensure comprehensive and unbiased insights, a structured questionnaire was developed, focusing on themes such as the advantages and challenges of 5D BIM, the comparison with traditional project management methods, and the technological and skill-based barriers to its adoption. The questions were carefully designed to prompt detailed and reflective responses while avoiding leading or biased inquiries, thereby mitigating potential response biases. A sample of the questions included:

1. "Can you describe the main challenges you face when implementing 5D BIM in your projects?"
2. "How do these challenges compare with those encountered in traditional project management approaches?"
3. "What steps do you think are necessary to overcome these challenges and fully realize the benefits of 5D BIM?"

3.5. Data Analysis

The data obtained from the interviews underwent a rigorous process of qualitative analysis. This analysis followed established procedures for qualitative research, including the following.

1. Transcription: The audio recordings of the interviews were transcribed verbatim to create written records of the conversations. Transcription is a critical step to ensure that all nuances and details of the interviews are preserved [68].
2. Thematic Analysis: Thematic analysis was employed to identify recurring themes, patterns, and meaningful insights within the interview data. This process involved systematically coding the transcripts, categorizing codes into themes, and iteratively refining the themes to ensure accuracy and validity [69].

3. Data Validation: To enhance the trustworthiness of the findings, data validation techniques, such as member checking, were employed. This involved sharing the analyzed findings with the interviewees to verify the accuracy and authenticity of the interpretations [65].

The qualitative analysis aimed to uncover key themes related to the application and challenges of 5D BIM in the construction industry, as well as to provide nuanced insights from the perspectives of the interviewees.

4. Results

In this section, we present the key findings of our research, which address the following research questions outlined in the introduction.

4.1. Current Challenges in Implementing 5D BIM

4.1.1. The Results from the Case Study

The successful implementation of 5D BIM in the construction industry hinges upon various factors, including the choice of software programs and the efficient handling of Industry Foundation Class (IFC) files. In this subsection, the current challenges faced by professionals when adopting 5D BIM are revealed through our rigorous evaluation process. To provide a comprehensive overview, we present valuable data and insights collected from our examination of different software programs, offering a nuanced perspective on the obstacles encountered during the implementation of 5D BIM.

Within our exploration, Table 3 categorizes the software programs based on their deployment type, distinguishing between cloud-based and downloadable options. This distinction is vital as it directly impacts accessibility, collaboration, and user experience. By examining the deployment type of each program, we gain insights into the diverse range of software solutions available to professionals in the construction industry.

Table 3. Type of program, download, or web-based.

Type of Program	Sparkel	BEXEL Manager	ISY Calcus
Cloud or Download	Cloud-based	Download	Download

Simultaneously, Table 4 explores the intricate process of importing IFC files, a critical step in 5D BIM implementation. This table offers a detailed account of challenges encountered during the importation process, with a focus on three essential aspects: quantities, area retrieval, and model retrieval. Through the experiences and difficulties documented with specific software programs, namely Sparkel, Bexel Manager, and ISY Calcus, we gain valuable insights into the complexities of data importation in the context of 5D BIM. These challenges shed light on the practical obstacles faced by professionals and provide essential information for improving the adoption and use of 5D BIM in construction projects.

Table 4. Import of Industry Foundation Class (IFC) with quantities.

	Sparkel	Bexel	ISY Calcus
Experience	Feels very simple to import IFC file.	Bexel provides a good overview for finding objects in imported IFC file. Quantities were incorrect when the wrong IFC edition was used.	Experienced annoying problems with retrieving quantities. Objects like windows were split up and placed elsewhere: 10 windows under an inner wall and one on an outer wall.
	Both Sparkel and Bexel have the same setup on how materials or elements are retrieved from the IFC file.		Cannot choose what to retrieve in terms of quantities. This is automatic.

Table 4. *Cont.*

	Sparkel	Bexel	ISY Calcus
Area Retrieval	Correctly linked area. (Chose to link manually, as it went very quickly.) Otherwise, I have a fairly similar approach to retrieving IFC data as Bexel.	Did not manage to link the area correctly the first few times. (Restarting the program resolved many of the issues.)	Had some trouble getting the area correctly linked. This was resolved by changing the IFC version.
	It displays more area compared to Revit: 154.7 m^2 > 152.473 m^2. Measuring the area at the center of the exterior wall.	It shows the same area as Revit: 152.473 m^2 Measuring the area at the center of the exterior wall.	It displays the same area as Revit: 152.473 m^2 Measuring the area at the center of the exterior wall.
Model Retrieval	All building parts were correctly imported.	All building parts were correctly imported.	A small portion of the roof was missing at the top of the ridge. This caused the roof to be divided into two. (This might be due to an issue with the IFC format.)

4.1.2. Navigating the Complexities of IFC Quantity Imports

The process of importing IFC quantities, while theoretically straightforward, involves intricate challenges in practice. The primary task is the verification of data accuracy post-import, necessitating a comparison with the original Revit files and supplemental manual checks to ensure fidelity in the quantity of data. This verification process is critical due to occasional inconsistencies in the software's aggregation of similar materials.

Experience with BIM software can vary significantly across different platforms. For instance, Sparkel's design prioritizes user accessibility, which may facilitate quicker adaptation for new users. Conversely, BEXEL Manager requires a more comprehensive understanding from the outset, indicative of a more complex interface. ISY Calcus V 7.0 offers a systematic approach to cost calculation, though it also necessitates a foundational grasp of its detailed information presentation for effective use. The capacity for direct modifications of linked quantities varies among these programs, influencing their overall user operability.

The practical operability of BIM software can also be influenced by the interface layout and screen area requirements. Sparkel operates efficiently within the confines of a standard PC monitor, while BEXEL Manager and ISY Calcus V 7.0 benefit from larger or multiple screens to manage extensive data sets and detailed models. In ISY Calcus, the manipulation of price lines is restricted, which could lead to a more methodical process for error rectification. An 'undo' feature is notably absent in some platforms, which may impact workflow efficiency. Such operational nuances were systematically observed and cataloged to provide an objective evaluation of each program's user interface and functionality.

4.2. Evaluating Software Capabilities in Construction Project Management

In addressing the opportunities and benefits presented by 5D Building Information Modeling (BIM) in the construction industry (the second research question), we explored the evaluation of software capabilities within the context of construction project management. This assessment highlights the functionalities of various calculation software programs that can significantly impact project management processes.

The capabilities embedded within various calculation software programs offer a range of functionalities to streamline construction project management. Sparkel stands out with its pre-configured element register that includes pricing, allowing for an efficient connection of costs to model quantities. While BEXEL Manager and ISY Calcus lack this feature, ISY Calcus compensates with a comprehensive element register complete with predefined prices for building components such as interior walls.

The aspect of 4D planning—integrating the project timeline with the model—is notably absent in Sparkel and ISY Calcus, while BEXEL Manager provides this advanced feature, enhancing the project management process. All three programs offer quantity takeoffs from the model, enabling accurate material measurement and cost estimation. When it comes to documentation, Sparkel allows users to annotate directly on the model, BEXEL Manager facilitates the attachment of documentation for a 6D BIM perspective, and ISY Calcus enables the linking of information to the pricing line associated with the BIM model.

Linking the model to revenue streams such as invoicing is not possible in Sparkel and BEXEL Manager without additional software, whereas ISY Calcus provides this integration through ISY Bygg Office. While Sparkel and BEXEL Manager do not support standard connections, ISY Calcus allows for such integrations, potentially improving adherence to industry standards.

The visualization of total costs differs across the software: Sparkel provides a comprehensive but slightly cluttered view, BEXEL Manager categorizes costs neatly as defined in the cost items, and ISY Calcus offers an advanced and detailed presentation of all expenses per element and material. The ability to see when prices were last edited is available in Sparkel and BEXEL Manager but not found in ISY Calcus.

