Exploring the Potential of BIM in Addressing Key Challenges in Offshore Wind Energy Projects

Master Thesis

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Executive Summary

This thesis explores the potential of Building Information Modeling (BIM) to improve the execution and management of offshore wind projects. Offshore wind is a rapidly growing sector, driven by global energy transition goals and increasing demand for renewable energy. However, offshore wind projects face significant challenges throughout their lifecycle, including complex logistics and installation, grid connection and energy transmission issues, high capital costs and operational and maintenance expenses, supply chain disruptions, and regulatory barriers.

BIM has been widely adopted in the architecture, engineering, construction, and operations (AECOO) industry to improve project success and help mitigate challenges projects face. Despite BIM's success in the construction sector, its adoption in offshore wind remains limited and fragmented. This research addresses the gap by systematically evaluating BIM's potential to address key offshore wind project challenges. The primary research question guiding this study is:

To what extent can BIM be implemented in offshore wind construction projects to address existing challenges and improve project outcomes?

To answer the research question, several sub-questions were developed. First, the study explores the key challenges offshore wind construction projects face, including technical, financial, regulatory, and environmental issues. Second, it investigates BIM's specific capabilities for addressing complex project requirements, such as improving coordination, enhancing data management, and supporting lifecycle planning. Third, the study reviews existing research on the use of BIM in offshore wind and identifies gaps, particularly the lack of a structured, lifecycle-wide implementation strategy. Fourth, it examines how offshore wind organizations can evaluate where and to what extent BIM should be integrated into their workflows, focusing on decision-making tools and evaluation frameworks. Finally, the study assesses the added value of BIM across different project lifecycle phases, including design, construction, and operations, to understand where BIM can generate the most impact.

The research develops a Strategic BIM Prioritization Framework for Offshore Wind Projects (SBPF-OW), which systematically assesses BIM's potential benefits and guides decision-making on BIM adoption. The framework is tested using insights from semi-structured interviews and a focus group with offshore wind industry experts at EnBW, one of Germany's largest energy providers. The thesis follows a structured approach based on the Design Science Research Methodology (DSRM), which involves problem identification, solution development, evaluation, and refinement through iterative cycles.

Literature Review

The literature review establishes the theoretical foundation for this research by examining three core areas:

Project Success and Challenges in Offshore Wind: Offshore wind projects face high capital costs, complex logistics, regulatory uncertainties, and environmental constraints. Effective coordi-

nation, data management, and lifecycle continuity are critical to improving project success.

Capabilities and Success of BIM: BIM enhances project outcomes by improving design visualization, clash detection, scheduling, cost estimation, and facility management. Advanced applications include AI, digital twins, VR/AR, and blockchain for data security.

BIM in Offshore Engineering: Research on BIM in offshore projects is focused mainly on the oil and gas sector. While some studies demonstrate the benefits of digital twins and 4D/5D modelling, comprehensive lifecycle-wide BIM adoption remains rare in offshore wind.

The literature review highlights the research gap in understanding how BIM can be systematically applied to offshore wind projects. This gap informs the development of the SBPF-OW framework.

Research Design and Methodology

The research follows a structured DSRM to develop a solution for improving offshore wind project execution through BIM from the perspective of a specific stakeholder. The framework was designed to reflect EnBW's operational challenges and strategic priorities rather than provide a broad, generalized evaluation of the industry. This ensures that the solutions identified are relevant and actionable within EnBW's organizational context.

The research began with problem identification, focusing on operational inefficiencies, fragmented data management, and poor lifecycle integration as key barriers to offshore wind project success. The next step involved defining objectives and concentrating on creating a decision-making tool to evaluate BIM's applicability and value within offshore wind from this stakeholder's perspective.

The framework was developed based on insights from the literature and expert interviews conducted with EnBW employees. It was tested through Multi-Criteria Decision Analysis (MCDA), which systematically evaluates and ranks challenges based on technical feasibility, impact, cost-effectiveness, and plausibility. The framework was refined through a focus group with EnBW experts, validating the identified challenges and assessing how BIM can best address them within EnBW's operational environment.

The evaluation phase assessed the framework's effectiveness in identifying and prioritizing BIM use cases. Focusing on a single stakeholder allowed the framework to deliver a targeted and practical assessment of BIM's potential value. Finally, the findings were communicated to EnBW and documented, providing a clear record of the framework's development process and its potential to enhance offshore wind project success for this stakeholder.

Strategic BIM Prioritization Framework for Offshore Wind (SBPF-OW)

The key artefact developed in this thesis is the SBPF-OW, a structured decision-making tool to assess and prioritize the implementation of BIM in offshore wind projects. The framework identifies where BIM can deliver the most value within the operational context of a single stakeholder—in this case, EnBW—and supports strategic decision-making regarding BIM adoption.

The SBPF-OW framework consists of two integrated components: a static framework based on an MCDA matrix and a dynamic application process for iterative refinement and scenario-based validation. The static framework evaluates offshore wind project challenges using four weighted criteria: technical feasibility, impact, cost-effectiveness, and plausibility. The weighted scores from these criteria create a ranked list of challenges, ensuring that resources are directed toward areas where BIM can deliver the highest value.

The dynamic application process operationalizes the static framework by allowing continuous refinement and adaptation. Stakeholders assign weights to the criteria based on project-specific relevance and score challenges using insights from interviews and expert feedback. The highest-priority challenges are mapped to specific BIM capabilities such as enhanced data visualization, digital twins, and lifecycle management. Scenario development follows, defining how BIM can address these challenges, including the tools, processes, and expected outcomes involved.

Applying the SBPF-OW framework at EnBW identified data management and operations and maintenance (O&M) optimization as the highest-priority BIM use cases. The findings demonstrated that BIM could significantly improve data consistency, reduce information loss during handovers, and enhance decision-making throughout the project lifecycle.

Findings and Discussion

The findings confirm that BIM holds substantial potential for improving offshore wind project execution, particularly in data management, lifecycle integration, and operational efficiency. Applying the SBPF-OW at EnBW demonstrated that the most immediate benefits of BIM lie in improving data consistency, streamlining handovers, and supporting predictive maintenance in operations and maintenance (O&M).

The SBPF-OW framework effectively prioritized the most critical challenges for BIM implementation. Stakeholder feedback emphasized that improving data accessibility and reducing inconsistencies remain central priorities in offshore wind projects.

Limitations and Future Research

While the study provides valuable insights into BIM's potential in offshore wind, it reflects EnBW's specific priorities and project structure. The framework's applicability to other stakeholders remains untested, and the MCDA process involved some subjectivity in scoring. Additionally, the framework has not yet been tested in a live offshore wind project, which limits its real-world validation.

Future research should focus on validating the framework across different offshore wind stakeholders, including contractors and suppliers. A more integrated assessment method that reflects cross-phase synergies would provide a clearer picture of BIM's overall value. Pilot testing of BIM within an offshore wind project would offer empirical evidence of its benefits and highlight any implementation challenges.

Conclusion

The study demonstrates that BIM holds significant potential for improving offshore wind project execution, particularly in enhancing data management, lifecycle integration, and operational efficiency. The SBPF-OW framework provides a structured tool for evaluating BIM's applicability and prioritizing its implementation. Realizing BIM's full potential will require greater alignment among stakeholders and industry-wide standardization. Ultimately, BIM holds the potential to drive greater efficiency, transparency, and sustainability in offshore wind, supporting the sector's long-term competitiveness and growth.

Contents

List of Abbreviations

Abbreviation	Definition
AECOO	Architecture, Engineering, Construction, Owner and Operator
AI	Artificial Intelligence
AHP	Analytical Hierarchy Process
AR	Augmented Reality
BIM	Building Information Modeling
BSH	Bundesamt für Seeschifffahrt und Hydrographie (Federal Maritime and Hydrographic Agency)
CBR	Case-Based Reasoning
CDE	Common Data Environment
CEN	European Committee for Standardization (Comité Européen de Normalisation)
D	Design
DEX	Decision EXpert (Decision Support System)
DRSA	Dominance-Based Rough Set Approach
DSR	Design Science Research
DSRM	Design Science Research Methodology
EIA	Environmental Impact Assessment
EOL	End of Life
ER	Evidential Reasoning
EU	European Union
FM	Facility Management
GIS	Geographic Information Systems
GWEC	Global Wind Energy Council
IDM	Information Delivery Manual
IFC	Industry Foundation Classes
IFD	International Framework for Dictionaries
IPD	Integrated Project Delivery
IRENA	International Renewable Energy Agency
ISO	International Organization for Standardization
LCA	Life Cycle Assessment
LCOE	Levelized Cost of Electricity
LEED	Leadership in Energy and Environmental Design
LOD	Level of Development
MAUT	Multi-Attribute Utility Theory
MCDA	Multi-Criteria Decision Analysis
O&M	Operation and Maintenance
PD	Project Development

PLM	Project Lifecycle Management
RFID	Radio Frequency Identification
ROI	Return on Investment
SBPF-OW	Strategic BIM Prioritization Framework for Offshore Wind
TC	Technical Committee
VR	Virtual Reality

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1. Introduction

The global energy landscape is undergoing a rapid transformation driven by the necessity to reduce greenhouse gas emissions and transition to renewable energy sources. Offshore wind energy has emerged as a crucial element in this transition, offering large-scale, reliable, and clean power generation potential. However, the development of offshore wind projects is burdened with unique challenges, including complex logistics, environmental considerations, and stringent regulatory requirements.

Building Information Modeling (BIM) has been widely recognized in the Architecture, Engineering, Construction, Owner and Operator (AECOO) industry as a valuable tool for improving project outcomes. BIM facilitates the integration of design, construction, and operational data into a cohesive digital model, which enhances communication, reduces errors, and enables more efficient project management. Despite its proven benefits in conventional construction projects, the application of BIM within the offshore wind sector remains underexplored.

This research proposal aims to assess BIM's advantages in offshore wind construction and its potential impact on project success. By investigating how BIM can address the specific challenges faced by offshore wind projects and drawing lessons from its application in similar sectors of the AECOO industry, this study seeks to provide actionable insights for enhancing the efficiency and sustainability of offshore wind developments.

Subsequent chapters will detail the research objectives, theoretical framework, research design, and methodology, ultimately leading to the intended results and recommendations. The overarching goal of this research is to establish a comprehensive understanding of how BIM can be leveraged to support the ambitious growth targets set for the offshore wind industry, thereby contributing to the broader objectives of the global clean energy transition.

1.1 Background and Context

1.1.1 Energy Transition and the Role of Renewables

The global energy transition has become increasingly urgent in the face of rising greenhouse gas emissions, geopolitical tensions, and economic instability. Fossil fuel prices, while lower than their 2022 peaks, remain volatile due to ongoing conflicts, such as those in Ukraine and the Middle East. Additionally, persistent inflation and high debt levels pose economic challenges, while global temperatures have risen by 1.2°C above pre-industrial levels, intensifying extreme weather events and environmental degradation. The energy sector also contributes significantly to air pollution, which causes over 6 million premature deaths annually (International Energy Agency, 2023).

Despite these challenges, the transition to clean energy has accelerated. Since 2020, global investments in renewable energy technologies have increased by 40%, driven by the need to mitigate climate change, enhance energy security, and foster economic growth. Solar photovoltaic (PV) systems and wind energy have led this transformation, with notable advancements in manufacturing capacity and record-breaking additions to renewable electricity capacity. In 2023 alone, global renewable energy capacity grew by 507 GW, marking a 50% increase from the previous year. Solar PV and wind power accounted for most of this expansion, highlighting their pivotal role in decarbonizing the energy system (International Energy Agency, 2023; World Economic Forum, 2024).

While the rapid deployment of renewables offers significant hope for achieving climate targets, it is not without obstacles. Challenges such as supply chain vulnerabilities, balancing macroeconomic stability with environmental goals, and addressing disparities between developed and developing countries remain critical. The shift to a mineral-intensive energy system also presents complexities, particularly in meeting the growing demand for vital resources such as copper (Yergin, 2022). Nevertheless, advancements in renewable energy technologies demonstrate their capacity to support the global transition toward a more sustainable and resilient energy system.

1.1.2 Offshore Wind Energy: A Key Solution

Offshore wind energy represents a vital component of the global energy transition, offering a scalable and reliable renewable power source. Offshore locations benefit from superior wind resources, less interrupted and more consistent than onshore winds, enabling higher energy output and efficiency. These attributes make offshore wind essential for reducing greenhouse gas emissions and diversifying energy systems to enhance energy security. Additionally, technological advancements have significantly improved offshore wind projects' economic viability, solidifying their role in decarbonizing the global energy system (C. V. C. Weiss et al., 2018).

Offshore wind farms typically consist of multiple wind turbines installed at sea, supported by substructures such as monopiles, jackets, or floating platforms, depending on water depth and seabed conditions. Each turbine consists of a foundation, a tower, a nacelle housing the generator, and rotor blades. The turbines are interconnected via inter-array cables, which transport electricity to an offshore substation. The substation collects and transforms the power before transmitting it to shore through export cables. Together, these elements form the core infrastructure enabling the generation and transmission of wind energy. Figure 1.1 illustrates the components of an offshore wind turbine, while Figure 1.2 provides an overview of the key components of an offshore wind farm.

By the end of 2022, global offshore wind capacity reached 64.3 gigawatts (GW), reflecting a 16% increase from the previous year. This expansion was primarily driven by developments in China and Europe, with 8.8 GW of new capacity added globally in 2022, marking the second-highest

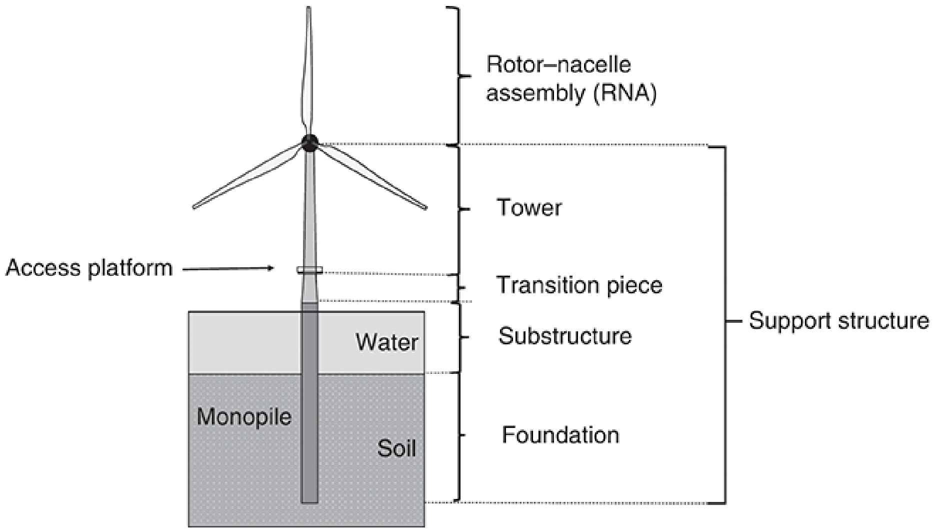


Figure 1.1: Components of an offshore wind turbine. Adapted from Nielsen (2024).