These programs also offer additional modules for purchase, enhancing their capabilities. For example, Bexel has a feature that allows for the monitoring of project costs, assuming the appropriate license is available. The use of the model itself is critical in verifying the correct linking of all components. It is essential for the software to provide user-friendly layer management and measurement tools, enabling users to verify details like corner measurements, which have been known to present issues. This holistic view of the software's usability underscores the importance of not just the model's accuracy but also the ease with which it can be manipulated and assessed for a successful project outcome.

The comprehensive assessment of calculation software programs reveals varying degrees of user accessibility and learning curves. Sparkel is recognized as the most straightforward platform, offering a user-friendly and intuitive interface that makes navigation and data entry relatively effortless. BEXEL Manager ranks as the second easiest to learn, with additional features and tools that tend to emerge as the user becomes more familiar with the program, necessitating a bit more time and experience to fully harness its capabilities.

ISY Calcus, while not inherently the most challenging, presents the most obstacles and issues during use. It demands a deeper understanding of potential errors and the intricacies that may arise, requiring a user to have a more comprehensive grasp of the software's inner workings. Each program's total evaluation reflects its ease of adoption, with an emphasis on how quickly a user can become proficient and effectively input data, as well as navigate potential errors and the overall complexity of the software environment.

4.3. Insights from Industry Professionals

The insights presented in this subsection emerge from a series of structured interviews conducted with professionals across the construction industry, aimed at understanding their perceptions and recommendations for the adoption of 5D Building Information Modeling (BIM). The diversity of roles among the interviewees, including those from management, technical, and software development sectors, provides a broad perspective on the current state and potential of 5D BIM in enhancing construction project outcomes. This exploration into the professional landscape serves to directly inform our study's objective of delineating the practical challenges and advantages of 5D BIM implementation. Through their experiences and viewpoints, we sought to capture a holistic understanding of 5D BIM's role in the construction industry, thereby grounding our research in the realities of current practice and paving the way for actionable insights into its more effective utilization [25].

4.3.1. Utilizing BIM and Estimation Software in Construction

The data collection for this study was conducted through in-depth interviews with various individuals holding different positions and experiences in the construction industry. The questions posed to each interviewee were primarily identical, except for the interview with Sparkel, which had a slightly different structure focusing more on the software itself, including issues, solutions, and the interaction between software developers and users in the construction industry. The responses provided valuable insights for a more objective result, highlighting similarities and differences in perspectives, particularly regarding the use of 5D-BIM/Estimation in the construction sector.

The current usage of software in the construction industry was explored in these interviews. When asked about the software being used and their likelihood to continue its use, the answers were unanimous. AF Group predominantly used ISY Calcus and ISY BYGGOFFICE. A calculator provided comprehensive details: "We use ARCHICAD for modeling and the advisors bring REVIT, we use SOLIBRI, we use TEKLA, Simplebim, and for estimations, we use BYGGOFFICE and ISY CALCUS". Additionally, it was mentioned that the ISY Description is used for tender descriptions. When questioned about their satisfaction and future use of these tools, one interviewee stated, "Yes, we use them almost daily, so we will continue to do so". However, there was a consensus that there is room for improvement, especially in the integration and development pace of these tools.

The use of the 4D time aspect was also discussed, and it appeared that it is not currently utilized due to its lack of perceived utility. This aspect, along with cost estimation, is supposed to be a primary use case for Sparkel. The application of BIM Estimation in projects was also explored, determining its suitability for both large and small projects, though rehabilitation projects were noted as more challenging. One interviewee expressed, "We use it in small projects and large ones like the Viking Age Museum. We use it universally, adapting our standard model and calculations to get accurate information immediately". Another added, "It works for rehabilitation too, though it's easier with new constructions. But we manage with rehabilitation projects as well". It was mentioned that projects need to be larger than 20 million to justify the use of these tools, as smaller projects are simpler to manage manually. The primary contract forms used were total contracts and collaborative contracts.

4.3.2. Assessing the Current Value and Challenges of 5D BIM in Construction

The current utility of 5D BIM in cost estimation was a primary focus of the interviews conducted for this study. A common benefit identified across responses was the ease of information flow. This improvement in information accessibility has made it simpler to maintain an overview of quantities and changes during a project's progression, facilitated by a visual model. As one estimator (#I2) remarked, "You have all the information in one model, a single point of reference". This ease of managing changes and visualizing cost implications was echoed by another interviewee (#I2, a BIM Technician), who noted the convenience of automatically updating quantities in the BIM model.

The interviewees were also asked about the challenges faced by construction firms that have not implemented 5D BIM compared to those with dedicated BIM departments. An interviewee (#I1) pointed out the advantage of having internal expertise, which helps in posing the right questions to extract useful information from the model. Another participant (#I2) mentioned that building a model from scratch provides better control over the project and helps to identify challenges during the modeling phase. The importance of being able to quickly adjust and observe the cost implications of changes was a recurring theme in the responses.

Furthermore, the discussion explored how 5D BIM serves as a decision-making tool in the early stages of project design. The visual element of BIM, allowing for quick comparison and evaluation of different design alternatives, was highlighted as a significant advantage. One respondent (#I4, a Technology Leader at Sparkel) emphasized the direct comparability of different design bases, while another (#I5) pointed out the opportunity to explore various design options, enhancing control and flexibility in building projects.

The aspect of time-saving, a common benefit associated with BIM and other digital tools, was also explored. Although the participants indicated that using BIM for estimations does not necessarily save a lot of time, it offers other advantages. One respondent (#I2) noted that while model creation might take longer, the availability of listed quantities for quick extraction compensates for the time invested. The responses collectively suggested that while initial time investment in BIM is significant, the subsequent phases of the project benefit from improved information quality and traceability due to the digital nature of the process.

4.3.3. Cost Savings Trends in 5D BIM Implementation across Different Project Scales

The integration of 5D Building Information Modeling (BIM) into the construction process has been associated with a trend of increasing cost savings across projects of varying scales. Figure 5 illustrates the percentage of cost savings achieved from the years 2015 to 2022, categorized by project size: small, medium, and large.

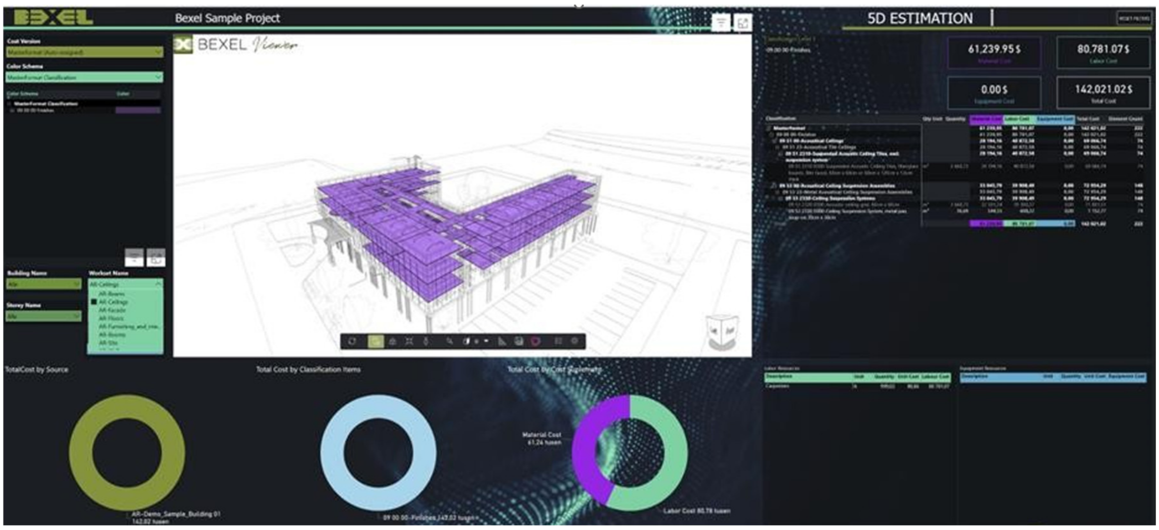


Figure 5. The Bexel viewer displays various elements where color coding, icons, and symbols provide insights into project data. The pie charts use color segments to represent proportions of different categories within the overall project scope, such as cost or material allocation. Icons and symbols within the interface likely correspond to specific functionalities, like navigation, editing, or data visualization tools, enabling an interactive exploration of the 5D estimation data. The detailed model in the center illustrates a structural component, possibly using color gradients or transparency to denote status or selection, facilitating a visual correlation with the quantitative data [25].

Observing the cost savings trajectory, it is evident that larger projects have consistently realized higher percentages of cost savings over the years. This pattern aligns with the complexity and scope of large projects, where the benefits of 5D BIM, such as accurate cost estimations and enhanced coordination, are more pronounced due to the scale of operations and resources involved.

From a modest beginning in 2015, where the cost savings were relatively low across all project sizes, there has been a notable upward trend. Small projects have exhibited a gradual increase in cost savings, suggesting that while the impact of 5D BIM is beneficial, it is less significant compared to larger projects. This could be attributed to the smaller scope and less complexity, which may not require the full extent of 5D BIM capabilities to manage costs effectively.

Medium-sized projects show a more variable pattern, with a significant rise in cost savings after 2018, indicating a growing maturity in applying 5D BIM methodologies within this segment. This could reflect an intermediate level of complexity in projects where the cost management aspect of 5D BIM starts to significantly counteract the initial investment in technology and training.

The large projects display the most dramatic increase, particularly post-2018, reaching the highest level of cost savings among the three categories by 2022. This steep rise suggests that as the construction industry becomes more adept at utilizing 5D BIM for larger projects, the return on investment grows substantially, underscoring the scalability benefits of 5D BIM.

This data underlines the positive correlation between the size of the construction project and the relative cost savings imparted by 5D BIM, reinforcing the strategic advantage for early adopters of this technology. As the construction industry continues to evolve, these trends provide a compelling argument for the broader adoption of 5D BIM, particularly in larger-scale projects where the potential for cost efficiency is most significant.

4.3.4. Efficiency Gains in Cost Estimation with 5D BIM

The adoption of 5D Building Information Modeling (BIM) has been pivotal in enhancing the efficiency of cost estimation processes in construction projects. Figure 6 compares the time spent on cost estimation using traditional methods versus 5D BIM, highlighting a clear distinction in efficiency gains.

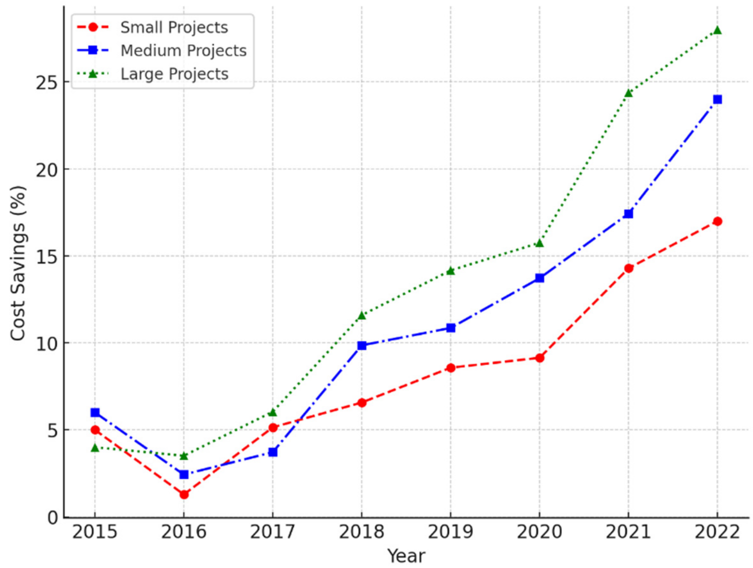


Figure 6. Trend analysis of cost savings achieved through Five-Dimensional Building Information Modeling (5D BIM) adoption in construction projects of varying sizes from 2015 to 2022.

The frequency distribution for traditional methods shows a wider spread in the number of hours spent, with a notable peak around 15 h. This spread indicates variability and potential inefficiencies in the traditional cost estimation process. In contrast, the distribution for 5D BIM is more concentrated, with the majority of instances requiring significantly fewer hours, peaking sharply between 5 and 10 h. This suggests that 5D BIM provides a more streamlined and time-efficient approach to cost estimation.

Notably, the 5D BIM approach reduces the time spent on cost estimation by more than 50% in the majority of cases observed. This reduction in time is not only indicative of the direct efficiency gains but also suggests indirect benefits such as the reduction in labor costs and the ability to allocate time to other critical tasks within the project lifecycle.

4.3.5. Mitigating Cost Overruns through 5D BIM in Complex Projects

The integration of 5D Building Information Modeling (BIM) into construction projects has been instrumental in managing and mitigating cost over-runs, especially as project complexity increases. The scatter plot provided reveals the relationship between project complexity and cost overruns for projects utilizing traditional cost management methods versus those employing 5D BIM.

Figure 7 displays a discernible pattern of higher cost over-runs associated with traditional methods as project complexity grows, shown by the purple 'X' markers(Figure 8).

These markers are scattered throughout the upper region of the graph, particularly as the complexity rating exceeds the midpoint of the scale. This trend underscores the challenges inherent in traditional cost management approaches when dealing with intricate project elements and coordination.

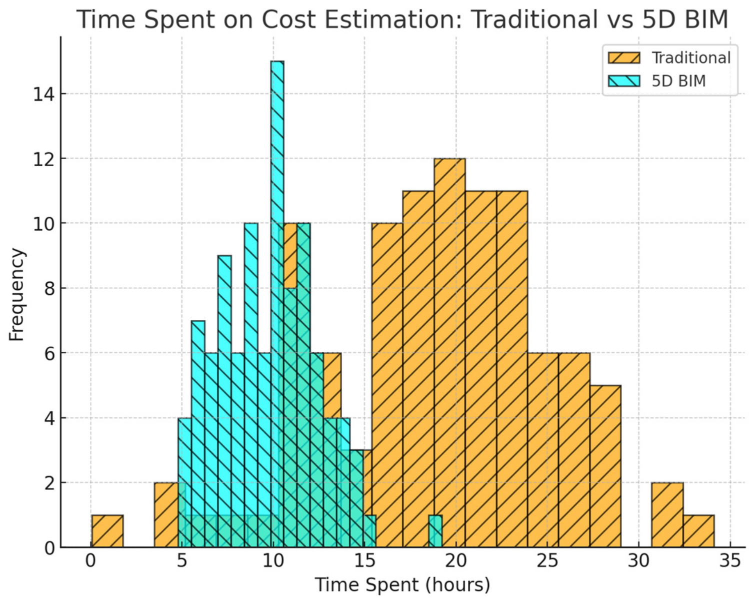


Figure 7. Comparative histogram employs two color patterns to distinguish between two methods of cost estimation. The teal crosshatch pattern represents the frequency of time spent using 5D Building Information Modeling (5D BIM) techniques, while the solid orange color denotes the traditional methods. These color distinctions allow for quick visual comparison of the time investment required for cost estimation by each method across various frequency intervals.