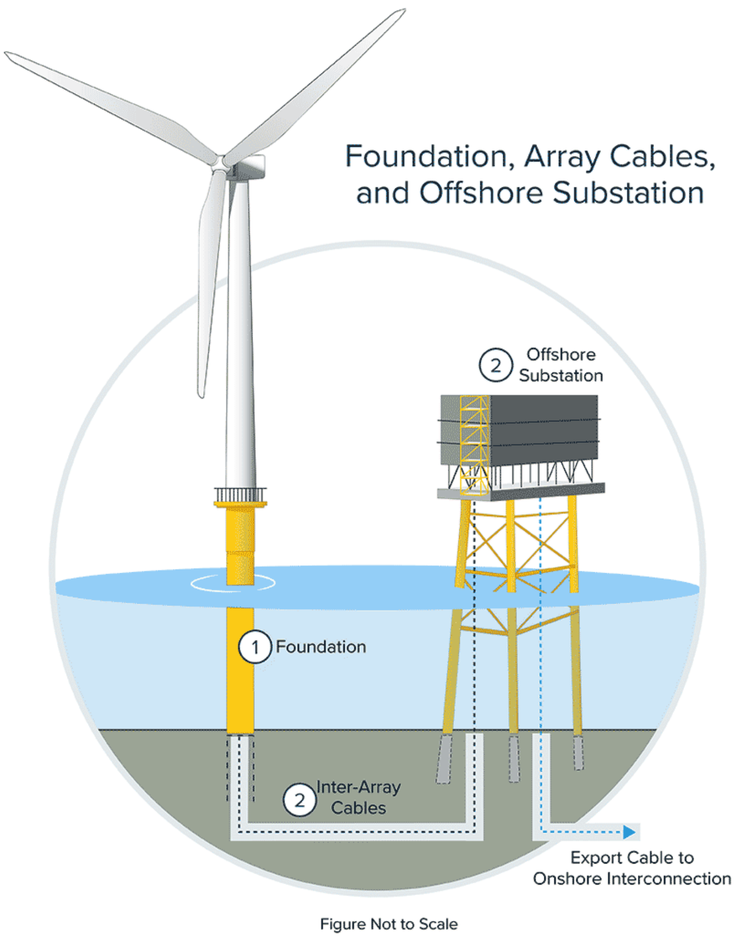


Figure 1.2: Key components of an offshore wind farm, including foundations, inter-array cables, and an offshore substation. Source: New York State Energy Research and Development Authority (NYSERDA) (2024).

installation year. According to the Global Wind Energy Council (GWEC), global offshore wind capacity is projected to grow by over 380 GW between 2023 and 2032, reaching 447 GW. Annual installation rates are expected to exceed 60 GW by the end of this period, emphasizing offshore wind's critical role in meeting global climate and energy targets (Global Wind Energy Council, 2023).

Europe continues to lead offshore wind development, with plans to add 150 GW by 2030. Achieving this target requires overcoming supply chain bottlenecks, installation vessel availability, workforce shortages, and financial pressures from rising material costs and interest rates. Additionally, regulatory hurdles such as lengthy permitting processes and auction designs demand innovative strategies to ensure sustainable growth (Blackburne, 2024; Eder, 2023; WindEurope, 2023).

1.1.3 Offshore Wind in Germany

Germany is a leader in offshore wind energy development, with an installed capacity of approximately 8,100 megawatts (MW) as of early 2023. Following a pause in 2021, project activity resumed in 2022, adding 600 MW of new capacity. In 2023, tenders were issued for areas totalling 7,000 MW across four regions, reflecting the country's commitment to expanding its offshore wind sector (Offshore-Windindustrie, 2024).

Germany aims to increase offshore wind capacity to 30 gigawatts (GW) by 2030 to support its energy transition goals. Achieving this target will require continued advancements in turbine technology, streamlined permitting processes, and strategic government initiatives to address supply chain and workforce challenges. These efforts highlight Germany's central role in shaping the future of offshore wind energy in Europe and beyond (Offshore-Windindustrie, 2024).

1.1.4 EnBW's Role in Offshore Wind Development

EnBW (Energie Baden-Württemberg AG) is a key player in Germany's offshore wind energy sector and one of the country's leading energy companies. The company manages multiple stages of offshore wind farm development, from planning and permitting to construction, operation, and maintenance. Its expertise spans coordinating complex engineering processes, ensuring regulatory compliance, and optimizing long-term operational efficiency.

EnBW's portfolio includes flagship projects such as Hohe See and Albatros, which contribute significantly to Germany's renewable energy capacity. With extensive experience in navigating the challenges associated with large-scale offshore projects, EnBW has established itself as a pivotal actor in supporting Germany's goal of achieving 30 GW of offshore wind capacity by 2030. The company's integrated approach across the wind farm lifecycle highlights its role as both a leader in the sector and a valuable source of practical insights for this research.

Furthermore, EnBW's increasing engagement with BIM across various industry channels has highlighted an internal knowledge gap regarding its applicability to offshore wind projects. This uncertainty about whether and where BIM could be effectively applied prompted the initiation of this research, which stems from the company's need for a structured evaluation of BIM's potential and shaped the direction and practical focus of this study.

1.1.5 BIM: Potential to Address Offshore Wind Needs

BIM has proven to be a transformative tool in the AECOO industry. It significantly improves project efficiency, data integration, and lifecycle management. As the offshore wind sector continues its rapid expansion, BIM presents a promising digital solution for addressing key challenges specific to this domain.

BIM's capacity to streamline complex workflows makes it particularly relevant for offshore wind projects, which often involve multiple stakeholders and intricate regulatory requirements. By integrating design, construction, and operational data into a centralized digital model, BIM enhances collaboration across project phases and reduces risks of delays. Furthermore, BIM's ability to simulate and visualize project elements aids regulatory compliance and environmental impact assessment.

Offshore wind projects, characterized by high capital costs and long operational lifespans, require meticulous planning and maintenance strategies. BIM enables more efficient asset management by providing accurate, up-to-date information throughout the project's lifecycle, from initial planning to decommissioning.

Despite its potential, BIM adoption in offshore wind remains limited. Several barriers hinder its widespread implementation. BIM requires substantial upfront investments in software, training, and organizational restructuring. Companies often face resistance to change from employees accustomed to document-based processes. Moreover, interoperability issues between BIM platforms and other digital tools commonly used in offshore wind projects can complicate integration. Maintaining a continuously updated BIM model throughout an offshore wind farm's decades-long lifecycle can also prove resource-intensive, raising concerns about long-term usability and cost-efficiency.

Addressing these barriers is critical to realizing BIM's full benefits. As the offshore wind industry strives to meet ambitious growth targets, adopting advanced digital tools like BIM will be essential for overcoming inefficiencies, enhancing collaboration, and ensuring sustainable development. However, successful BIM implementation depends on selecting the right software, fostering a cultural shift within organizations and ensuring that digital solutions remain intuitive, flexible, and aligned with the sector's operational realities.

1.2 Research Framework and Scope

1.2.1 Problem Statement

The offshore wind industry faces numerous challenges, including rising material costs, supply chain disruptions, environmental impacts, and local resistance to project development (Briscoe & Dainty, 2005; Cohen et al., 2014; Musarat et al., 2020; Wang et al., 2022). These issues hinder the efficiency and scalability required to meet ambitious growth targets. Similar challenges have been addressed in the AECOO industry by adopting BIM, a transformative digital solution.

BIM provides a centralized framework for managing project information, improving collaboration, accuracy, and decision-making throughout the project lifecycle (Yasser Yahya Al-Ashmori, 2020). By enabling better planning and transparency, it has proven effective in mitigating material cost fluctuations, reducing supply chain inefficiencies, and engaging stakeholders through data-rich models (Alizadehsalehi et al., 2020).

However, BIM's application in offshore wind remains limited. Examples from Europe, mainly the UK and Scandinavian countries, demonstrate the potential for overcoming obstacles through structured BIM implementation (Hammoud, 2021). This highlights the untapped opportunity to explore BIM's applicability in offshore wind projects, where it could address lifecycle inefficiencies and support the sector's digital transformation.

1.2.2 Research Objectives

This research investigates how BIM can address the challenges faced by offshore wind projects, contributing to their successful execution and operation. Building on the problem statement, the study seeks to identify areas where BIM's potential aligns with the industry's needs.

To achieve this, the research will analyze the key challenges impacting offshore wind project success and evaluate how BIM's capabilities can address these issues. It will also explore existing research on BIM in the context of offshore engineering to identify gaps and opportunities, ensuring the study builds on current knowledge. By systematically aligning the challenges with BIM's potential, the study aims to create a foundation for answering the research questions and offering actionable insights for the industry.

1.2.3 Research Questions

This subsection translates the problem statement and objectives into a central research question and supporting sub-questions. The central research question guides the overall research focus, while the sub-questions explore aspects necessary for understanding BIM's role in offshore wind projects. A roadmap for answering the research question and subquestion can be found in *Chapter 1.3 (Roadmap Thesis), p. 7*

Central Research Question

To what extent can BIM be implemented in offshore wind construction projects to address existing challenges and improve project outcomes?

Research-Sub Questions

To investigate this central question, the following sub-questions are addressed:

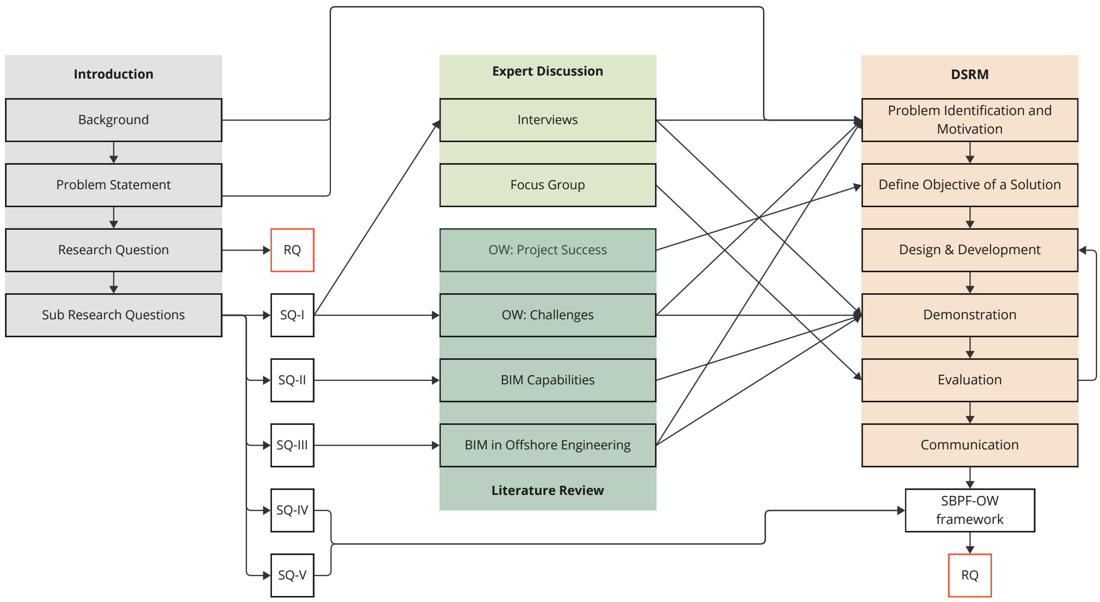
1. *What are the key challenges faced by offshore wind construction projects?*

2. *What capabilities does BIM offer for addressing complex project requirements?*

3. *What research exists on the application of BIM within the offshore wind sector, and what gaps remain?*

4. *How can organizations in offshore wind evaluate where and to what extent BIM should be integrated into their workflows?*

5. *What is the added value of BIM for offshore wind construction projects across different lifecycle phases?*



- RQ To what extent can BIM be implemented in offshore wind construction projects to address existing challenges and improve project outcomes?
- SQ-I What are the key challenges faced by offshore wind construction projects?
- SQ-II What capabilities does BIM offer for addressing complex project requirements?
- SQ-III What research exists on the application of BIM within the offshore wind sector, and what gaps remain?
- SQ-IV How can organizations in offshore wind evaluate where and to what extent BIM should be integrated into their workflows?
- SQ-V What is the added value of BIM for offshore wind construction projects across different lifecycle phases?

Figure 1.3: Roadmap Thesis

1.2.4 Scope

This research investigates the applicability of BIM in offshore wind projects, aiming to provide a holistic foundation for understanding BIM's potential in this context. BIM, as a concept, is both extensive and somewhat ambiguous. It encompasses a wide range of capabilities and applications that could each be explored in detail. Similarly, offshore wind projects are massive undertakings involving numerous stakeholders and spanning up to a decade for planning and permitting, multiple years for manufacturing and construction, and over 30 years of operation.

Given the nascent application of BIM in offshore wind, this study does not aim to exhaustively resolve all industry challenges or address BIM's full range of capabilities. Instead, it focuses on exploring BIM's potential to address key challenges, providing actionable insights, and laying the groundwork for more detailed, specialized research. The scope is deliberately broad to ensure a holistic view while remaining realistic within the constraints of a master's thesis and the resources available.

This research seeks to establish a clear basis and guide future studies in refining and expanding upon the findings. This will ensure that BIM's application in offshore wind is beneficial and feasible for the industry's continued growth and development.

1.2.5 Significance of the Study

This research advances academic understanding and practical applications of BIM within the offshore wind sector. By addressing a nascent area of inquiry, the study bridges gaps in existing research while providing actionable insights for industry stakeholders.

From an academic perspective, the research enriches knowledge by investigating BIM's potential in an underexplored context. While BIM has been extensively studied and applied within the AECOO industry, its adaptation to offshore wind projects remains limited. By identifying key challenges, capabilities, and gaps, the study provides a basis for further specialized research into BIM's role in addressing offshore wind's unique demands.

On a practical level, the study offers a framework for prioritizing areas where BIM can create the most value. This guidance is particularly relevant as the offshore wind industry expands and seeks digital solutions to support its operational and sustainability goals. The findings are designed to assist developers, operators, and policymakers in making informed decisions about adopting BIM in this complex and evolving sector.

Ultimately, this research lays the groundwork for future exploration, ensuring that subsequent studies and implementations are focused, relevant, and aligned with the needs of the offshore wind industry.

1.3 Methodology and Thesis Roadmap

1.3.1 Research Methodology

This research employs a Design Science Research Methodology (DSRM) to systematically explore how BIM can address challenges in offshore wind projects. DSRM provides a structured problem-solving approach, focusing on theoretical development and practical application. The methodology is tailored to align with the study's objectives, ensuring that each step contributes to addressing the research objectives. The research methodology is detailed in *Chapter 3 (Research Design), p. 36.*

Overall Framework

The six stages of the DSRM (detailed discussion in *Chapter 3.1 (Design Science Research Methodology), p. 37*) guide the systematic exploration of where BIM can address challenges in offshore wind projects. The process begins with identifying key challenges through a literature review and interviews, followed by defining objectives that align BIM's capabilities with the identified needs.

The methodology is centred on a multi-criteria decision analysis (MCDA) approach, which provides a structured framework for evaluating and prioritizing the factors where BIM can deliver the most value. The framework is iteratively developed, demonstrated, and refined through industry feedback to ensure its practical relevance. This thesis communicates the entire research process, from identifying challenges to refining the framework. It serves as a record of the research and delivers actionable insights to academic and industry audiences.

By structuring the research this way, the study ensures its findings are grounded in academic rigour and real-world applicability, offering a clear foundation for future research and practical implementation.

Data Collection and Analysis

The study utilizes qualitative methods and structured decision-making tools to address the central research question and sub-questions.