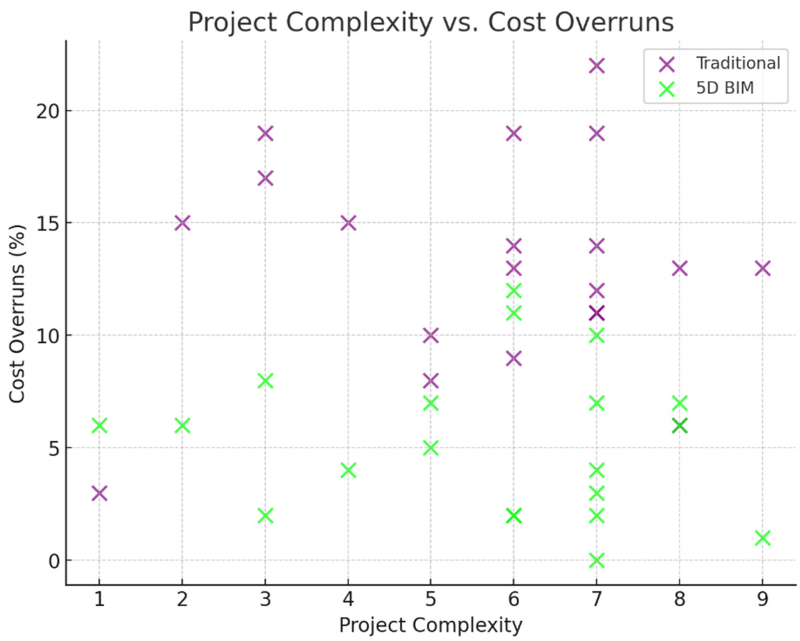


Figure 8. Impact of Five-Dimensional Building Information Modeling (5D BIM) on cost over-runs across varying levels of project complexity.

Conversely, the green ‘X’ markers (Figure 8), representing projects managed with 5D BIM, are primarily clustered towards the lower end of the cost over-runs axis, regardless of the complexity rating. This distribution indicates that 5D BIM effectively keeps cost over-runs to a minimum, even as project complexity rises. The concentration of green markers below the 5% cost over-run line emphasizes 5D BIM's capability to deliver accurate cost predictions and control, affirming its value as a cost management tool.

This evidence from the field resonates with the paper's findings that adopting 5D BIM can lead to significant improvements in managing the financial aspects of construction projects. While the figure itself focuses on cost overruns, it supports the broader results of the study by illustrating how 5D BIM contributes to a more resilient cost management strategy in the face of complex project demands. This resilience is paramount for construction firms aiming to maintain budgetary control and project profitability in an industry characterized by intricate and multifaceted projects.

4.3.6. The Future Path of 5D BIM Adoption in the Construction Industry

The anticipated timeline for the broad integration of 5D BIM within the construction industry is a subject of scholarly interest and industry speculation. Interviews with industry practitioners provided insights that align with current literature, indicating a trend where leading firms are spearheading the adoption of 5D BIM technologies [70]. Notably, large Norwegian contractors like Veidekke, Skanska, and AF have been identified as early adopters, utilizing 5D BIM at varying levels of complexity and integration.

The widespread adoption of 5D BIM is contingent upon advancements in software usability. Literature suggests that enhanced user interface design is critical for increased adoption across the industry [71]. A study by Liu et al. corroborates the view that streamlined software interfaces significantly affect the learning curve and usability for both large and small firms [72].

While individual predictions can vary, a consensus within academic and industry circles indicates that larger construction firms are likely to first normalize the use of 5D BIM, setting a precedent for smaller entities [73]. Moreover, influential public sector builders are recognized as key players in standard setting, which is essential for driving industry-wide change [74]

Technological innovations, such as the integration of AI and natural language processing, are posited to play a transformative role in the usability of 5D BIM. The development of tools that abstract the complexities of BIM and allow for more intuitive interaction, like recent AI-driven platforms, aligns with predictions of an accelerated transition to 5D BIM methodologies [75].

Discussions about the IFC standard reveal that, despite the advancements encapsulated in IFC 4, software tool compatibility remains a hurdle [76]. This reflects a gap between the development of standards and their practical implementation in software solutions.

The strategy employed by Sparkel and other innovators to enhance the frequency of 5D BIM usage by simplifying the user experience through better interaction design and AI is evidence of the industry's response to these challenges. The shift towards platforms that utilize natural language for creating BIM models could democratize the technology, making it accessible to a wider range of professionals [77].

Concerning the challenges faced by developers, the literature on software innovation stresses the importance of sustained investment and a culture of risk-taking [78]. Feedback from industry partners reveals diverse levels of engagement and a demand for immediate value, especially from contractors. This is in contrast with sectors that are more amenable to gradual investment, recognizing the longer-term benefits and enduring the transition phase.

5. Discussion

In this chapter, the discussion revolves around the findings from the results section, using theories, collected data from interviews, and the authors' own case study to address the main research question.

5.1. Software

The summary of experiences with various software used in the process provides insights into several key aspects such as utility, user-friendliness, and difficulty. The utility is found to be moderate, with noticeable variances in ease of use among different programs, particularly in areas like model navigation and uploading of IFC files. The challenge in using the software is significant, demanding a certain level of expertise to spot potential errors.

A collective evaluation of different software experiences reveals that Sparkel ranks as the most user friendly, followed by Bexel, with ISY Calcus being the most complex due to various encountered issues. Key evaluation criteria included interface design, functional capabilities, learning curve, and efficiency in IFC transfer, a noted problem area.

In a case study involving a simple model, the analysis suggests that new users might prefer software with lesser functionality but higher ease of use, such as Sparkel. ISY Calcus encountered technical difficulties in IFC file uploads, leading to inaccuracies or omissions in the model. Conversely, while Sparkel offers a more intuitive interface, it currently lacks some features found in more advanced software. However, its regular monthly updates and the recent integration of AI technology for IFC file extraction show its potential for growth.

The software industry, particularly in this sector, is witnessing dynamic competition, with startups like Sparkel rapidly evolving and challenging established players like ISY Calcus and Bexel. This competition is fostering innovation, with user feedback playing a pivotal role in guiding development, as indicated by a representative from Sparkel.

Despite the considerable potential of these software programs, a major challenge is the effective implementation of IFC files, which often results in unsuccessful attempts. This issue, underscored by an interviewee, points to a disconnect between software updates and upgrades in the IFC format.

5.2. Exploring the Current Application and Implications of Software in Construction

The interviews revealed that while there is a general perception of time saving with the use of 5D BIM, there is still potential for greater efficiency. Accuracy in cost estimation has been identified as a benefit, although there is room for improvement in terms of required expertise. Handling changes in projects has become simpler and more effective, yet the overall costs could be further optimized. The software programs themselves, particularly in terms of user-friendliness and technical capabilities, also have significant room for improvement, especially regarding IFC translation.

The exploration of these software programs aimed to assess their interfaces, capabilities, ease of use, and effectiveness in IFC transfer. A recurring issue was problems with elements missing or not being included in quantity calculations. While the software programs share the common ground of utilizing IFC files, their suitability varies based on project complexity. For instance, Sparkel's user-friendly interface makes it more suitable for simpler projects compared to ISY Calcus and Bexel, which may overwhelm users with excessive information in straightforward models.

Each software program possesses unique strengths and weaknesses, influenced by their particular development environments. Notably, ISY Calcus stands out in the Norwegian market due to its integration with the NS3420 standard—a comprehensive Norwegian standard for construction and property management that specifies requirements for materials, products, and execution of work [79]. This integration is essential for companies like the AF Group that operate within Norway, as it ensures compliance with local construction norms and facilitates precise cost calculations, tender documentation, and project management. While other programs such as Sparkel may offer superior user interfaces or more efficient IFC (Industry Foundation Classes) import capabilities for BIM (Building Information Modeling) processes, they lack direct incorporation of NS3420. This omission can be a significant drawback for firms that prioritize adherence to national standards, as the alignment with NS3420 can streamline workflows, improve precision in cost estimation, and ensure regulatory compliance. Consequently, for companies operating in environments where NS3420 compliance is a necessity, the advantages of software alignment with such standards can overshadow other features, no matter how sophisticated they might be.