- **Literature Review**: The literature review (*Chapter 2 (Literature Review), p. 11*) explores offshore wind challenges, BIM capabilities, and existing research on their intersection. It provides the theoretical foundation for the study and informs the MCDA framework.

- **Semi-Structured Interviews**: Interviews with industry stakeholders (*Chapter 4 (Interview Analysis), p. 55*) capture practical insights and validate findings from the literature review. They also help identify barriers to BIM adoption and areas of opportunity.

- **Multi-Criteria Decision Analysis (MCDA)**: MCDA (part of framework development *Chapter 5.2 (Iterative Development, Demonstration and Evaluation), p. 76*)prioritizes factors based on BIM's feasibility, impact, cost-effectiveness, and plausibility. This structured approach ensures a balanced evaluation of challenges.

- **Focus Groups**: Focus groups (*Chapter 5.3 (Focus Group), p. 86*) provide expert feedback on the MCDA framework and validate the findings, enhancing the credibility of the recommendations.

The combination of DSRM, MCDA, and qualitative methods ensures that the research comprehensively addresses the complexity of offshore wind projects and BIM's potential application. By focusing on actionable outcomes, the methodology provides a robust foundation for guiding future research and industry practices.

1.3.2 Expected Outcomes and Contributions

This research is designed to produce both a tangible output for industry application and a refined evaluation approach that can inform future academic work. The primary outcome is the development of the Strategic BIM Prioritization Framework for Offshore Wind Projects (SBPF-OW), a structured decision-support tool enabling EnBW and other offshore wind stakeholders to evaluate BIM's applicability across various project phases and prioritize areas where BIM adoption is likely to yield the most value.

The framework is grounded in insights from the literature review, semi-structured interviews, and the MCDA evaluation, with validation and refinements drawn from focus group discussions involving offshore wind experts. As such, it offers EnBW a tailored, evidence-based approach to assess BIM adoption opportunities while accounting for organizational context and practical constraints. Beyond immediate application, the framework can support future BIM implementation efforts within EnBW, helping guide the transition from document-based data management toward an integrated, model-based approach.

Additionally, the SBPF-OW framework provides a structured evaluation method that can be adapted for use by other offshore wind developers and stakeholders. This methodological contribution strengthens the research's applicability beyond EnBW, facilitating more targeted BIM adoption strategies across the sector. Equating BIM capabilities with offshore wind challenges, evaluated through multiple criteria, offers a replicable approach for assessing digital solutions in other complex infrastructure domains.

2. Literature Review

This chapter provides the theoretical foundation and contextual background necessary for developing the framework proposed in this thesis. It is divided into three main parts, each contributing to different aspects of the research objectives and ultimately aiding in answering the central research question: *To what extent can BIM effectively address challenges in offshore wind projects and enhance their success?*

The first part explores the concept of project success, starting with a general definition and extending to its specific application in the context of offshore wind projects. This section establishes the basis for the Design Science Research Methodology objectives stage by analysing various success factors and criteria. It identifies the need to incorporate multiple perspectives when evaluating BIM's value for offshore wind, ensuring a more comprehensive understanding of how BIM can support the industry's unique challenges.

The second part reviews challenges commonly faced in offshore wind projects, as identified in recent reports by key industry organizations. These challenges range from technical and logistical issues to regulatory and environmental barriers. By categorizing and analyzing these hurdles, this section provides critical input for the Multi-Criteria Decision Analysis at the core of the final framework. Additionally, it sets the stage for assessing BIM's capabilities in addressing these challenges.

The third part shifts focus to BIM itself. It begins with an overview of BIM's core capabilities and then explores its successes and barriers to adoption in the AECOO industry. Understanding these factors is essential for the later stages of the thesis, where BIM's effectiveness in tackling offshore wind challenges will be rated. This section is particularly valuable for the MCDA process, as it highlights BIM's strengths and limitations, enabling a nuanced assessment of its potential.

Finally, the chapter concludes with a review of existing literature on BIM in offshore engineering. This section identifies research gaps, particularly the lack of holistic approaches to using BIM for offshore wind challenges. It also highlights areas where BIM has already shown promise, providing critical insights for the framework's design. By outlining existing knowledge and pinpointing areas requiring further exploration, this review supports the MCDA process and reinforces the thesis's focus on addressing the industry's challenges through BIM.

This chapter connects the broader context of offshore wind project challenges, BIM's potential, and the thesis methodology, laying the groundwork for the subsequent framework development and analysis.

2.1 Offshore Wind Projects

This section investigates two aspects of offshore wind projects: the criteria for defining project success and the hurdles encountered during implementation. These insights form the foundation for assessing BIM's applicability and potential impact within the offshore wind sector.

The first subsection defines project success by examining criteria and factors relevant to offshore wind projects, specifically focusing on EnBW's perspective. This analysis provides benchmarks for evaluating BIM's role in improving project outcomes and guiding the DSRM process through problem identification and objective setting. These success criteria are integral to the MCDA framework, which systematically evaluates where BIM can deliver the most value.

The second subsection explores the key hurdles faced while implementing offshore wind projects, which are mentioned in the literature. These include technical, financial, regulatory, environmental, and workforce-related challenges. By categorising and analysing these hurdles, this research identifies areas where BIM's capabilities can provide targeted solutions.

2.1.1 Project Success in Offshore Wind Projects

Defining project success in offshore wind projects is critical for evaluating how BIM can address challenges and improve outcomes across the project lifecycle. Offshore wind projects are inherently complex, involving long timelines, significant financial investments, and diverse stakeholder involvement, making success a multi-dimensional and evolving concept.

Definition of Project Success

The concept of project success remains debatable, with no universally agreed-upon definition, particularly in the context of construction projects (Alzahrani & Emsley, 2013). Traditionally, success has been defined by straightforward metrics such as completing the project within budget, on schedule, and meeting performance standards (Pinto, 1988). However, this narrow view is increasingly considered insufficient because it overlooks other essential factors contributing to a project's overall success (Shokri-Ghasabeh & Kavousi-Chabok, 2009).

For example, a project may meet its time, cost, and quality targets but still be considered unsuccessful if it fails to satisfy end-user needs or struggles with market acceptance (Dvir et al., 2003). This illustrates that project success is multi-dimensional, influenced by varying stakeholder perspectives, and evolves (de Wit, 1988).

Success Criteria and Factors

The literature distinguishes between project success, success criteria, and success factors, each playing a unique role in evaluating project outcomes:

- **Project Success:** The ultimate goal, representing the overall achievement of the project, including financial, technical, and strategic objectives (Shenhar et al., 2001).

- **Success Criteria:** Specific benchmarks used to evaluate whether a project is successful, such as meeting deadlines, staying within budget, achieving performance specifications, and satisfying stakeholder needs (Ika, 2009; Pinto & Slevin, 1988).

- **Success Factors:** Key conditions or elements that significantly enhance the likelihood of achieving success criteria, such as effective communication, skilled project management, and adequate resource allocation (Belassi & Tukel, 1996).

Success factors contribute to meeting success criteria, ultimately determining whether the project is successful from various stakeholder perspectives (Shokri-Ghasabeh & Kavousi-Chabok, 2009).

The Impact of Perspective on Project Success

Project success is not an absolute concept but is influenced by the stakeholders' perspectives. Each stakeholder possesses distinct priorities and criteria for assessing whether a project is successful, which affects the factors considered crucial to achieving that success.

Offshore wind projects involve multiple stakeholders with differing objectives. A project developer ensures financial viability over short-, medium-, and long-term horizons, optimises return on investment, and secures revenue through power purchase agreements. In contrast, a contractor responsible for foundation installation measures success by completing their scope of work on schedule, within budget, and with high vessel utilization rates. A citizen of the country where the wind farm is built may view success solely in affordable electricity and reliable energy availability, without concern for construction or operational efficiency. These perspectives illustrate how project success is defined differently depending on the stakeholder's role and priorities.

This variation extends to evaluating BIM's impact on offshore wind projects. While BIM offers advantages such as improved data management, better coordination, and lifecycle optimization, its relevance and benefits depend on the perspective from which it is assessed. A developer may prioritize BIM's ability to improve cost forecasting and risk mitigation, whereas a contractor might value its role in construction sequencing and clash detection. BIM's most significant potential for operations and maintenance teams lies in integrating digital twins to enhance predictive maintenance and asset tracking.

As a result, BIM cannot be expected to deliver uniform benefits across all stakeholder groups. Its impact must be assessed based on the specific needs and responsibilities of each party involved in the project. Recognizing these differing perspectives is essential for ensuring that BIM implementation strategies align with the priorities of those who will ultimately use and benefit from them.

EnBW's Perspective on Project Success

Given EnBW's comprehensive involvement across the lifecycle of offshore wind projects, this research adopts their perspective in the demonstration phase of the DSRM to define project success. This ensures the findings are relevant and actionable within a real-world industry context. EnBW measures success across three primary timeframes:

- **Short-Term Success:** Achieving operational efficiency, cost control, and schedule adherence during planning and construction. Metrics include minimizing CAPEX, regulatory compliance, and effective stakeholder engagement (Turner & Zolin, 2012).

- **Medium-Term Success:** Ensuring stable energy production, optimized operational practices, and reliable maintenance strategies. Metrics include consistent energy output and adherence to operational budgets (Turner & Zolin, 2012).

- **Long-Term Success:** Effective lifecycle management, including planning for decommissioning or repowering, maintaining a strong market position, and achieving sustainability objectives (de Wit, 1988; Pinto, 1988).

2.1.2 Hurdles in Offshore Wind Project Implementation

This section addresses the key hurdles offshore wind projects face during implementation, highlighting limitations in project management. These challenges will guide the Design Science Research Methodology (DSRM) by shaping the problem context and informing the framework's development.

The categorization of challenges in this section is derived from three sources: the *Global Wind Energy Council (GWEC) 2023 and 2024 Global Offshore Wind Reports* (Global Wind Energy Council, 2023, 2024), and the *Rabobank 2023 Bottlenecks Report* (Janipour, 2023). These reports were selected because they provide authoritative and up-to-date analyses of the offshore wind sector, particularly regarding its key challenges and limitations. These specific sources are chosen over others based on their combination of global, regional, and sector-specific insights. The *GWEC* reports offer a comprehensive, global view of the offshore wind industry, identifying challenges related to policy frameworks, supply chain constraints, and technological advancements. Produced by leading experts and widely regarded as essential resources for understanding current and future trends in offshore wind, these reports are invaluable for providing a broad and well-rounded perspective on the sector. Their focus on both market dynamics and regulatory issues makes them particularly relevant for identifying the hurdles that offshore wind projects face during implementation. The *Rabobank 2023 Bottlenecks Report* focuses on the European offshore wind sector, offering an in-depth analysis of specific barriers such as permitting delays, raw material shortages, and inflationary pressures. Rabobank's expertise in infrastructure finance and market analysis makes this report especially valuable for understanding the financial and logistical challenges that offshore wind projects face in Europe, a key region for offshore wind development. By focusing on Europe's unique market conditions and regulatory environment, the Rabobank report provides critical insights that complement the global perspective of the GWEC reports.

While other reports could have been considered, these three were chosen for their depth, credibility, and relevance to the global offshore wind market and the specific challenges of the European region. Given the sector's rapid development, the reports' timeliness is also crucial. Older sources might not capture the most recent regulatory shifts, technological innovations, or economic pressures significantly impacting project outcomes. Using these authoritative and current reports, the challenges identified reflect the sector's most recent realities.

Table 2.1 consolidates the challenges from these sources, which are then combined and analyzed to provide a structured framework for understanding the hurdles offshore wind projects face today.

Technical Challenges

Several technical hurdles complicate the installation and long-term operation of offshore wind turbines. These challenges range from complex logistics and environmental factors to grid connection issues and material degradation.

- **Complex Logistics and Installation:** Installing offshore wind turbines involves navigating harsh marine environments, complicating transportation and installing significant components like turbines and foundations. Ocean conditions, including high winds and waves, can lead to substantial delays and increased costs. As Barrington Energy (2024) notes, addressing these challenges requires improved atmospheric wind energy models, field studies, and robust data integration systems to effectively predict and manage adverse conditions. Moreover, obstacles such as submarine trenches and underwater boulders further complicate installation, requiring advanced geophysical surveys and technologies like sonar (Barrington Energy, 2024).
- **Grid Connection and Energy Transmission:** One of the primary technical challenges in

Global Wind Energy Council (2024)	Global Wind Energy Council (2023)	Janipour (2023)
Financing Challenges	Environmental Impact Issues	Delays in Permitting Processes
Transition to Green Energy Production	Technological Limitations	Bottlenecks in Manufacturing Capacity
Supply Chain Constraints	Supply Chain Disruptions	Rising Material Costs due to Inflation
Delays in Permitting Approval	Benefits to Local Communities	Logistical Complexities
Challenges with Social Acceptance	Gaps in Workforce Skills	Increased Competition from China
Shortages in Qualified Workforce	Offshore-Onshore Integration	Dependency on Imported Raw Materials
Modernization of Energy Grids	Vessel Capacity Shortages	Technological Complexity of Projects
	Regulatory Permitting Issues	Availability of Specialized Vessels
	Rising Costs due to Inflation	
	High Logistical Costs	
	High Interest Rates for Project Financing	
	Decommissioning Challenges	

Table 2.1: Consolidated Challenges from Global Wind Energy Council (2024), Global Wind Energy Council (2023) and Janipour (2023)

offshore wind projects is energy transmission from offshore farms to the mainland grid. The installation and maintenance of subsea cables, essential for power transmission, are prone to issues like cable failures and costly repairs. As highlighted by Barrington Energy (2024), around 75% of offshore wind insurance claims relate to cable problems, underscoring the importance of detailed site surveys and early engagement with suppliers to mitigate risks. Efficient transmission systems are essential to maintaining stable power output (Global Wind Energy Council, 2023; Janipour, 2023).

- **Turbine Technology:** Offshore wind turbines must operate in extremely harsh conditions, facing the challenges of saltwater corrosion, mechanical fatigue, and biofouling. Technological advancements are needed to improve the durability and efficiency of turbines, particularly concerning corrosion resistance and operational longevity. Barrington Energy (2024) emphasizes that ongoing innovations in materials science and manufacturing processes are crucial to extending the lifespan of turbines and reducing the need for frequent repairs and maintenance (Altaghlibi, 2023; Global Wind Energy Council, 2023).

Financial Challenges

The offshore wind industry faces significant financial challenges, primarily driven by rising costs and unstable market conditions. Offshore wind projects require substantial capital investments, with costs escalating due to inflation, rising commodity prices, and supply chain bottlenecks.

- **High Capital Costs:** Offshore wind projects have high upfront capital costs, including turbine production, installation infrastructure, and grid connection. These costs have been exacerbated by increasing material prices, particularly for steel, and higher interest rates. According to A. Weiss et al. (2024), the levelized cost of electricity (LCOE) for offshore wind projects has increased by 40–60% in recent years, adding further pressure on profitability.

- **Financing and Investment Risks:** Given the long payback periods, offshore wind projects are perceived as high-risk investments, especially compared to cheaper renewable energy sources like onshore wind and solar. Financing these projects has become more complex as developers face reduced subsidies, rising costs, and increased competition in seabed leasing auctions. Altaghlibi (2023) highlights that the financial landscape for wind power has become more uncertain, with many projects facing delays or cancellations due to funding shortages.

- **Operational and Maintenance Costs:** The operational and maintenance costs of offshore wind projects are significantly higher than those of onshore projects, mainly due to the remote locations and harsh environments. Regular maintenance, particularly of subsea cables, adds to the financial burden, making long-term cost management a crucial issue for developers (Global Wind Energy Council, 2023).

Supply Chain Challenges

The offshore wind industry faces various supply chain challenges that impact wind farms' timely and cost-effective deployment. These challenges stem from material shortages, price volatility, limited manufacturing capacity, and global competition, especially from China.

- **Material Shortages and Price Volatility:** Offshore wind projects rely heavily on key raw materials, such as steel, copper, and rare earth elements, subject to global price volatility. Rising costs of these materials have been a significant issue, driven by supply chain disruptions and increased global demand. For instance, European steel prices remain elevated compared to pre-pandemic levels, while China enjoys a cost advantage due to lower domestic prices (Janipour, 2023). Additionally, the supply of critical materials, such as neodymium used in turbine magnets, is largely controlled by China, further exacerbating supply risks (Altaghlibi, 2023; Barrington Energy, 2024).

- **Limited Manufacturing and Installation Capacity:** The global demand for offshore wind turbines has outpaced manufacturing and installation capacities, particularly in Europe. European turbine manufacturers are struggling with bottlenecks in production, driven by rising costs and competition from Chinese manufacturers who can produce turbines at a lower price. The shortage of specialized vessels for turbine installation further delays project timelines, potentially leading to a significant gap in installation capacity by 2030 (Global Wind Energy Council, 2023; Janipour, 2023). These supply chain constraints are expected to slow down the deployment of offshore wind farms across Europe, threatening to derail the EU's ambitious targets for offshore wind capacity.

- **Competition from China:** Chinese wind turbine manufacturers have rapidly gained a competitive edge, offering turbines at significantly lower prices than their European counterparts. The price difference has grown more pronounced since 2021, with Chinese turbine prices falling by nearly 48% compared to 2020 levels, while prices in Europe have continued to rise (Altaghlibi, 2023; Global Wind Energy Council, 2024). While cheaper imports may reduce upfront costs, over-reliance on foreign suppliers, particularly from China, poses significant risks. Outsourcing manufacturing entirely to China could lead to long-term vulnerabilities, including geopolitical risks, supply chain disruptions, and a loss of technological leadership. Relying too heavily on foreign suppliers can expose domestic industries to fluctuating trade policies, potential sanctions, and supply interruptions during international conflicts or crises. Moreover, the offshore wind industry is critical to Europe's green transition and energy security, making it essential to maintain control over crucial manufacturing processes within the region. A robust domestic supply chain would safeguard local jobs and enhance Europe's ability to innovate, scale production, and meet ambitious renewable energy targets (Global Wind Energy Council, 2023; Janipour, 2023). European manufacturers are advocating for more robust policy measures, such as financial incentives and quotas for EU-built turbines, to ensure the region remains competitive and self-sufficient in the long term.

Environmental Challenges

Offshore wind farms present several environmental challenges that need to be addressed to ensure the sustainable development of these projects. The key concerns include impacts on marine ecosystems, underwater noise pollution, impact on seabird populations, and the potential alteration of habitats.

- **Marine Ecosystem Impact:** Offshore wind turbines can significantly affect marine habitats during the construction and operation phases. Noise from pile driving during installation and ongoing underwater noise from turbine operation can disturb marine mammals and fish. Bailey et al. (2014) points out that pile-driving noise has been shown to cause behavioural changes and even physical harm to marine life, particularly to species like porpoises and seals. Further, electromagnetic fields from underwater cables may affect species sensitive to such fields, including sharks and rays (Bailey et al., 2014; Global Wind Energy Council, 2024).

- **Seabird Collision and Habitat Displacement:** One of the primary environmental concerns with offshore wind turbines is the risk of bird collisions with the turbine blades. Seabirds, particularly those that migrate through wind farm areas, are at risk of fatal collisions, which could negatively impact vulnerable populations. According to Bailey et al. (2014), there is also evidence that offshore wind farms may displace birds from critical feeding or breeding grounds, leading to increased energy expenditure and reduced reproductive success. Long-term monitoring is necessary to understand the population-level effects of these disturbances.

- **Changes to Benthic and Pelagic Habitats:** Offshore wind installations can alter local marine ecosystems by introducing complex structures that act as artificial reefs. These can provide new habitats for aquatic life but disrupt existing benthic habitats and food webs. Bailey et al. (2014) notes that while artificial reefs may increase biodiversity in some areas, the cumulative impact of large-scale offshore wind development remains uncertain and could lead to habitat fragmentation or displacement of species reliant on specific environments.

- **Cumulative Environmental Impacts:** The cumulative impacts of multiple offshore wind farms and other marine activities present a significant environmental challenge. Bailey et al.

(2014) emphasizes the importance of cumulative impact assessments (CIA) to evaluate the combined effects of multiple developments on marine ecosystems. The interconnected nature of marine environments means that the effects of noise, habitat alteration, and species displacement can accumulate across a wide area, necessitating a holistic approach to environmental management (Altaghlibi, 2023; Global Wind Energy Council, 2023).

Regulatory Challenges

The offshore wind industry faces significant regulatory challenges contributing to project delays and increased costs. These challenges arise from complex regulatory frameworks, fragmented permitting systems, and the bureaucratic hurdles that impede project development.

- **Lengthy Permitting Processes:** One of the most critical regulatory challenges for offshore wind projects is the lengthy and fragmented permitting process. In many regions, developers must obtain approval from multiple regulatory bodies, each with its requirements and timelines. According to IRENA and GWEC (2023), the absence of a centralized permitting authority often delays, as developers must navigate various agencies. Furthermore, the process is exacerbated by the lack of digitized tools to streamline data sharing and approvals, which increases the time needed to coordinate across authorities.

- **Bureaucratic Complexity:** Offshore wind projects are also burdened by bureaucratic complexity. The permitting process often involves extensive environmental and legal reviews, which can be subject to multiple rounds of consultations and legal challenges. A report by Energy Transitions Commission (2023) on planning and permitting barriers highlights that environmental impact assessments (EIAs) for offshore wind farms, particularly those in sensitive marine environments, can take years to complete. Additionally, integrating stakeholder feedback and conflicting interests from other maritime sectors, such as shipping and fishing, further complicates the process.

- **Lack of Streamlined Digital Resources:** Another significant barrier is the absence of streamlined digital platforms to facilitate the permitting process. Many permitting systems still rely on outdated, paper-based systems that do not allow efficient communication between agencies. The lack of a centralized digital platform hampers the ability to track the progress of permits and leads to redundant requests for information, further delaying projects (IRENA and GWEC, 2023). By implementing digital permitting platforms, governments could enhance transparency and coordination, significantly reducing the administrative burden on developers.

- **Unclear and Inconsistent Regulations:** Offshore wind projects often face regulatory uncertainty due to inconsistent interpretations of permitting rules. The disconnect between developers and permitting entities creates confusion, especially when regulations are adapted from other industries, such as oil and gas, and do not fully align with the needs of offshore wind development. This lack of clarity can lead to prolonged negotiations and delays as both parties attempt to interpret and comply with the rules (IRENA and GWEC, 2023).

Workforce-Related Challenges

The offshore wind industry faces substantial workforce-related challenges as it scales to meet ambitious European and US capacity targets. The growing demand for specialized labour and logistical and training issues have created significant bottlenecks in the sector's development.

- **Skill Shortages:** A major challenge in the offshore wind industry is the shortage of skilled workers. The need for engineers, technicians, and project managers with expertise in offshore environments has increased dramatically. According to the Global Wind Energy Council (GWEC), the rapid expansion of offshore wind farms in Europe and the US is outpacing the availability of skilled labour, creating a labour gap that could delay projects and raise costs (Global Wind Energy Council, 2024). Germany has seen a decline in offshore wind employment due to market uncertainties, dropping from 29,800 workers in 2016 to 21,700 in 2021 (Eckardt et al., 2023).

- **Training and Retention:** The offshore wind industry requires more robust training programs to address the skill gap. Europe and the US have initiated programs to train workers, but these efforts are insufficient. In Europe, Germany's vocational training system is relatively advanced, but there are still shortages in specialized roles such as electrical component manufacturing and turbine maintenance (Eckardt et al., 2023). Retention is also a significant issue, as workers in offshore wind often transition to other renewable energy sectors or return to traditional industries like oil and gas.

- **Logistical and Geographic Barriers:** Offshore wind farms are often located in remote locations, presenting logistical and workforce challenges. Workers must be deployed to offshore installations for extended periods, leading to high turnover rates and recruitment difficulties. Improving offshore living conditions, such as enhanced accommodations and shorter rotations, could help mitigate these issues. Additionally, logistical improvements, such as more efficient transportation methods to and from offshore platforms, are necessary to maintain a stable workforce (Altaghlibi, 2023; Global Wind Energy Council, 2024).

End-of-Life Challenges

As offshore wind farms end their operational lives, the decommissioning phase presents unique challenges. These challenges span regulatory, technical, environmental, and economic aspects that must be carefully navigated to ensure a sustainable and efficient end-of-life process.

- **Regulatory Uncertainty:** The regulatory landscape governing offshore wind farm decommissioning remains underdeveloped and fragmented. Many existing regulations have been adapted from the oil and gas sector, which often fails to adequately address the specific requirements of offshore wind projects. This creates uncertainty for operators when planning and executing decommissioning activities. E. T. et al. (2019) highlights that current guidelines are frequently vague and ill-suited for offshore wind, leading to inconsistent practices across jurisdictions. Topham and McMillan (2017) further emphasizes that the absence of clear, standardized decommissioning regulations increases uncertainty and can escalate costs for operators. Moreover, recent European Union policies, such as the Waste Framework Directive (European Parliament and Council of the European Union, 2008), the Circular Economy Action Plan (European Commission, 2020a), and the Landfill Directive (Council of the European Union, 1999), introduce additional considerations regarding material recovery, recycling obligations, and waste reduction. These requirements may add complexity to decommissioning efforts, particularly concerning the recycling of blades, steel, and concrete components. As summarized in Table 2.2, these evolving regulatory demands highlight the growing need for clearer, sector-specific decommissioning guidelines tailored to offshore wind.

- **Technical and Logistical Challenges:** The technical complexity of decommissioning offshore wind farms is significant. Decommissioning operations require specialized vessels and

Policy / Directive	Key Focus	Relevance to Offshore Wind End-of-Life Circularity
Circular Economy Action Plan (European Commission, 2020a)	Waste reduction, circular product design, increased resource efficiency	Pushes for design for disassembly, reuse, and recycling of turbine components, supporting circularity efforts in offshore wind.
Waste Framework Directive (European Parliament and Council of the European Union, 2008)	Waste hierarchy (prevention, reuse, recycling, recovery, disposal), extended producer responsibility	Encourages recycling over landfilling; promotes lifecycle thinking in turbine component disposal and recycling strategies.
Landfill Directive (Council of the European Union, 1999)	Reduce landfill waste	Increasing pressure to end landfilling of decommissioned wind turbine blades; supports industry-led call for a landfill ban on blades by 2025.
Renewable Energy Directive (European Parliament and Council of the European Union, 2023)	Renewable energy targets, lifecycle sustainability	Pushes for sustainability throughout the lifecycle of offshore wind farms, emphasizing responsible resource use and decommissioning practices.
Eco-design for Sustainable Products Regulation (European Commission, 2022)	Sustainable product design, reparability, recyclability	Likely to influence future turbine design, encouraging easier disassembly, material recovery, and recyclability.
Offshore Renewable Energy Strategy (European Commission, 2020b)	Offshore wind capacity expansion to 300 GW by 2050	Stresses the need for sustainability across the offshore wind project lifecycle, including end-of-life management and recycling.

Table 2.2: Overview of Key EU Policies Relevant to End-of-Life and Circularity in Offshore Wind Turbines

heavy-lifting equipment, often in short supply due to high demand from the wind and oil industries. The unpredictable nature of marine environments adds to the logistical challenges, with weather conditions frequently causing delays. As noted by E. T. et al. (2019), the shortage of appropriate vessels for lifting and transporting significant components like turbines and foundations can prolong the process, raising both costs and risks. Furthermore, each decommissioning site has unique characteristics, requiring customized solutions, as outlined by Topham and McMillan (2017).

- **Environmental Impact:** Decommissioning can have significant environmental consequences, particularly disturbing marine ecosystems. Complete removal of subsea infrastructure, such as cables and foundations, can cause severe disruption to the seabed and aquatic habitats. Recent studies, such as Topham and McMillan (2017), suggest that partial removal of infrastructure could be a more environmentally friendly option. Leaving parts of the foundations in situ can create artificial reefs that benefit marine life, reducing the environmental footprint. O. P. B. et al. (2019) also emphasizes the importance of careful monitoring post-decommissioning to ensure that ecosystems recover effectively.

- **Economic Viability:** The costs associated with decommissioning are substantial, and many projects do not fully account for these expenses during the planning phase. Topham and McMillan (2017) points out that initial cost estimates often fail to capture the full scope of the decommissioning process, leading to budget overruns. Sustainable decommissioning practices, such as recycling materials and repowering existing infrastructure, can add further costs but offer long-term environmental benefits. O. P. B. et al. (2019) highlights the need for comprehensive cost analysis and lifecycle planning to ensure that decommissioning is economically viable and sustainable.

2.2 BIM

BIM has emerged as a transformative technology within the AECOO industry, offering a unified platform for managing project data throughout the lifecycle of a construction project. Its integration of 3D design, data management, and real-time collaboration has revolutionized project planning, execution, and operations. BIM supports more accurate decision-making, improved stakeholder collaboration, and better overall project outcomes by providing a centralized, consistent flow of information (Azhar, 2011; Eastman et al., 2011).

The BIM chapter lays the groundwork for evaluating BIM's applicability to offshore wind projects. It provides a detailed exploration of BIM's capabilities, offering the theoretical foundation necessary for connecting BIM's functionalities to the unique challenges of offshore wind. By systematically analyzing BIM's core and advanced functionalities, this chapter aligns with the DSRM by informing both the problem identification and artefact design phases.

This chapter also establishes the basis for mapping BIM's capabilities to specific hurdles in offshore wind projects. These insights will later support the MCDA, where BIM's potential to address offshore wind challenges will be assessed and prioritized. Additionally, by detailing BIM's potential applications across all phases of a project—from planning and construction to operations and decommissioning—the chapter directly contributes to the evaluation criteria for the thesis.

This chapter bridges the gap between theoretical concepts and practical applications by comprehensively understanding BIM's functionalities. It ensures the thesis remains academically rigorous and industry-relevant, creating a foundation for developing actionable solutions to enhance offshore wind project management.

2.2.1 BIM as a Concept

Definition and Evolution of BIM

BIM does not have a universally agreed-upon definition, and various interpretations exist depending on the perspective and role of the user (Borkowski, 2023; Izadi Moud & Abbasnejad, 2013). One definition describes BIM as a digital technology that establishes a computable representation of a facility's physical and functional characteristics, serving as a repository of information for the facility owner or operator throughout its lifecycle (National Institute of Building Sciences, 2007). Another definition by S. van Nederveen et al. (2010) presents BIM as a comprehensive model of information that supports all lifecycle processes and can be directly interpreted by computer applications, incorporating information about a building's properties such as function, shape, material, and processes. These definitions highlight the potential for different interpretations influenced by the user's viewpoint, organizational type, and specific objectives.