Measuring the full benefits and drawbacks of integrating cost estimation with BIM models is complex due to the uniqueness of projects. Therefore, it is vital to consider experiences from projects using 5D BIM and those that do not. The potential benefits of using 5D BIM include time and cost savings and increased ease of work. While the time-saving aspect might not be significant initially, it tends to grow as users develop templates, libraries, and expertise. Additionally, increased experience and competency are significant benefits, enhancing efficiency and quality with each project.

5.3. Current Utility

Interviewees generally have positive attitudes towards 5D BIM, recognizing its significant benefits in enabling quick changes, updating the entire model, and providing a rapid overview of cost changes. The greatest advantage of using 5D BIM is its ability to save time by avoiding the need to re-calculate quantities for every minor model change. Handling changes efficiently is repeatedly mentioned as a key benefit. The authors believe that easier change management leads to quicker and earlier modifications in the process. Accurate cost estimation is crucial in the bidding phase, especially when pricing multiple changes. Improved accuracy in cost estimations tied directly to the model updates, leading to more precise area calculations and likely time savings.

The incorporation of 5D BIM in projects offers a significant advantage over traditional methods, particularly in terms of the trustworthiness of estimates and efficiency. In the long run, it could become a requirement for large projects to ensure quality in bids from all parties. A minimum standard for models might also be necessary.

5.4. Current Challenges

The construction industry encounters notable hurdles in the pursuit of effective BIM implementation, particularly in terms of model quality and the establishment of a standardized communicative framework. Despite BIM's maturation over the years, research indicates that there remains a significant gap in BIM competency across the industry [80]. This shortfall is not solely attributable to software limitations; indeed, the proficiency of practitioners in using BIM technology is a pivotal factor [81,82]. For instance, the recurrent challenge of inaccurate object labeling in models exacerbates the difficulties in cross-disciplinary collaboration between architects and engineers [83].

Advancements in the Industry Foundation Class (IFC) standards are widely recognized as essential for the evolution of BIM. While the implementation of the latest IFC4 standard is seen as a positive step towards better data interoperability, its adoption has been slow. The majority of BIM software still relies on the older IFC2x3 standard, which does not support the latest interoperability enhancements [84]. This lag in standard adoption may be attributed to the industry's inherent conservatism and hesitation by management in large firms to invest in digital transformation despite acknowledging its potential benefits.

These challenges are compounded by the industry's cautious approach to the adoption of new technologies. A study by Takyi and Zhang suggests that the reluctance to invest in digitalization stems from a complex mix of factors, including cost concerns, uncertainty about the return on investment, and the need for extensive staff retraining [85]. Additionally, the findings in the literature highlight that the top-down approach to technological adoption in larger construction firms often encounters resistance due to the perceived disruption it may cause to established workflows [86].

5.5. The Road Ahead

There is a continuous evolution in technology, with a need for industry leaders to believe in and invest in development. Alongside software development, raising competency levels is also crucial. Demand for advanced BIM applications could accelerate the adoption of new possibilities and put pressure on software providers. A common library for more efficient collaboration in 5D BIM and BIM, in general, could be a goal. Ensuring a universal naming standard, like NS8360, might simplify collaboration but must avoid becoming overly complex.

The potential integration of artificial intelligence in this field is exciting, though the industry is still far from fully relying on AI. The authors' work on this project has affirmed the staying power of 5D BIM in the industry. Large companies must recognize the importance of making necessary investments to accelerate development. This report aims to highlight the opportunities that 5D BIM presents and the challenges that need addressing, particularly the need for a change in attitudes within the traditionally conservative construction industry.

Building upon the insightful findings and discussions surrounding the utilization of software in the construction industry, it is imperative to reflect on the broader educational and experiential learning context, as highlighted by Borkowski's research on BIM education [87].The dynamic competition among BIM software platforms, such as Sparkel, Bexel, and ISY Calcus, not only underscores the importance of innovation in technological development but also emphasizes the critical need for an educated workforce capable of navigating these advancements. Borkowski's emphasis on experiential learning and the development of a conceptual framework for BIM education resonates deeply with the current industry challenges and opportunities discussed.

The integration of BIM into educational curricula, as proposed by Borkowski, offers a viable solution to the competency gap observed in the construction industry. His advocacy for a shift from traditional lecture-based teaching to interactive, problem-solving educational environments mirrors the industry's need for professionals who are not only technically proficient but also adaptable and innovative. The findings from our interviews and case studies suggest that the successful implementation of BIM, particularly 5D BIM, hinges on the ability of the workforce to efficiently use these software tools, underscoring the importance of Borkowski's call for enhanced BIM education.

Moreover, the learning approach advocated by Borkowski could significantly contribute to bridging the gap between theoretical knowledge and practical application in the construction industry. This method, focusing on concrete experiences and reflective observation, aligns with the industry's requirement for professionals who can effectively manage and implement BIM technologies. By fostering a deeper understanding of BIM through experiential learning, educational institutions can prepare students to navigate the complexities of modern construction projects, thereby enhancing the industry's overall capacity to leverage BIM for improved efficiency, accuracy, and collaboration.

6. Conclusions

The exploration into the integration of 5D Building Information Modeling (BIM) within the construction industry has culminated in a nuanced understanding of the multifaceted challenges and opportunities that characterize this technological advancement. Central to our empirical findings is the revelation that while the potential of 5D BIM to significantly enhance project management and cost estimation is undeniable, its adoption is hindered by tangible obstacles. These obstacles, including software usability issues, interoperability challenges, and general industry resistance to shifting technological paradigms, represent not just technical barriers but also cultural and educational gaps within the sector.

Our analysis has demonstrated that the usability and interoperability of BIM software are critical pain points, affecting the efficiency with which professionals can implement 5D BIM methodologies. The difficulties in navigating these software interfaces and the complexities involved in managing IFC standards are not merely operational challenges but are indicative of a broader need for industry standards and educational programs that can bridge these gaps.

The opportunity for 5D BIM to revolutionize cost estimation and project management within the construction industry is profound. The empirical evidence supports the assertion that the effective implementation of 5D BIM can lead to more accurate, dynamic, and streamlined project management processes. This, in turn, underscores the critical need for a concerted effort to overcome the existing barriers to adoption. The industry must prioritize the development of more intuitive BIM software interfaces and the standardization of data exchange protocols to facilitate easier adoption and more effective utilization of 5D BIM technologies.

In response to our findings, we recommend the following actions for industry practitioners and software developers.

1. Software developers should focus on improving the user interface and experience of BIM software to lower the barrier to entry for professionals across the construction industry.
2. Industry bodies should work towards the standardization of IFC and other data exchange protocols to ensure interoperability across different BIM software, simplifying the process of model sharing and collaboration.
3. Educational institutions and professional bodies should develop and offer targeted training programs to upskill current professionals and educate new entrants about the nuances of 5D BIM, focusing on both technical skills and the strategic implications of its use.
4. Encourage collaboration among software developers, construction firms, and educational institutions to ensure that the evolution of 5D BIM technologies is aligned with the practical needs and challenges of the industry.

By addressing these recommendations, the construction industry can move towards a more integrated, efficient, and cost-effective approach to project management. This study's conclusions, grounded in empirical evidence and analysis, offer a roadmap for overcoming the current barriers to 5D BIM adoption and harnessing its full potential to benefit the construction industry at large. Future research should continue to explore the evolving landscape of BIM technologies, focusing on longitudinal studies that assess the impact of these recommended actions on industry adoption and project outcomes.

Author Contributions: Conceptualization, C.N.R.; methodology, H.H.H.; software, F.Z., S.S. (Sigurd Sandbeck), S.S. (Sami Said) and M.A.S.; validation, H.H.H. and C.N.R.; resources, H.H.H.; data curation, F.Z., S.S. (Sigurd Sandbeck), S.S. (Sami Said) and M.A.S.; writing—original draft preparation, H.H.H. and C.N.R.; writing—review and editing, H.H.H. and C.N.R.; supervision, C.N.R.; project administration, H.H.H. All authors have read and agreed to the published version of the manuscript.