BIM has undergone significant development, and there is no consensus on who originally introduced the concept. According to Latiffi et al. (2014), the term "BIM" was first introduced by Professor Charles Eastman in the 1970s, who initially developed the concept of a Building Description System (BDS) aimed at improving design coordination by creating a database for building elements. Borkowski (2023) claims that the BIM concept was first mentioned in an article by Giles A. (Sander) van Nederveen and Frits P. Tolman in 1992, introducing a method for modelling multiple perspectives on buildings using aspect models with an intuitive and straightforward way to represent building information (G. van Nederveen & Tolman, 1992). BIM originated in 1957 with PRONTO and evolved through systems like Sketchpad, RUCAPS, and GLIDE in the following decades. It gained significant traction in the early 2000s when Jerry Laiserin popularized it as a comprehensive process for managing building data throughout its lifecycle (Borkowski, 2023). Since then, BIM has become a cornerstone for improving project management and communication in the AECOO sector, with definitions evolving to reflect its broader application beyond just 3D modelling Borkowski (2023). Today, BIM is understood not only as a tool for creating digital representations of physical and functional characteristics of buildings but also as an information management methodology that spans the entire lifecycle of a project, from design and construction to operation and eventual demolition (Izadi Moud & Abbasnejad, 2013) (Borkowski, 2023).

BIM Standardization and Interoperability

Achieving seamless interoperability is fundamental to realizing BIM's potential across the AECOO industry. This requires a standardized approach to data exchange, processes, and terminology, formalized through three complementary standards developed by buildingSMART International: Industry Foundation Classes (IFC), Information Delivery Manual (IDM), and International Framework for Dictionaries (IFD) (Laakso & Kiviniemi, 2012; Ramaji et al., 2014; Santos, 2010).

IFC (ISO 16739-1:2024) is an open, vendor-neutral data schema that provides a standardized digital representation of building elements, properties, and relationships. It enables reliable data exchange between BIM software platforms, ensuring consistency across disciplines and lifecycle phases (Laakso & Kiviniemi, 2012). IFC has evolved to address sector-specific needs, with recent versions (e.g., IFC 4.3) extending support to infrastructure projects, including bridges, railways, roads, and ports, though its application to offshore wind farms remains underdeveloped (Yu et al., 2023).

IDM (ISO 29481-1:2016, ISO 29481-3:2022) defines when, by whom, and for what purpose information is exchanged throughout a project's lifecycle. Part 1 establishes the methodology and format for determining information requirements, while Part 3 introduces a machine-readable data schema to facilitate the digital implementation of these processes. It maps out information delivery requirements and aligns stakeholders on the data needed at each stage, reducing coordination errors (L. Zhang et al., 2012). Model View Definitions (MVDs) translate these requirements into machine-readable IFC subsets for software implementation (Ramaji et al., 2014).

IFD (ISO 12006-3:2016) ensures consistent interpretation of construction terms and properties across languages and disciplines by providing unique identifiers for building concepts. It facilitates semantic interoperability, particularly in international projects where terminology may vary (Ramaji et al., 2014; Santos, 2010).

These standards — IFC, IDM, and IFD — collectively form the foundation of openBIM interoperability, enabling accurate data exchange, process alignment, and semantic consistency. This relationship is often visualized as an interoperability triangle, with IFC representing data, IDM representing processes, and IFD representing terms (Figure 2.1). This conceptual model highlights the complementary nature of data structures, process definitions, and terminological precision in facilitating seamless BIM collaboration. The visualization in Figure 2.1 is adapted from buildingSMART International's conceptual depictions and industry interpretations (*Open BIM Standards: IFC, IDM, IFD*, 2010).

Importance in the AECOO Industry

BIM has revolutionized the AECOO industry by transforming how projects are designed, built, and managed. BIM enhances collaboration, improves communication, and helps prevent costly errors by integrating comprehensive project data into a single digital model (Borkowski, 2023). This allows real-time access to accurate information across all project stages, enabling better decision-making and coordination among stakeholders (Izadi Moud & Abbasnejad, 2013). The adoption of BIM

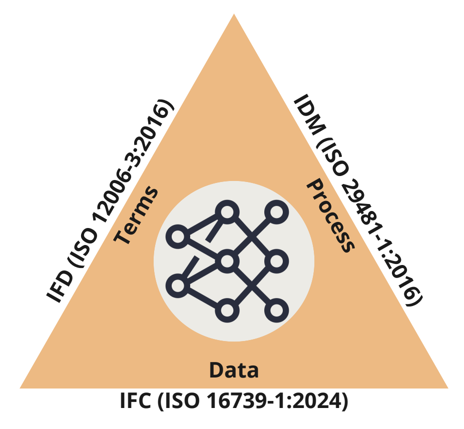


Figure 2.1: The interoperability foundation of BIM, illustrating the relationship between Data, Process, and Terms, adapted from buildingSMART International (*Open BIM Standards: IFC, IDM, IFD*, 2010).

has improved efficiency, streamlined workflows, and increased productivity, as it automates clash detection, cost estimation, and lifecycle management (Latiffi et al., 2014). BIM's ability to provide a multi-dimensional view of building data throughout the lifecycle has made it an essential tool for managing complex relationships and vast amounts of information in construction projects (Borkowski, 2023). While BIM was initially embraced for its design capabilities, its benefits extend beyond that to improve construction execution, facility management, and long-term asset performance (Izadi Moud & Abbasnejad, 2013). The broad impact of BIM on the AECOO industry is undeniable, as it offers new opportunities to optimize both the technical and economic aspects of projects, making it a critical tool for future advancements in construction practices (Latiffi et al., 2014).

2.2.2 Capabilities of BIM

The categorization of BIM capabilities presented in this section is structured to align with the different phases of a project's lifecycle, ensuring that each capability is connected to the stage where it provides the most value. This structure illustrates BIM's role from design to operation, maintenance, and decommissioning, covering a full spectrum of applications. The categorization choices are based on three key arguments: relevance to lifecycle phases, established research, and industry trends. BIM's utility evolves as the project progresses, offering unique tools to address specific challenges at each stage. For example, during the design phase, 3D modelling, clash detection, and simulations are vital in visualizing spatial relationships, identifying conflicts, and optimizing design decisions before construction begins (Azhar et al., 2012; Ivson et al., 2020). In the construction phase, 4D (time) and 5D (cost estimation) modelling play an integral role in improving scheduling and cost control, reducing risks and enhancing resource efficiency (El-Habashy et al., 2023; Smith, 2014). As the project transitions to operation and maintenance, BIM's ability to support 6D modelling enables more effective facility management, helping extend asset lifespans and improve maintenance scheduling (Nicał & Wodyński, 2016; Valinejadshoubi et al., 2020). The inclusion of these capabilities is supported by well-established research, which highlights BIM's effectiveness in reducing errors and costs during construction. At the same time, 4D and 5D modelling is increasingly recognized for its impact on time and cost management (Azhar et al., 2012; Jupp, 2017). Furthermore, this categorization reflects industry trends, such as integrating AI, VR, and AR with BIM, which illustrates the industry's shift towards digital transformation and more efficient project management (Panya et al., 2023; Rane, 2023). By incorporating these advanced capabilities, this categorization captures BIM's current applications and anticipates its future role. Ultimately, by dividing BIM capabilities into design, construction, operation, and advanced phases, this approach provides comprehensive coverage of how BIM can be applied across different project stages, offering a systematic understanding of its utility throughout the lifecycle.

Design

- **3D Modeling and Visualization**: BIM enhances design by providing detailed 3D models that serve as a central database for all building-related information. These models enable architects, engineers, and other stakeholders to visualize the design in real time, facilitating better communication and more informed decision-making throughout the project lifecycle Ivson et al., 2020. BIM's 3D models help to identify spatial relationships and potential design conflicts early in the process, reducing the likelihood of errors later in the construction phase Azhar et al., 2012.

- **Walkthroughs and Simulations**: One of BIM's visualization capabilities is its ability to generate walkthroughs and simulations. These allow stakeholders to virtually experience the project and explore how different design decisions impact the overall structure. Such simulations are instrumental in understanding the project's progress and predicting potential challenges during construction Ivson et al., 2020. Virtual simulations help project teams in planning and anticipating outcomes, making it easier to resolve issues before they arise on-site Azhar et al., 2012.

- **Clash Detection**: One of the key capabilities enabled by BIM is the automation of clash detection. This process identifies conflicts between building systems— structural, mechanical, and electrical components—before construction begins. By utilizing BIM tools for clash detection, project teams can reduce the risk of costly rework and delays by identifying inconsistencies that might be overlooked in traditional 2D plans Izadi Moud and Abbasnejad, 2013. This ensures better coordination and accuracy among all design elements, improving efficiency and project outcomes Azhar et al., 2012.

Construction

- **4D Modeling (Time)**: 4D BIM integrates time into the traditional 3D model, allowing for the visualization and tracking of construction schedules and phases (El-Habashy et al., 2023). By linking schedule data with the 3D BIM model, project managers can simulate construction activities over time, improving control and coordination of project timelines. This method enhances decision-making and communication and reduces risks associated with delays and errors during construction (Jupp, 2017). 4D BIM also enables the visualization of how different construction stages interact and overlap, helping teams identify potential time-space conflicts, such as clashes between ongoing construction activities and material deliveries. This promotes more efficient construction processes by optimizing the use of site resources and minimizing delays (Hosseini et al., 2016; Jupp, 2017). Additionally, 4D BIM facilitates stakeholder collaboration, allowing contractors, engineers, and architects to use the same platform to visualize and discuss construction schedules. The ability to test different construction sequences and adjust plans before work begins helps reduce on-site issues and improves overall project efficiency (Hosseini et al., 2016; Jupp, 2017).

- **5D Modeling (Cost Estimation)**: 5D BIM integrates cost data into the BIM model, providing real-time cost estimation throughout the design and construction phases. By linking the 3D model with time (4D) and cost data, 5D BIM allows project teams to generate accurate cost estimates and monitor expenses as the project progresses (Smith, 2014). This real-time integration enables more efficient decision-making, as design changes automatically update cost estimates, reducing the time spent on manual calculations (Smith, 2016). The ability to simulate multiple design and construction scenarios with associated costs helps project managers optimize resource allocation and stay within budget constraints. Additionally, 5D BIM supports better collaboration between cost managers, designers, and contractors by providing a shared platform for all stakeholders to access and update cost data in real-time (Smith, 2014). Integrating cost management with the BIM model reduces the risk of cost overruns and enhances project transparency, as all parties have access to the most current cost information (Smith, 2016).

- **BIM and Safety**: BIM offers significant advantages in improving construction safety by enhancing hazard identification, safety planning, and communication. One of the most impactful applications is the previously described 4D-BIM, which integrates time (schedules) into 3D models for dynamic site layout and safety planning. This enables stakeholders to anticipate safety risks, such as falls or equipment hazards, and address them before construction begins (Sulankivi et al., 2010). Additionally, BIM facilitates automated, rule-based safety checking, which can identify hazards based on design models and suggest preventive measures, thereby improving overall safety planning and reducing the risk of on-site accidents (S. Zhang et al., 2013).

Operation, Maintenance and Decommissioning

- **6D Modeling (Facilities Management)**: 6D BIM extends BIM's capabilities into the facility management phase by incorporating data for the entire lifecycle of the building, enabling better asset management, maintenance scheduling, and operational efficiency (Nicał & Wodyński, 2016; Valinejadshoubi et al., 2020). BIM-based facilities management platforms can store and organize data related to the maintenance of building systems and equipment, such as HVAC, lighting, and sensor-based monitoring systems, ensuring that facility managers have real-time access to critical information (Nicał & Wodyński, 2016; Valinejadshoubi et al., 2020). By integrating sensor-based data with the BIM model, facility managers can monitor the performance of building systems and receive automated alerts about maintenance issues. This helps prevent failures, extend the lifespan of building assets, and optimize operational efficiency through predictive maintenance (Valinejadshoubi et al., 2020). Visualizing maintenance data in 3D and accessing historical information on maintenance activities further enhances decision-making processes, resulting in a more efficient facility management workflow (Nicał & Wodyński, 2016).

- **Decommissioning / End-of-Life (EOL)**: BIM can significantly support decommissioning by enabling the strategic planning, visualization, and management of end-of-life tasks. When integrated early in the project lifecycle, BIM allows for decommissioning strategies to be embedded from the outset. This foresight ensures that materials, components, and systems can be efficiently dismantled, reused, or recycled, reducing long-term costs and environmental impacts (Cheng et al., 2017; Daniska & Vrban, 2023). BIM's 4D modelling capabilities are beneficial for visualizing deconstruction sequences, helping to prevent clashes and optimize the use of resources during dismantling. Meanwhile, 5D modelling integrates cost data with time and resource information, ensuring the decommissioning process is cost-effective and well-coordinated (Cheng et al., 2017). By simulating various decommissioning scenarios—such as reuse, recycling, or complete removal—BIM allows stakeholders to make informed decisions based on environmental and economic considerations (Daniska & Vrban, 2023). Furthermore, in the circular economy context, BIM can promote sustainable decommissioning by supporting the recovery and reuse of salvaged materials. Recent developments, such as the "Deconstruction Information Model" (DIM), provide structured data on building components, aiding in sustainable dismantling practices. This shift from traditional demolition to deconstruction aligns with circular economy principles, helping reduce construction waste and extend the lifecycle of materials (Charef, 2022).

Integration Across Phases

- **Centralized Data Management**: One of the primary advantages of BIM is its ability to centralize all project-related data into a single, accessible platform. This central repository allows for the efficient storage and management of 3D models, schedules, cost estimates, and other relevant data, making it easily accessible to all stakeholders involved in a project. Such centralized data management improves decision-making, enhances collaboration, and minimizes the risk of errors caused by data fragmentation or miscommunication (Azhar et al., 2012; Lou et al., 2021). Additionally, BIM's use of open standard formats, such as Industry Foundation Classes (IFC), ensures interoperability across various software systems, enabling seamless data exchange between different disciplines (Lou et al., 2021; Singh et al., 2011).

- **Real-time Collaboration and Updates**: BIM fosters real-time collaboration by enabling multiple stakeholders to access, modify, and update project data simultaneously. Through the use of cloud-based BIM platforms, real-time data sharing is made possible, reducing the need for traditional document-based communication and lowering the risk of versioning conflicts (Lou et al., 2021; Shin, 2017). BIM automatically reflects updates across the system as changes are made to the model, ensuring all participants work with the most up-to-date information. This capability is critical for maintaining data consistency and improving communication between architects, engineers, contractors, and other key players in the project (Ivson et al., 2020; Singh et al., 2011).

- **Sustainability Assessments**: BIM is an essential tool for conducting sustainability assessments, allowing for evaluating a project's environmental impact across its lifecycle. BIM supports the integration of lifecycle assessment (LCA) and assesses the energy performance, material usage, and overall carbon footprint of a building. Through tools such as energy performance simulations and material efficiency tracking, BIM helps reduce energy consumption and minimize the environmental impact of construction processes (Chong et al., 2016; Olawumi & Chan, 2018). Additionally, BIM is crucial for aligning projects with ecological certifications, such as LEED, by providing the necessary data for evaluating criteria like energy efficiency, water usage, and materials selection. Integrating BIM with sustainability analysis tools allows for real-time optimization of environmental performance during the design and construction phases. By incorporating eco-indicators and sustainability metrics, BIM ensures that projects meet regulatory and voluntary environmental standards (Alwan et al., 2015; Lee et al., 2015). BIM's ability to assess energy consumption, materials lifecycle, and waste management further enhances its role in promoting sustainable practices in the construction industry (Chong et al., 2016).

Advanced Capabilities

- **Integration with GIS**: The integration of BIM with Geographic Information Systems (GIS) brings together detailed building data with large-scale geographic and environmental information, offering significant benefits for site analysis, planning, and infrastructure management. BIM focuses on the thorough, structured data of a building's physical and functional characteristics, while GIS excels in managing and analyzing spatial data related to the environment and terrain (Liu et al., 2017). When combined, BIM and GIS provide a more holistic view of the built and natural environments. This integration enables enhanced decision-making, particularly in site selection, environmental impact assessments, and urban planning. For example, GIS can offer crucial insights into site topography, utilities, and environmental risks, while BIM delivers precise building designs and construction details. Together, they can optimize construction site layouts, including the positioning of cranes and equipment, and assess potential risks such as flood zones or unstable terrains (Xia et al., 2022). Additionally, the integration supports infrastructure planning on a larger scale, enabling urban planners to model future developments more accurately, taking both building-specific details and broader geographic information into account. This makes the combined use of BIM and GIS particularly useful in disaster preparedness, emergency management, and long-term urban sustainability planning (Liu et al., 2017).

- **BIM and Artificial Intelligence (AI)**: The integration of AI with BIM offers immense potential for transforming the construction industry, though only a few applications will be discussed here. AI enhances BIM's capacity for predictive analytics, allowing project managers to forecast delays, risks, and necessary interventions by analyzing historical and real-time data (Bassir et al., 2023; Rane, 2023). AI also supports generative design, automating the creation of optimal building models based on predefined criteria such as cost, material efficiency, and sustainability (Bassir et al., 2023). Additionally, AI assists in real-time adjustments to construction schedules, dynamically optimizing resource allocation to enhance project efficiency (Rane, 2023). Regarding safety, AI-powered systems using computer vision and drone technologies enable continuous monitoring of construction sites, identifying hazards and deviations from design to prevent costly rework (Rane, 2023).

- **BIM and Virtual Reality (VR) / Augmented Reality (AR)**: The integration of BIM with VR and AR technologies brings numerous advantages to the construction process by enhancing design visualization, project coordination, and real-time site management. VR enables users to immerse themselves in a fully realized digital environment, allowing stakeholders to interact with 3D BIM models in a simulated space, improving design understanding and communication (Panya et al., 2023). AR overlays BIM data onto the physical environment, supporting real-time construction monitoring, facility management, and on-site inspections, enhancing decision-making and reducing errors (Alavi, 2024; Sidani et al., 2021). The combined use of BIM with VR and AR improves the ability to simulate different project scenarios, identify potential design clashes early, and optimize construction workflows dynamically and interactively (Panya et al., 2023). Furthermore, these technologies facilitate enhanced safety training by allowing workers to engage with realistic simulations of construction environments and potential hazards, leading to a more informed and prepared workforce (Sidani et al., 2021).

- **BIM and Blockchain**: Integrating blockchain with BIM can significantly enhance data security, transparency, and management in construction projects. Blockchain provides a decentralized ledger that ensures data immutability and traceability, which can dramatically improve the integrity of collaborative BIM processes (Tao et al., 2021). While BIM alone does not inherently rely on blockchain, adding blockchain technology can secure design changes, transactions, and data exchanges, reducing risks such as data manipulation or unauthorized access (Nawari & Ravindran, 2019). Furthermore, blockchain can be integrated with distributed file storage systems like the Interplanetary File System (IPFS) to manage the large volumes of data generated by BIM, providing a scalable and secure solution (Tao et al., 2021). This fusion creates a more reliable and transparent system for managing construction data, fostering trust and collaboration among all project stakeholders (Nawari & Ravindran, 2019).

- **BIM and Lean Construction**: Integrating BIM and Lean Construction techniques enhances project efficiency by reducing waste, improving workflows, and maximizing value creation in the construction process. Lean construction minimizes non-value-adding activities, such as material waste and rework. At the same time, BIM facilitates this by providing detailed digital models that improve communication, clash detection, and decision-making (Andújar-Montoya et al., 2019; Michalski et al., 2022). Combining these two methodologies leads to better project coordination and productivity by ensuring that information flows seamlessly across all stakeholders and phases of a project. By visualizing project timelines and resource needs in BIM, Lean principles can be applied to optimize schedules and reduce delays (Michalski et al., 2022). Together, BIM and Lean practices help create more predictable outcomes and drive continuous improvements in construction performance (Andújar-Montoya et al., 2019).

2.2.3 Maturity, Success and Hurdles of BIM

Maturity in the AECOO Industry

BIM has seen significant global adoption, driven by its ability to improve collaboration, project efficiency, and cost management. As of 2021, the global BIM market was valued at over USD 9.6 billion, with projections indicating a growth rate of 16.33% annually until 2027 (Infotech, 2024). In Europe, the implementation of BIM is particularly advanced, mainly due to government mandates and industry initiatives. Many countries have introduced BIM mandates for public projects, requiring its use to increase efficiency and standardization. The United Kingdom remains a leader, introducing mandatory BIM Level 2 for government-funded projects in 2016, leading to widespread adoption across the construction sector (PlanRadar, 2021). Germany followed suit by mandating BIM for public infrastructure projects in 2020, accelerating its use in the design and execution phases of large-scale projects (Plus, 2021). In France, BIM has become mandatory for specific public construction projects since 2022, although the country still lacks a unified BIM standard (Plus, 2021). These mandates have driven up BIM usage, but smaller companies in some regions still face challenges in adopting the technology fully (Mitera-Kiełbasa & Zima, 2024). Despite the rapid progress, the initial expectations for BIM to revolutionize the industry have not been fully realized due to barriers such as insufficient training and resistance to change (Mitera-Kiełbasa & Zima, 2024).

Barriers to BIM Adoption

Implementing BIM in the Architecture, Engineering, and Construction (AEC) industry has faced several barriers that hinder its full-scale adoption across organizations and sectors. These challenges manifest at various organizational levels and influence BIM's maturity.

- **Lack of Expertise and Training:** One of the primary obstacles to adopting BIM is the limited availability of trained professionals. Many firms, especially those in the early stages of BIM maturity, struggle to provide adequate training for their teams, which results in slow or ineffective adoption (Manzoor et al., 2021; Siebelink et al., 2020). The high complexity of BIM tools further exacerbates this challenge, leaving organizations underprepared for large-scale implementation (Kassem et al., 2012).

- **High Initial Costs:** The costs associated with BIM adoption are a notable barrier, particularly for small and medium-sized enterprises (SMEs). These costs include purchasing software licenses, upgrading hardware, and investing in training programs. The high initial investment discourages companies from fully embracing BIM (Fadeyi & Oluwafemi, 2020; Siemiatkowski & Wasilewski, 2020) without an immediate return. Additionally, there is a lack of understanding of the business value of BIM for (Kassem et al., 2012)

- **Cultural Resistance to Change:** Resistance to adopting new technologies is prevalent within the construction industry. Many professionals hesitate to change established workflows, viewing BIM as a disruptive innovation that complicates rather than simplifies processes. This cultural resistance is often more pronounced in firms with lower BIM maturity (Emmitt et al., 2020).

- **Uneven Adoption of BIM Standards:** While ISO 19650 and CEN/TC 442 provide a standardized framework for BIM information management in Europe, their adoption and implementation remain inconsistent across countries, creating challenges for cross-border collaboration and reducing the efficiency of BIM processes (Hajdu et al., 2022).

- **Legal and Contractual Issues:** Legal uncertainties around intellectual property rights and the ownership of BIM models create additional barriers. Firms are often reluctant to adopt BIM because of concerns about liability and data control, particularly in projects that involve multiple stakeholders (Fadeyi & Oluwafemi, 2020).

- **Insufficient Management Support:** A lack of top management support is a critical barrier in organizations with low BIM maturity. Without solid leadership advocating for BIM adoption, project teams often lack the motivation, resources, and direction to integrate the technology into their processes effectively (Siebelink et al., 2020).

2.3 Literature Review on BIM and Offshore Engineering

This chapter reviews the literature on BIM and its application in offshore engineering. It plays a crucial role within the DSRM framework by informing the design and development phases. By synthesizing current research, this chapter establishes the state of knowledge on the use of BIM in offshore projects, helping to identify gaps and opportunities for further exploration. These insights will guide the subsequent stages of artefact development and evaluation, ensuring that the proposed BIM framework aligns with the needs of offshore wind projects.

The chapter is structured to reflect the lifecycle of offshore engineering projects. BIM's potential applications are categorized into design, construction, operation and maintenance, and decommissioning phases, ensuring that all relevant aspects of the project lifecycle are covered. Additionally, the chapter includes a section on research that spans the entire lifecycle of offshore engineering projects, highlighting BIM's comprehensive utility.

The findings from this literature review also directly inform the MCDA process. By providing a detailed understanding of BIM's capabilities and its applicability at different project stages, the chapter reinforces the ratings assigned to the various factors in the MCDA matrix. This ensures that the prioritization of factors is grounded in theoretical knowledge and practical evidence, contributing to a robust evaluation of BIM's potential in offshore wind projects.

The literature reviewed for this chapter was selected through a systematic search process, following the PRISMA 2020 framework to ensure transparency and reproducibility. A Scopus database search using the keywords ”BIM” AND ”offshore engineering” initially identified 53 studies. After removing one duplicate and excluding four non-English articles (Chinese), 48 records remained for title and abstract screening. At this stage, 21 studies were excluded because their title and abstracts indicated irrelevance to the research scope. Specifically, they did not focus on offshore engineering or address BIM meaningfully. This left 27 studies for full-text retrieval, but five could not be accessed. A full-text review of 22 studies was then conducted, leading to the exclusion of five additional studies. Of these, four were removed due to lack of relevance to BIM in offshore wind, as they focused either on general construction applications of BIM (e.g., buildings, bridges) or alternative digital tools unrelated to BIM. Additionally, one study was excluded due to severe methodological weaknesses, as it lacked a straightforward research approach, empirical validation, or structured argumentation, making its scientific contribution questionable. While several included studies had limited real-world application, they still provided theoretical insights or relevant discussions that contributed to the research framework. Ultimately, 17 studies were included in this review, forming the basis for assessing BIM's applicability across different offshore wind project lifecycle stages. The article selection process is visually summarized in Figure 2.2, ensuring clarity in the methodology.

This chapter provides a detailed overview of the current state of research and lays the groundwork for the practical application of BIM in offshore wind projects. By identifying key areas where BIM has been successfully implemented and highlighting the remaining challenges, this review will help shape the problem-identification and objective-setting phases of the DSRM process.

2.3.1 Design

Ma (2019) focuses on improving visual accuracy in the design of marine architectural structures through BIM. The study proposes a BIM-based framework for generating stereo parallax, which enhances 3D visualization in virtual scenes. This approach addresses the difficulties of designing unmarked offshore structures by automating stereo disparity generation, allowing designers to visualize and plan complex structures more accurately. However, the study is primarily theoretical and

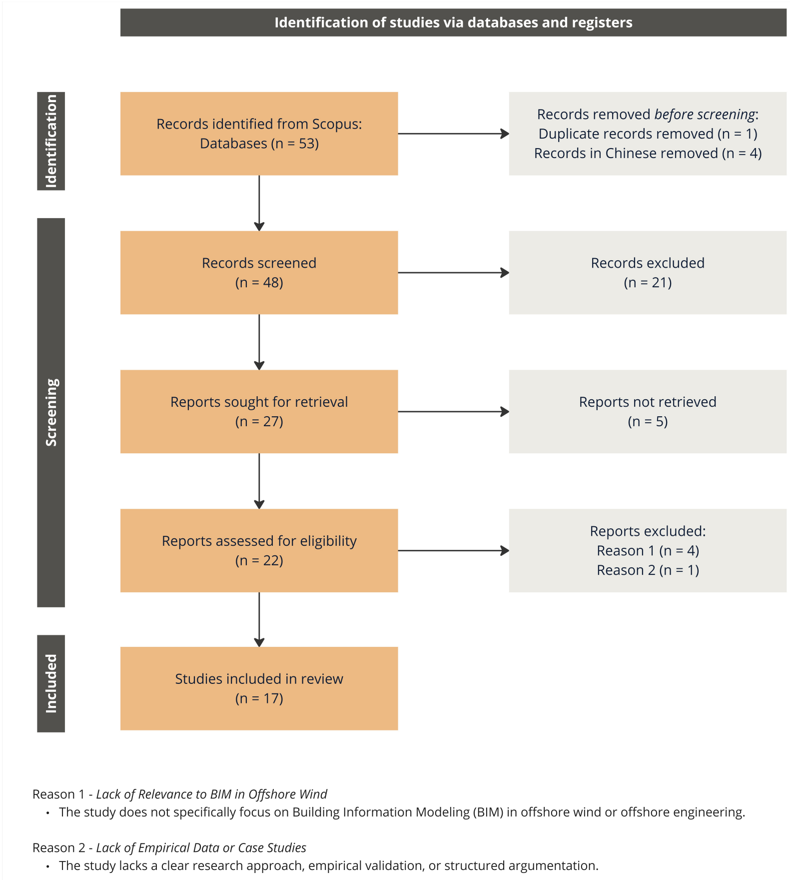


Figure 2.2: Systematic Literature Selection Process

lacks real-world validation, which limits its immediate applicability. Additionally, stereo parallax improves visual accuracy but requires significant computational resources, potentially impractical for larger, more complex projects without substantial investment in hardware and software infrastructure. Although the research is centred on marine architecture, its methods could benefit offshore wind projects, where detailed planning and visualization of large, complex structures are essential. Nevertheless, the scalability of this approach for wind farms remains uncertain, and further research is needed to confirm its effectiveness in larger applications.

Similarly, Wei et al. (2020) introduces a Digital Twin system for Front End Engineering Design (FEED) in offshore oil and gas field development, leveraging BIM and Case-Based Reasoning (CBR) to create digital models of subsea equipment. Reusing digital models from previous projects improves design efficiency and reduces the time required to develop new designs. However, this approach relies heavily on the quality of the existing case set. It may not be as effective for new or unique projects where past designs are not applicable. Additionally, the reliance on CBR introduces limitations when faced with highly innovative designs, as the system may struggle to accommodate elements not present in the existing dataset. While Digital Twins can accelerate the design process and allow less experienced users to contribute, the absence of real-world testing and reliance on historical data can hinder its adaptability in rapidly evolving fields like offshore engineering, where unique project requirements frequently arise.

2.3.2 Construction

Jie (2024) applies BIM with Radio Frequency Identification (RFID) technology to improve the precision of hoisting crane positioning in offshore construction. Integrating RFID data with BIM models reduces positioning errors to within 0.4 meters, significantly enhancing accuracy compared to traditional methods like laser ranging. While promising for crane operations, this method represents a small fraction of BIM's potential in offshore construction.