Funding: This research received no external funding.

Data Availability Statement: Data are not publicly available because data from this work cannot be shared.

Conflicts of Interest: The authors declare no conflict of interest.

References

1. Hosamo, H.H.; Nielsen, H.K.; Kraniotis, D.; Svennevig, P.R.; Svidt, K. Improving Building Occupant Comfort through a Digital Twin Approach: A Bayesian Network Model and Predictive Maintenance Method. *Energy Build.* **2023**, *288*, 112992. [CrossRef]
2. Shabani, A.; Hosamo, H.; Plevris, V.; Kioumarsi, M. A Preliminary Structural Survey of Heritage Timber Log Houses in Tonsberg, Norway. In Proceedings of the 12th International Conference on Structural Analysis of Historical Constructions (SAHC) Interdisciplinary Projects and Case Studies, Online, 29 September–1 October 2021. [CrossRef]
3. Ying, C.N.; Rolfsen, A.K.; Lassen, D.; Han, H.; Hosamo, C. The Use of the BIM-Model and Scanning in Quality Assurance of Bridge Constructions. In *ECPPM 2021—eWork and eBusiness in Architecture, Engineering and Construction*; CRC Press: Boca Raton, FL, USA, 2021.
4. Azhar, S.; Malik, K.; Tayyab, M. Building Information Modeling (BIM): Now and Beyond. *Australas. J. Constr. Econ. Build.* **2020**, *12*, 15–28.
5. Manish, M.; Mandhar, M. BIMing the Architectural Curricula: Integrating Building Information Modelling (BIM) in Architectural Education. *Int. J. Archit.* **2013**, *1*, 1–20.
6. Shirowzhan, S.; Sepasgozar, S.M.; Edwards, D.J.; Li, H.; Wang, C. BIM Compatibility and Its Differentiation with Interoperability Challenges as an Innovation Factor. *Autom. Constr.* **2020**, *112*, 103086. [CrossRef]
7. Borkowski, A.S. Evolution of BIM: Epistemology, Genesis and Division into Periods. *J. Inf. Technol. Constr.* **2023**, *28*, 646–661. [CrossRef]

8. Lin, Y.-C. Construction 3D BIM-Based Knowledge Management System: A Case Study. *J. Civ. Eng. Manag.* **2014**, *20*, 186–200. [CrossRef]
9. MMartins, S.S.; Evangelista, A.C.J.; Hammad, A.W.A.; Tam, V.W.Y.; Haddad, A. Evaluation of 4D BIM Tools Applicability in Construction Planning Efficiency. *Int. J. Constr. Manag.* **2022**, *22*, 2987–3000. [CrossRef]
10. Çelik, U. 4D and 5D BIM: A System for Automation of Planning and Integrated Cost Management. In *Advances in Building Information Modeling*; Salih, O., Ozan, O.O., Umit, I., Eds.; Communications in Computer and Information Science; Springer International Publishing: Cham, Switzerland, 2020; pp. 57–69. [CrossRef]
11. Nicał, A.K.; Wodyński, W. Enhancing Facility Management through BIM 6D. *Procedia Eng.* **2016**, *164*, 299–306. [CrossRef]
12. Cantisani, G.; Panesso, J.D.C.; Del Serrone, G.; Di Mascio, P.; Gentile, G.; Loprencipe, G.; Moretti, L. Re-Design of a Road Node with 7D BIM: Geometrical, Environmental and Microsimulation Approaches to Implement a Benefit-Cost Analysis between Alternatives. *Autom. Constr.* **2022**, *135*, 104133. [CrossRef]
13. Di Martino, B.; Mirarchi, C.; Ciuffreda, S.; Pavan, A. Analysis of Existing Open Standard Framework and Ontologies in the Construction Sector for the Development of Inference Engines. In *Complex, Intelligent, and Software Intensive Systems*; Barolli, L., Khadeer, H.F., Ikeda, M., Eds.; Springer International Publishing: Cham, Switzerland, 2020; pp. 837–846. [CrossRef]
14. Patacas, J.; Dawood, N.; Kassem, M. BIM for Facilities Management: A Framework and a Common Data Environment Using Open Standards. *Autom. Constr.* **2020**, *120*, 103366. [CrossRef]
15. Jiang, S.; Jiang, L.; Han, Y.; Wu, Z.; Wang, N. OpenBIM: An Enabling Solution for Information Interoperability. *Appl. Sci.* **2019**, *9*, 5358. [CrossRef]
16. BuildingSmart International. Available online: https://www.buildingsmart.org/ (accessed on 24 December 2023).
17. BIM Collaboration Format (BCF)—BuildingSMART International. Available online: https://www.buildingsmart.org/standards/bsi-standards/bim-collaboration-format-bcf/ (accessed on 23 April 2019).
18. Information Delivery Manual (IDM). BuildingSmart Technical. Available online: https://technical.buildingsmart.org/standards/information-delivery-manual/ (accessed on 23 January 2024).
19. Eastman, C.M. *BIM Handbook: A Guide to Building Information Modeling for Owners, Managers, Designers, Engineers and Contractors*; John Wiley & Sons: New York, NY, USA, 2011.
20. Slongo, C.; Malacarne, G.; Matt, D.T. The IFC File Format as a Means of Integrating Bim and Gis: The Case of the Management and Maintenance of Underground Networks. *ISPRS Ann. Photogramm. Remote Sens. Spat. Inf. Sci.* **2022**, *V-4-2022*, 301–309. [CrossRef]
21. Noardo, F.; Ohori, K.A.; Krijnen, T.; Stoter, J. An Inspection of IFC Models from Practice. *Appl. Sci.* **2021**, *11*, 2232. [CrossRef]
22. Venkataraman, R.R.; Pinto, J.K. *Cost and Value Management in Projects*; John Wiley & Sons: New York, NY, USA, 2023.
23. Ofori, G. *Building A Body of Knowledge in Project Management in Developing Countries*; World Scientific: Singapore, 2023.
24. Jiang, R.; Wu, C.; Lei, X.; Shemery, A.; Hampson, K.D.; Wu, P. Government Efforts and Roadmaps for Building Information Modeling Implementation: Lessons from Singapore, the UK and the US. *Eng. Constr. Arch. Manag.* **2021**, *29*, 782–818. [CrossRef]
25. Svetel, I.; Ivanišević, N.; Isailović, D. BIM Based Project and Digital Building Model Management: Applications and Emerging Standards. In *Keeping Up with Technologies to Act Responsively in Urban Environment, Proceedings of the 7th International Academic Conference on Places and Technologies*; University of Belgrade Faculty of Architecture: Belgrade, Serbia, 2020; pp. 390–396.
26. Yap, J.B.H.; Shavarebi, K.; Skitmore, M. Capturing and Reusing Knowledge: Analysing the What, How and Why for Construction Planning and Control. *Prod. Plan. Control* **2021**, *32*, 875–888. [CrossRef]
27. Hosamo, M.; Singh, S.P.; Mohan, A. Analytical Modeling of RRM-ATM Switch for Linear Increment and Exponential Decay of Source Data Rate. *J. Comput. Networks* **2017**, *4*, 56–64. [CrossRef]
28. Elmousalami, H.H.; Ali, A.H.; Kineber, A.F.; Elyamany, A. A Novel Conceptual Cost Estimation Decision-Making Model for Field Canal Improvement Projects. *Int. J. Constr. Manag.* **2023**, *24*, 651–663. [CrossRef]
29. Ganbat, T.; Chong, H.-Y.; Liao, P.-C.; Lee, C.-Y. A Cross-Systematic Review of Addressing Risks in Building Information Modelling-Enabled International Construction Projects. *Arch. Comput. Methods Eng.* **2019**, *26*, 899–931. [CrossRef]
30. Hosamo, M.; Singh, S.; Mohan, A. Random Early Detection Method for ABR Service. *Comput. Electr. Eng.* **2008**, *34*, 290–308. [CrossRef]
31. Picciotto, R. Towards a 'New Project Management' Movement? An International Development Perspective. When Project Management Meets International Development, What Can We Learn? *Int. J. Proj. Manag.* **2019**, *38*, 474–485. [CrossRef]
32. Moins, B.; France, C.; Bergh, W.V.D.; Audenaert, A. Implementing Life Cycle Cost Analysis in Road Engineering: A Critical Review on Methodological Framework Choices. *Renew. Sustain. Energy Rev.* **2020**, *133*, 110284. [CrossRef]
33. Liew, S.C.; Bong, V.N.S.; Fong, R.M.Y.Y. Improving Construction Project Management Via 4D and 5D BIM in Sarawak: An Overview. In *Proceedings of ASEAN-Australian Engineering Congress (AAEC2022)*; Chung, S.C., Basil, T.W., Khairul, H.B.S., Kong, D., Eds.; Lecture Notes in Electrical Engineering; Springer Nature: Singapore, 2022; pp. 235–247. [CrossRef]
34. Datta, S.D.; Sobuz, H.R.; Mim, N.J.; Nath, A.D. Investigation on the Effectiveness of Using Building Information Modeling (BIM) Tools in Project Management: A Case Study. *Rev. De La Construccion* **2023**, *22*, 306–320. [CrossRef]
35. Mustafa, M.; Mohd-Rahim, F.; Chia, L. The Role of 5D Building Information Modelling in Construction Project Cost Management: An Overview and Future Directions. *J. Proj. Manag. Pract.* **2023**, *3*, 95–112. [CrossRef]
36. Alzara, M.; Attia, Y.A.; Mahfouz, S.Y.; Yosri, A.M.; Ehab, A. Building a Genetic Algorithm-Based and BIM-Based 5D Time and Cost Optimization Model. *IEEE Access* **2023**, *11*, 122502–122515. [CrossRef]