2.3.3 Operation and Maintenance

Two studies by Eichner et al. (2022) and Eichner et al. (2024) build upon one another, presenting a BIM-based framework for managing data related to inspections, structural health monitoring (SHM), and repairs in offshore wind farms. The 2022 study introduces a framework for consistently handling inspection and SHM data, enabling more accurate predictions of structural conditions and optimizing future maintenance activities. The 2024 study builds on this by incorporating a Reference Designation System (RDS-PP) to standardize data and streamline decision-making for maintenance strategies. While these frameworks show potential for improving the efficiency of offshore wind farm maintenance, their reliance on post-construction data collection limits the ability to integrate BIM fully from the early project phases, potentially missing opportunities for more proactive lifecycle management.

Similarly, O'Shea and Murphy (2020) and Ciuriuc et al. (2022) follow a comparable approach by integrating sensor data with BIM to enhance structural health monitoring. Both papers emphasize using sensor data to monitor environmental and structural conditions in real-time. However, Ciuriuc et al. (2022) takes a step further by proposing a framework for automated maintenance scheduling based on sensor data. In contrast, O'Shea and Murphy (2020) focuses more on visualizing the data for asset management in an offshore lighthouse. These approaches highlight the growing role of BIM in predictive maintenance. Still, they also expose a limitation: integrating such advanced systems into existing offshore structures requires significant sensor technology and digital infrastructure investment, which may not always be feasible for older installations.

2.3.4 Decommissioning

Decommissioning in offshore engineering involves disassembling and removing large, often aged structures such as oil platforms. BIM has been proposed as a tool that could optimize this process, and the research conducted by Yi Tan, Yongze Song, Xin Liu, Xiangyu Wang, and Jack C.P. Cheng between 2017 and 2018 provides theoretical evidence that BIM may offer benefits in this area.

Tan et al. (2017) developed a BIM-based framework to optimise the disassembly process of offshore oil and gas platforms, integrating BIM with advanced algorithms such as A* and genetic algorithms to generate efficient lift paths and module layouts. This system offers a more accurate and reliable method for disassembly, reducing reliance on manual, experience-driven practices. Building on this, Cheng et al. (2017) introduced a semi-automated 4D/5D BIM framework that models different decommissioning scenarios, incorporating time and cost analysis to expedite model creation and scenario evaluation.

In 2018, the same group further advanced their research by integrating BIM with Geographic Information Systems (GIS) to optimize vessel transport during the disassembly of multiple offshore platforms (Tan et al., 2018). Their framework uses heuristic algorithms to improve vessel deployment and resource sharing, which is especially useful in cluster projects. Although all three studies focus on offshore oil and gas platforms, the principles and methodologies proposed could be adapted to decommissioning other large-scale offshore structures, such as wind farms, where similar logistical challenges and resource management issues are present.

2.3.5 Entire Lifecycle

BIM's application throughout the entire lifecycle of offshore engineering projects has been the focus of several studies, addressing its potential benefits in cost management, construction optimization, and maintenance. L. Yang and Hu (2020) explore using BIM in life cycle cost management for marine engineering projects, focusing on reducing inefficiencies and improving cost control across all stages, from design to decommissioning. Their study highlights BIM's potential to streamline communication and data sharing among project stakeholders, leading to better decision-making. However, they also note that the effectiveness of BIM in reducing costs depends on early and comprehensive integration into the project lifecycle, a challenge for projects where BIM is introduced late in the process.

Similarly, Bezkorovayniy et al. (2018) examine the application of BIM in managing the design and construction phases of offshore oil and gas facilities. They propose using BIM to improve coordination between engineering processes, particularly for complex offshore platforms. While their approach promises better project management and communication, the study also points out challenges in fully implementing BIM due to data management issues and the complexity of offshore operations. The lack of effective project lifecycle management (PLM) integration is another limitation, as it reduces the overall efficiency of BIM's application in coordinating project elements across different stages.

Jia et al. (2019) extend the application of BIM to offshore wind farms, establishing an application framework that spans the entire project lifecycle, including design, construction, operation and maintenance (O&M), and decommissioning. This framework integrates BIM with Geographic Information Systems (GIS) and real-time data collection systems to optimize scheduling, cost management, and risk assessment. However, Jia et al. (2019) also recognize that while their framework shows promise, there is limited real-world validation of its effectiveness across all lifecycle stages.

In conclusion, while the studies by L. Yang and Hu (2020), Bezkorovayniy et al. (2018), and Jia et al. (2019) demonstrate the potential benefits of applying BIM across the lifecycle of offshore projects, they also highlight significant challenges. These include early BIM integration, effective data management, and real-world validation to ensure BIM delivers its full potential throughout a project's entire lifecycle.

2.3.6 Remaining Relevant Studies

El-Habashy et al. (2023) investigates the barriers preventing the adoption of 4D BIM in offshore construction projects. Using fuzzy structural equation modelling, the study identifies critical barriers such as the lack of awareness, uncertainties over return on investment (ROI), and a shortage of experienced users in the offshore construction sector. While the study is centred on the offshore oil and gas industry, its findings apply to offshore wind projects with similar adoption challenges. However, it is essential to note that specific challenges, such as risks associated with platform decommissioning, may not be directly transferable to the offshore wind context. The study offers valuable insights into overcoming these barriers, making it relevant for BIM integration in offshore wind construction (El-Habashy et al., 2023).

Cheng et al. (2018) presents a BIM-integrated agent-based evacuation evaluation model designed for improving evacuation planning and safety management on offshore oil and gas platforms. This model integrates dynamic escape path planning and real-time environment sensing to simulate evacuation scenarios. While the primary focus is on the oil and gas sector, the methodology can be adapted for offshore wind projects, particularly in planning evacuation routes and managing emergencies. However, specific oil and gas production hazards may not fully apply to the wind sector (Cheng et al., 2018).

Finally, Tan et al. (2019) introduces a 4D acoustic simulation approach, supported by BIM, to assess and mitigate the noise impact on offshore maintenance workers. The simulation predicts noise levels over time and optimizes maintenance schedules to minimize worker exposure to harmful noise. Though designed for offshore oil and gas platforms, this approach is highly adaptable to offshore wind projects, particularly for optimizing maintenance schedules during high-noise activities, such as turbine maintenance. This study highlights how BIM can improve occupational safety in offshore operations (Tan et al., 2019).

2.3.7 Conclusion and Summary

This chapter has reviewed the current literature on applying BIM in offshore engineering, focusing on the design, construction, operation and maintenance, and decommissioning phases. Despite extensive theoretical exploration of BIM's potential benefits, the application remains fragmented, with many studies investigating specific BIM capabilities in isolation, without fully integrating them into comprehensive frameworks for offshore wind projects. Key areas such as design accuracy, real-time data integration for structural health monitoring, and resource management during decommissioning have been addressed, but mainly within controlled or theoretical settings rather than real-world applications.

Moreover, much of the research focuses on the oil and gas sector, which, while relevant, does not fully address the unique challenges of offshore wind projects. The lack of empirical validation and comprehensive investigation into BIM's full potential in this sector leaves significant gaps in understanding how BIM can be holistically applied to improve project outcomes across the entire lifecycle of offshore wind projects.

This research, therefore, remains highly relevant, as it seeks to bridge these gaps by exploring BIM's applicability to offshore wind in a more integrated and validated manner. The key research gap lies in the absence of a comprehensive framework that evaluates BIM's role across the lifecycle of offshore wind projects—particularly in addressing unique logistical, environmental, and operational challenges specific to the sector. This thesis aims to provide a structured investigation into where and how BIM can be effectively utilized in offshore wind projects, building on the fragmented knowledge from previous studies and providing real-world insights to further the discourse.

3. Research Design

This chapter outlines the methodological approach taken to explore the challenges in offshore wind projects and evaluate the role of digital tools, particularly BIM, in addressing them. It provides a structured framework for developing the Strategic BIM Prioritization Framework for Offshore Wind Projects (SBPF-OW) and ensuring its alignment with theoretical insights and practical industry needs.

The chapter introduces the Design Science Research Methodology (DSRM), a structured process for creating and evaluating practical solutions. DSRM is the backbone of this research, guiding the development, demonstration, and refinement of the SBPF-OW framework. The methodology ensures the framework is systematically grounded in real-world challenges while maintaining academic rigour.

Next, the chapter details the qualitative methods employed, including semi-structured interviews and focus group discussions. These methods capture insights from offshore wind industry professionals, providing critical input for identifying challenges, prioritizing factors, and validating the framework. The interviews explore lifecycle challenges, coordination practices, and digital tool usage, while the focus groups refine the framework through stakeholder feedback.

Multi-criteria decision Analysis (MCDA) is also introduced as a key analytical tool. MCDA enables the systematic evaluation and prioritization of challenges based on feasibility, impact, cost-effectiveness, and plausibility criteria. This structured approach ensures that the framework delivers actionable and transparent insights into where BIM can most effectively be applied in offshore wind projects.

This chapter establishes a cohesive foundation for developing and validating the SBPF-OW framework by connecting the research questions to the methods and analytical tools. It bridges the theoretical exploration of BIM and offshore wind challenges with the practical application of the framework, aligning with the overall objectives of this thesis.

3.1 Design Science Research Methodology

3.1.1 Introduction

Design Science Research (DSR) effectively addresses practical problems by developing and testing artefacts. In contrast to descriptive research, which focuses on understanding ”what is,” DSR aims to create prescriptive knowledge about ”what can be” by designing solutions that benefit humans, whether through tangible or intangible artefacts Gregor and Zwikael (2024). This research paradigm emphasizes constructing and evaluating these artefacts, making it well-suited for areas like project management and offshore wind, where innovation and practical applications are crucial (Ahlemann et al., 2013).

3.1.2 Selection of Research Method

This thesis evaluates to what extent BIM can address the critical challenges offshore wind energy projects face. The chosen research methodology must balance academic rigour and practical applicability, providing actionable insights for theory and industry practice.

Several research methodologies were considered:

- **Qualitative/Quantitative Cost-Benefit Analysis**: This method allows for a detailed assessment of the costs and benefits of implementing a new solution. While quantitative analysis provides measurable, numerical data, qualitative insights can uncover less tangible benefits, such as improved collaboration. However, this approach may not fully capture offshore wind projects' complexities and evolving challenges.
- **Design Thinking**: Initially considered, design thinking fosters innovative, user-centred solutions through an iterative process of prototyping and testing. While it promotes creativity and stakeholder involvement, its focus on early-stage ideation can sometimes fall short in providing the rigorous evaluation required for complex technical environments like offshore wind.
- **Empirical Studies**: Empirical studies rely on controlled data collection through experiments or observations to test hypotheses. While this method provides statistically validated results, it is less suited to offshore wind projects' evolving and complex nature, which require flexible approaches to account for varied and interconnected challenges. Empirical studies typically isolate variables, which limits their ability to capture the broader, dynamic context that offshore wind projects operate within, such as rapidly changing project conditions and multifaceted technical requirements.

Ultimately, **Design Science Research (DSR)** was selected as the most appropriate approach for this thesis. DSR is focused on creating and evaluating artefacts—such as methods, frameworks, or systems—that directly address real-world challenges (Gregor & Zwikael, 2024). This method aligns with the thesis's objectives, which seek to explore BIM's potential in addressing offshore wind project challenges and develop a foundational framework to guide its application. DSR also encourages academic rigour and relevance, making it an ideal fit for the dual needs of theory and practice (Ahlemann et al., 2013).

3.1.3 Introduction to DSR

DSR aims to develop artefacts that solve practical problems while advancing scientific knowledge Peffers et al. (2007). The artefacts created can be tangible, such as buildings or machines, or intangible, such as frameworks and methods. In project management, artefacts often take the form of prescriptive methodologies that assist managers in solving issues like resource allocation, scheduling, or stakeholder engagement (Gregor & Zwikael, 2024). This aligns with the scope of BIM research, which seeks to apply design principles from the AECOO industry to the offshore wind sector.

3.1.4 General Application of DSR

Peffers et al. (2007) developed a widely accepted framework for Design Science Research consisting of six key steps. They applied and evaluated the methodology in their publication across four case studies, all showing positive results. Additionally, Gregor and Zwikael (2024) provided further validation by identifying DSRM, as outlined by Peffers et al. (2007), as the most commonly applied method within the cases they evaluated in their study of design science research applications. The methodology follows six steps:

1. **Problem Identification and Motivation**: The first step is to define a relevant, real-world problem that warrants investigation. The issue must be significant and justify the need for a solution. Researchers should explain the problem's scope, its implications for industry and academia, and why solving it is essential. This phase often includes a review of the current state of knowledge and practice, highlighting any gaps or inefficiencies the research aims to address. To create a solution that fully addresses a complex problem, it's helpful to deconstruct the problem into more minor elements so that the solution can consider all aspects.

2. **Define Objectives for a Solution**: Once the problem has been identified, the next step is establishing clear objectives for the proposed solution. These objectives should outline what the solution is expected to achieve. This could involve both qualitative goals and quantitative targets. It is essential to align these objectives with the broader goals of the industry and ensure they address the complexities of the problem.

3. **Design and Development**: In this phase, the artefact, a framework, model, or method, is designed and developed. The design process should be grounded in relevant theoretical foundations and guided by the objectives defined in the previous step. The artefact should be a novel or an improved solution tailored to address the identified problem effectively. Researchers should document the design process in detail, explaining the rationale behind the chosen design decisions, the theoretical underpinning, and the potential challenges in implementation.

4. **Demonstration**: The next step is demonstrating the artefact's practical application. This could involve case studies, simulations, or real-world implementation in a controlled setting. The demonstration phase is crucial in showing how the artefact operates in practice and how it solves the defined problem. The demonstration helps identify any preliminary issues and improvements before full-scale evaluation.

5. **Evaluation**: During the evaluation phase, the performance of the artefact is tested against the predefined objectives. This step assesses whether the artefact effectively solves the problem and how it can be refined for further optimization. Any expected and actual outcome discrepancies should be documented for future iterations.

6. **Communication**: Finally, the research results and the artefact must be communicated to academic and industry audiences. This includes sharing the design process, the evaluation outcomes, and the findings' implications. The communication phase is crucial for ensuring the

wider adoption and use of the artefact. This involves publishing findings in peer-reviewed journals for academic audiences, while industry practitioners may require presentations, reports, or workshops to introduce the new solution Peffers et al. (2007).

3.1.5 Application of Design Science Research Methodology (DSRM) in the Context of This Thesis

In this thesis, the Design Science Research Methodology (DSRM), as outlined by Peffers et al. (2007), will be applied to systematically develop, demonstrate, and evaluate the Strategic BIM Prioritization Framework for Offshore Wind Projects (SBPF-OW). This artefact is designed to determine where BIM can be most effectively applied within offshore wind projects by identifying, ranking, and prioritizing key challenges. The methodology provides a structured approach to align BIM's potential with the unique challenges of the offshore wind industry, ensuring that the research is both theoretically grounded and practically relevant. Peffers et al. (2007) acknowledge that research does not necessarily need to follow the steps outlined by them and that researchers might begin the process at any of the steps. The choice for this thesis fell on starting from step 1, representing a problem-centred approach triggered by an observed problem. This observed problem emerged from EnBW's uncertainty about BIM's applicability to their offshore wind projects, highlighting the practice-driven origin of this research. Figure 3.1 summarizes the steps and required input.