37. Mozardo, A.S. Analysis of the Application of BIM 4D and BIM 5D for Cost Estimation in Tender Processes—A Case Study in a Steel Structure Construction Company. Master's Thesis, Universidade do Minho, Braga, Portugal, 2021.
38. Aibinu, A.; Venkatesh, S. Status of BIM Adoption and the BIM Experience of Cost Consultants in Australia. *J. Prof. Issues Eng. Educ. Pract.* **2014**, *140*, 04013021. [CrossRef]
39. Nadeem, A.; Wong, A.K.D.; Wong, F.K.W. Bill of Quantities with 3D Views Using Building Information Modeling. *Arab. J. Sci. Eng.* **2015**, *40*, 2465–2477. [CrossRef]
40. Khosakitchalert, C.; Yabuki, N.; Fukuda, T. Automated Modification of Compound Elements for Accurate BIM-Based Quantity Takeoff. *Autom. Constr.* **2020**, *113*, 103142. [CrossRef]
41. Sepasgozar, S.M.E.; Costin, A.M.; Karimi, R.; Shirowzhan, S.; Abbasian, E.; Li, J. BIM and Digital Tools for State-of-the-Art Construction Cost Management. *Buildings* **2022**, *12*, 396. [CrossRef]
42. Farouk, A.M.; Rahman, R.A. Integrated Applications of Building Information Modeling in Project Cost Management: A Systematic Review. *J. Eng. Des. Technol.* **2023**, *ahead-of-print*. [CrossRef]
43. Elghaish, F.; Abrishami, S.; Hosseini, M.R.; Abu-Samra, S. Revolutionising Cost Structure for Integrated Project Delivery: A BIM-Based Solution. *Eng. Constr. Arch. Manag.* **2020**, *28*, 1214–1240. [CrossRef]
44. Zhou, M.; Jiayuan, W. The Integrated Technology of BIM5D and VR is Applied in the Construction Management of Building Engineering. In *Proceedings of the 23rd International Symposium on Advancement of Construction Management and Real Estate*; Long, F., Zheng, S., Wu, Y., Yang, G., Yang, Y., Eds.; Springer: Singapore, 2021; pp. 732–746. [CrossRef]
45. Elghaish, F.; Abrishami, S.; Abu Samra, S.; Gaterell, M.; Hosseini, M.R.; Wise, R. Cash Flow System Development Framework within Integrated Project Delivery (IPD) Using BIM Tools. *Int. J. Constr. Manag.* **2021**, *21*, 555–570. [CrossRef]
46. Ranjbar, A.A.; Ansari, R.; Taherkhani, R.; Hosseini, M.R. Developing a Novel Cash Flow Risk Analysis Framework for Construction Projects Based on 5D BIM. *Build. Eng.* **2021**, *44*, 103341. [CrossRef]
47. Wang, W.; Guo, H.; Li, X.; Tang, S.; Li, Y.; Xie, L.; Lv, Z. BIM Information Integration Based VR Modeling in Digital Twins in Industry 5.0. *J. Ind. Inf. Integr.* **2022**, *28*, 100351. [CrossRef]
48. Hussain, O.A.I.; Moehler, R.C.; Walsh, S.D.C.; Ahiaga-Dagbui, D.D. Minimizing Cost Overrun in Rail Projects through 5D-BIM: A Systematic Literature Review. *Infrastructures* **2023**, *8*, 93. [CrossRef]
49. Hamad, M. *Revit 2018 Architecture*; Walter de Gruyter GmbH & Co KG: Berlin, Germany, 2023.
50. Ali, S.B.M.; Mehdipoor, A.; Samsina Johari, N.; Hasanuzzaman, M.; Rahim, N.A. Modeling and Performance Analysis for High-Rise Building Using ArchiCAD: Initiatives towards Energy-Efficient Building. *Sustainability* **2022**, *14*, 9780. [CrossRef]
51. Wangara, J. Quality Management in BIM: Use of Solibri Model Checker and CoBIM Guidlines for BIM Quality Validation. Bachelor's Thesis, Metropolia Ammattikorkeakoulu, Helsinki, Finland, 2018.
52. Sparkel.Io—AI. Assisted Takeoffs for BIM, Documents and Drawings. Available online: https://sparkel.io/ (accessed on 24 December 2023).
53. Alshabab, M.S.; Vysotskiy, A.E.; Khalil, T.; Petrochenko, M.V. BIM-Based Quantity Takeoff in Autodesk Revit and Navisworks Manage. In *Proceedings of EECE 2019*; Anatolijs, B., Nikolai, V., Vitalii, S., Eds.; Lecture Notes in Civil Engineering; Springer International Publishing: Cham, Switzerland, 2020; pp. 413–421. [CrossRef]
54. María Rodrigo-Ortega, J.; Luis Fuentes-Bargues, J. Classification of Software in the BIM Process According to the PMBoK Knowledge Areas and Levels of Development (LOD). In *Project Management and Engineering Research*; Muñoz, J.L.A., Blanco, J.L.Y., Capuz-Rizo, S.F., Eds.; Lecture Notes in Management and Industrial Engineering; Springer International Publishing: Cham, Switzerland, 2021; pp. 75–91. [CrossRef]
55. Sing, M.C.; Sophie, Y.L.; Chan, K.H.; Liu, H.J.; Humphrey, R. Scan-to-BIM Technique in Building Maintenance Projects: Practicing Quantity Take-Off. *Int. J. Build. Pathol. Adapt.* **2022**. *ahead-of-print*. [CrossRef]
56. Hussain, O.A.I.; Moehler, R.C.; Walsh, S.D.C.; Ahiaga-Dagbui, D.D. Minimizing Cost Overrun in Rail Projects through 5D-BIM: A Conceptual Governance Framework. *Buildings* **2024**, *14*, 478. [CrossRef]
57. Malla, V.; Jagannathan, M.; Delhi, V.S.K. Identification of BIM Dimension-Specific Contract Clauses in EPC Turnkey Projects. *J. Leg. Aff. Disput. Resolut. Eng. Constr.* **2022**, *14*, 04521040. [CrossRef]
58. Gomes, A.M.; Gomes, A.M.; Azevedo, G.; Azevedo, G.; Sampaio, A.Z.; Sampaio, A.Z.; Lite, A.S.; Lite, A.S. BIM in Structural Project: Interoperability Analyses and Data Management. *Appl. Sci.* **2022**, *12*, 8814. [CrossRef]
59. Leicht, D.; Castro-Fresno, D.; Dìaz, J.; Baier, C. Multidimensional Construction Planning and Agile Organized Project Execution—The 5D-PROMPT Method. *Sustainability* **2020**, *12*, 6340. [CrossRef]
60. Liu, Z.; Lu, Y.; Shen, M.; Peh, L.C. Transition from Building Information Modeling (BIM) to Integrated Digital Delivery (IDD) in Sustainable Building Management: A Knowledge Discovery Approach Based Review. *J. Clean. Prod.* **2021**, *291*, 125223. [CrossRef]
61. Yang, A.; Han, M.; Zeng, Q.; Sun, Y. Adopting Building Information Modeling (BIM) for the Development of Smart Buildings: A Review of Enabling Applications and Challenges. *Adv. Civ. Eng.* **2021**, *2021*, e88114762021. [CrossRef]
62. Harrison, C.; Thurnell, D. 5D BIM in a consulting quantity surveying environment. In Proceedings of the Building a Better New Zealand Conference 2014, Auckland, New Zealand, 3–5 September 2014; pp. 43–53.
63. Demirdöğen, G.; Diren, N.S.; Aladağ, H.; Işık, Z. Lean Based Maturity Framework Integrating Value, BIM and Big Data Analytics: Evidence from AEC Industry. *Sustainability* **2021**, *13*, 10029. [CrossRef]
64. van der Heijden, J. Construction 4.0 in a Narrow and Broad Sense: A Systematic and Comprehensive Literature Review. *J. Affect. Disord.* **2023**, *244*, 110788. [CrossRef]

65. Creswell, J.W.; Creswell, J.D. *Research Design Qualitative, Quantitative, and Mixed Methods Approaches*, 4th ed.; Sage: Newbury Park, UK, 2017. Available online: https://www.scirp.org/reference/referencespapers?referenceid=2969274 (accessed on 26 January 2024).
66. Patton, M.Q. *Qualitative Evaluation and Research Methods*; Sage: Thousand Oaks, CA, USA, 2015. Available online: https://scirp.org/reference/referencespapers?referenceid=1838631 (accessed on 26 January 2024).
67. Guest, G.; Bunce, A.; Johnson, L. How Many Interviews Are Enough? An Experiment with Data Saturation and Variability. *Field Methods* **2006**, *18*, 59–82. [CrossRef]
68. Skukauskaite, A. Transparency in Transcribing: Making Visible Theoretical Bases Impacting Knowledge Construction from Open-Ended Interview Records. *Forum Qual. Sozialforschung Forum Qual. Soc. Res.* **2012**, *13*, 1532. [CrossRef]
69. Wiltshire, G.; Ronkainen, N. A Realist Approach to Thematic Analysis: Making Sense of Qualitative Data through Experiential, Inferential and Dispositional Themes. *J. Crit. Realism* **2021**, *20*, 159–180. [CrossRef]
70. Oyuga, J.O.; Gwaya, A.; Njuguna, M.B. Investigation of the Current Usage of BIM Capabilities by Large-Sized Building Contractors in Kenya Based on Theory of Innovation Diffusion. *Constr. Innov.* **2021**, *23*, 155–177. [CrossRef]
71. Moses, T.; Heesom, D.; Oloke, D. Implementing 5D BIM on Construction Projects: Contractor Perspectives from the UK Construction Sector. *J. Eng. Des. Technol.* **2020**, *18*, 1867–1888. [CrossRef]
72. Liu, Z.; Lu, Y.; Nath, T.; Wang, Q.; Tiong, R.L.K.; Peh, L.L.C. Critical Success Factors for BIM Adoption during Construction Phase: A Singapore Case Study. *Eng. Constr. Arch. Manag.* **2021**, *29*, 3267–3287. [CrossRef]
73. Smith, P. Project Cost Management with 5D BIM. Procedia—Social and Behavioral Sciences. In Proceedings of the 29th IPMA World Congress WC2015, Panama City, Panama, 28 September–1 October 2016; pp. 193–200. [CrossRef]
74. Aragó, A.B.; Hernando, J.R.; Saez, F.J.L.; Bertran, J.C. Quantity Surveying and BIM 5D. Its Implementation and Analysis Based on a Case Study Approach in Spain. *J. Build. Eng.* **2021**, *44*, 103234. [CrossRef]
75. Urbieta, M.; Urbieta, M.; Laborde, T.; Villarreal, G.; Rossi, G. Generating BIM Model from Structural and Architectural Plans Using Artificial Intelligence. *J. Build. Eng.* **2023**, *78*, 107672. [CrossRef]
76. Dinis, F.M.; Martins, J.P.; Guimarães, A.S.; Rangel, B. BIM and Semantic Enrichment Methods and Applications: A Review of Recent Developments. *Arch. Comput. Methods Eng.* **2022**, *29*, 879–895. [CrossRef]
77. Miettinen, R.; Paavola, S. Beyond the BIM Utopia: Approaches to the Development and Implementation of Building Information Modeling. *Autom. Constr.* **2014**, *43*, 84–91. [CrossRef]
78. Azeem, M.; Ahmed, M.; Haider, S.; Sajjad, M. Expanding Competitive Advantage through Organizational Culture, Knowledge Sharing and Organizational Innovation. *Technol. Soc.* **2021**, *66*, 101635. [CrossRef]
79. Beskrivelsessystem Bygg Og Anlegg—NS 3420. Available online: https://standard.no/fagomrader/ns-3420-/ (accessed on 28 February 2024).
80. Almeida, R.; Chaves, L.; Silva, M.; Carvalho, M.; Caldas, L. Integration between BIM and EPDs: Evaluation of the main difficulties and proposal of a framework based on ISO 19650:2018. *J. Build. Eng.* **2023**, *68*, 106091. [CrossRef]
81. Borkowski, A.S. A Literature Review of BIM Definitions: Narrow and Broad Views. *Technologies* **2023**, *11*, 176. [CrossRef]
82. Aladağ, H.; Demirdöğen, G.; Demirbağ, A.T.; Işık, Z. Understanding the perception differences on BIM adoption factors across the professions of AEC industry. *Ain Shams Eng. J.* **2023**, *14*, 102545. [CrossRef]
83. Bassier, M.; Vincke, S.; De Winter, H.; Vergauwen, M. Drift Invariant Metric Quality Control of Construction Sites Using BIM and Point Cloud Data. *ISPRS Int. J. Geo-Inf.* **2020**, *9*, 545. [CrossRef]
84. De Gaetani, C.I.; Mert, M.; Migliaccio, F. Interoperability Analyses of BIM Platforms for Construction Management. *Appl. Sci.* **2020**, *10*, 4437. [CrossRef]
85. Takyi-Annan, G.E.; Zhang, H. Assessing the Impact of Overcoming BIM Implementation Barriers on BIM Usage Frequency and Circular Economy in the Project Lifecycle Using Partial Least Squares Structural Equation Modelling (PLS-SEM) Analysis. *Energy Build.* **2023**, *295*, 113329. [CrossRef]
86. Tang, X.; Wei, S.; Chen, X. How Do Technology-Driven Stressors Influence Workarounds? Moderating Roles of Support Structures and Trait Resilience. *Int. J. Inf. Manag.* **2024**, *74*, 102718. [CrossRef]
87. Borkowski, A.S. Experiential Learning in the Context of BIM. *STEM Educ.* **2023**, *3*, 190–204. [CrossRef]