1. **Problem Identification and Motivation**: Offshore wind energy is essential for achieving global energy transition targets, yet inefficiencies in various areas hinder its growth. BIM has addressed similar challenges in the Architecture, Engineering, and Construction (AEC) industry, but its application in offshore wind remains fragmented and limited.

   This research was initiated in response to a practical need identified by EnBW. The company recognised its potential by engaging with BIM through various industry channels. Still, it lacked the internal knowledge to assess whether and where BIM could be effectively applied within their offshore wind projects. This uncertainty served as the primary impetus for this research, exemplifying a problem-centred, practice-driven starting point.

   A literature review in *Chapter 2.3 (Literature Review on BIM and Offshore Engineering), p. 31* examines existing research on BIM in offshore wind, emphasising the lack of holistic approaches and structured frameworks for its application. Furthermore, *Chapter 2.1 (Offshore Wind Projects), p. 12* explores the perspectives of offshore wind stakeholders, noting that each presents unique challenges and definitions of project success. A key issue is the lack of a structured method for these stakeholders to evaluate where and to what extent BIM can benefit their specific needs.

   Industry perspectives are incorporated through semi-structured interviews with offshore wind professionals to bridge this gap, summarized in *Chapter 4 (Interview Analysis), p. 55.* These interviews provide practical insights into real-world challenges, processes, and the extent to which BIM-related tools and methodologies are currently applied. The combination of literature review and empirical data ensures that the problem is well-defined and contextualized within both theoretical and industry perspectives.

   The background, research motivation, and overarching problem statement are introduced in *Chapter 1 (Introduction), p. 1*, laying the foundation for this research and establishing the necessity of developing a structured BIM prioritization framework for offshore wind projects.

2. **Define Objectives for a Solution**: The artefact is considered successful if it provides a structured approach for assessing the feasibility of BIM for different offshore wind stakeholders. It should help determine how much BIM can benefit specific industry actors based on their unique challenges and needs.

   Further refinement will be required if the framework fails to offer clear and actionable insights or does not adequately reflect stakeholder priorities. The evaluation will be based on whether the framework allows for a systematic assessment and supports informed decision-making regarding BIM implementation in offshore wind projects.

3. **Design and Development**: The development of the artefact will focus on establishing a structured framework that enables offshore wind stakeholders to assess the applicability of BIM in addressing industry challenges. The framework will define a method for identifying key challenges in offshore wind projects, mapping BIM capabilities to these challenges, and evaluating the relevance and benefits of BIM applications.

   A key part of this process will be determining an approach to define and categorize challenges within offshore wind projects. This requires identifying industry needs and understanding where improvements can be made. Additionally, the framework will establish a way to align BIM functionalities with these challenges, ensuring that potential applications are systematically explored.

   The framework will also include a method for evaluating whether BIM applications provide tangible benefits. The approach for this assessment will be developed based on the research findings (Refer to *Chapter 5.2 (Iterative Development, Demonstration and Evaluation), p. 76* for application).

4. **Application**: The developed framework will be applied to the case of EnBW's offshore wind business to assess its practical relevance. This application will explore how the framework functions in a real-world industry setting and whether it provides meaningful insights into the use of BIM for offshore wind projects.

   The application will examine industry-specific challenges and evaluate potential BIM applications within the structure defined by the framework. The process will help determine whether the framework effectively supports decision-making and whether adjustments are necessary to improve its applicability (Refer to *Chapter 5.2 (Iterative Development, Demonstration and Evaluation), p. 76* for application).

5. **Evaluation**: The evaluation will assess whether the developed framework effectively supports the identification of offshore wind challenges, mapping BIM applications, and evaluating their benefits. It will also determine whether the framework provides structured and actionable insights for industry stakeholders.

   The evaluation will also consider whether the framework needs refinement to improve its applicability and accuracy. If limitations are identified, adjustments will be made to enhance its ability to guide decision-making in offshore wind projects. The evaluation results will inform the final version of the framework and its potential for broader application (Refer to *Chapter 5.2 (Iterative Development, Demonstration and Evaluation), p. 76* for application).

6. **Communication**: In this step, the research findings will be communicated primarily through the thesis, which will be presented to EnBW and published in the TU Delft Repository.

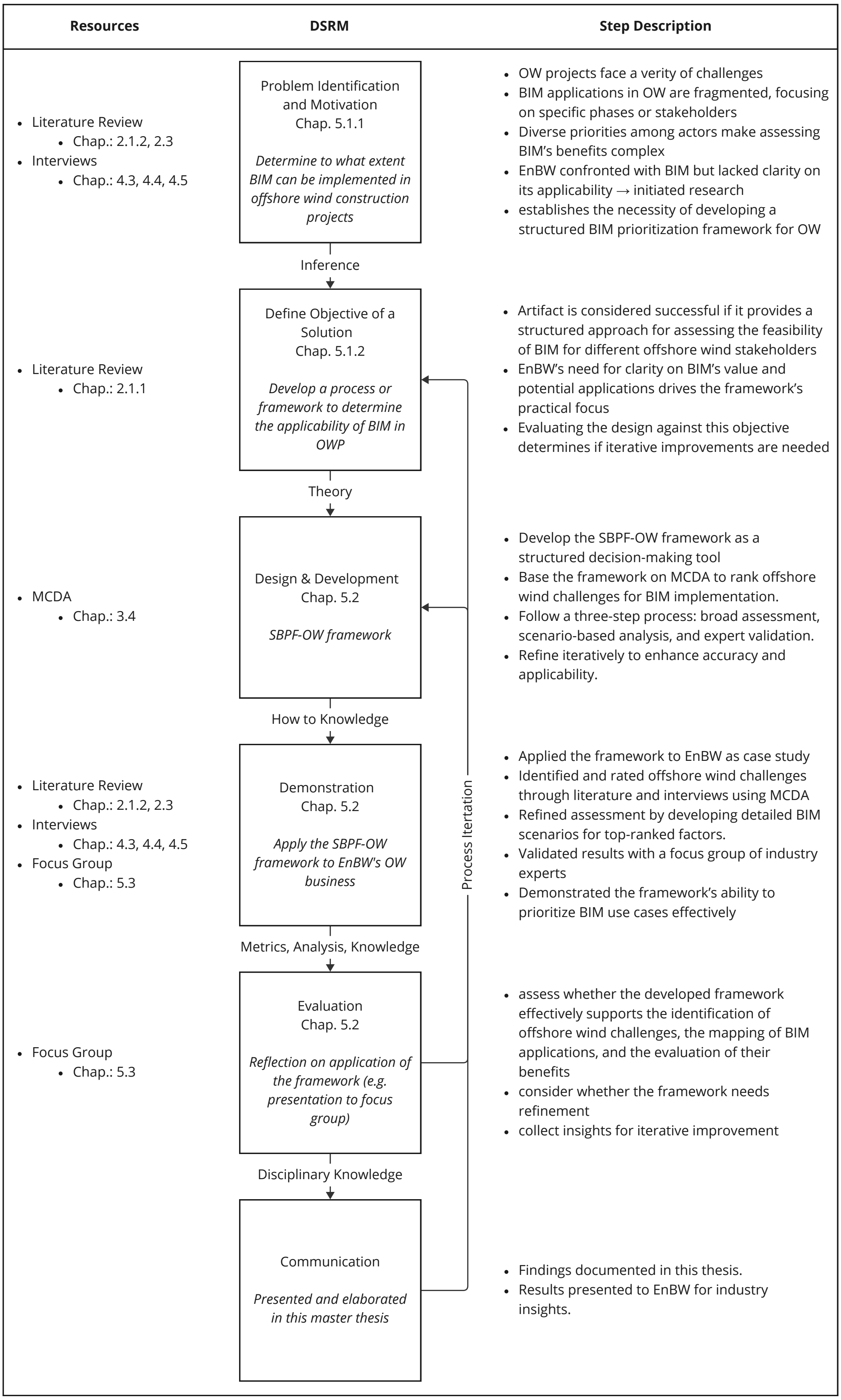


Figure 3.1: DSRM Application

3.1.6 Expected Outcome of the Thesis: Strategic BIM Prioritization Framework for Offshore Wind Projects (SBPF-OW)

The **Strategic BIM Prioritization Framework for Offshore Wind Projects (SBPF-OW)** is a decision-making tool developed to evaluate and prioritize where BIM can be most effectively applied to address challenges in offshore wind projects. Beyond providing strategic guidance for resource allocation, the framework is central to answering the research question.

The SBPF-OW framework consists of:

- A **Static Framework**, represented by an MCDA matrix that incorporates:
  - Key challenges (factors) relevant to offshore wind project success.
  - Evaluation criteria, including technical feasibility, impact, cost-effectiveness, and plausibility.
- A **Dynamic Application Process**, which iteratively:
  - Assigns weights to criteria and scores factors using literature, interviews, and focus group feedback.
  - Produces ranked lists of factors to highlight where BIM's potential is strongest.
  - Develops high-level scenarios for applying BIM to top-ranked factors.
  - Refines the framework and its outputs based on stakeholder insights and evaluations.

The framework prioritizes challenges and generates insights into BIM's applicability. It provides a structured approach to determining where BIM can be most beneficial across the lifecycle of offshore wind projects. Through iterative refinement, the SBPF-OW framework ensures its outputs are grounded in practical insights and academic rigour. This enables strategic decision-making and addresses the central research question regarding BIM's value for offshore wind projects. The actual framework resulting from the DSRC is outlined in *Chapter 5.4 (Final Artefact: Strategic BIM Prioritization Framework for Offshore Wind Projects (SBPF-OW)), p. 91.*

3.1.7 Advantages and Drawbacks of DSRM

One of the strengths of DSRM is its focus on developing practical solutions that can be directly applied to real-world problems, making it relevant to academics and industry practitioners. The methodology provides a straightforward, structured approach, guiding researchers from problem identification to solution evaluation (Peffers et al., 2007). However, DSRM can be resource- and time-intensive, particularly during the iterative cycles of design and evaluation. Additionally, evaluating artefacts in large-scale, complex environments like offshore wind projects may introduce challenges due to the numerous variables involved (Ahlemann et al., 2013).

3.2 Literature Review

3.2.1 Introduction

The literature review is critical to this research, serving as the foundation for applying DSRM. A systematic review of the existing literature will ensure that this research builds upon current knowledge and identifies gaps the thesis aims to fill. According to Chigbu et al. (2023), a well-conducted literature review synthesizes existing research, informs the research design, and provides context for the study.

3.2.2 Purpose of the Literature Review

The primary purpose of this thesis's literature review is threefold. First, it establishes the state of knowledge in BIM and its core capabilities. Second, it explores the specific challenges offshore wind projects face. Finally, it provides insights from BIM applications in offshore engineering, particularly oil and gas, drawing parallels that can inform the offshore wind sector. This structured approach will shape the DSRM process, guiding the development and evaluation phases of the research.

3.2.3 Use of the Literature Review in This Thesis

As mentioned in the previous paragraph, the literature review is threefold, and all three parts serve different goals and build on different bodies of previous research and literature. This paragraph describes the differing approaches to the literature review applied to all three parts; it roughly follows the methodology outlined by Snyder (2019):

- ***Chapter 2.1 (Offshore Wind Projects), p. 12***: The integrative review approach was chosen to identify and categorize challenges in offshore wind, providing a comprehensive understanding of the hurdles that BIM might address. Unlike a descriptive review, the integrative review synthesizes the existing literature to create a fresh perspective on current issues, making it ideal for an emerging field like offshore wind. Given the sector's rapid evolution, recent literature is essential for capturing contemporary challenges such as supply chain issues, regulatory changes, and environmental concerns. This approach allows the review to focus on selecting recent, relevant sources to ensure that the identified challenges reflect the most up-to-date industry realities. Instead of creating a new framework, this review categorizes these challenges to serve as the foundation for subsequent stages in the DSRM process. By analyzing these challenges, the integrative review ensures that the research is grounded in the latest developments, making it more relevant and applicable to offshore wind project management.
- ***Chapter 2.2 (BIM), p. 22***: This subchapter employs a semi-systematic review methodology suitable for topics studied across different disciplines or where diverse methods have been applied. Since BIM literature spans various industries and has only recently begun to address offshore wind projects, a semi-systematic approach was the most effective for synthesizing knowledge from these areas. The semi-systematic review facilitated the collection of perspectives from diverse sources and allowed for a thorough assessment of BIM's capabilities, limitations, and relevance. This methodology provided flexibility in drawing from multiple fields and sources, ensuring the review covered all relevant BIM functionalities, from 3D modelling and visualization to sustainability assessments and lifecycle management. By structuring the review along the lifecycle of offshore projects—design, construction, operation, and decommissioning—the semi-systematic approach ensured comprehensive coverage of BIM's role in

addressing challenges at each project stage, forming the foundation for later chapters that apply BIM to offshore wind project development.

- ***Chapter 2.3 (Literature Review on BIM and Offshore Engineering), p. 31***: This subchapter applies a systematic literature review (SLR) methodology, adhering to a structured and reproducible process for synthesizing research findings. The PRISMA 2000 framework guided the review process, ensuring transparency, rigor, and replicability in identifying, screening, and including relevant studies. A systematic search was conducted using predefined inclusion criteria, explicitly targeting BIM applications in offshore engineering to minimize bias and ensure a comprehensive overview of the field. The literature search was performed using Scopus, applying the keywords "BIM" and "offshore engineering," which initially yielded 52 papers. After removing duplicates and applying relevance-based filtering, the selection was refined to 17 studies that met the eligibility criteria. This structured approach ensured that only the most relevant and high-quality studies were included, capturing a comprehensive cross-section of research across different project lifecycle phases—including design, construction, operation, and decommissioning. Employing PRISMA 2000 in this review process reinforced the study's methodological transparency and reproducibility, allowing for an unbiased synthesis of existing research and providing a solid foundation for assessing BIM's role in offshore engineering.

3.3 Semi-Structured Interviews

This thesis will use semi-structured interviews to gather qualitative insights from EnBW employees involved in offshore wind projects. These interviews serve two purposes: first, to gain practical insights into offshore wind projects by understanding industry processes and lifecycle challenges, and second, to support the testing of the framework by deriving a list of relevant challenges from the interview data. This chapter explains the rationale for using semi-structured interviews, the participant selection process, the design of interview questions, and how the collected data will be analyzed within the Design Science Research Methodology (DSRM) framework. The outcome of the interviews can be found in *Chapter 4 (Interview Analysis), p. 55.*

3.3.1 The Need and Usefulness of Semi-Structured Interviews

Semi-structured interviews are valuable in qualitative research because they allow flexibility in exploring topics while ensuring that discussions remain focused on critical themes (Adeoye-Olatunde & Olenik, 2021). This method is beneficial for understanding participants' experiences and perspectives, making it relevant to the context of this thesis.

Semi-structured interviews offer several advantages:

- **Exploratory Depth**: By allowing open-ended questions, interviews can uncover new issues or opportunities that may not be evident in structured surveys (Adams, 2015).
- **Flexibility**: Interviews allow adjusting follow-up questions based on responses, ensuring a deeper understanding of complex topics, such as project coordination and lifecycle management in offshore wind (Adeoye-Olatunde & Olenik, 2021).
- **Rich Data**: Interviews can yield rich, detailed qualitative data essential for the iterative design and development of solutions within the DSRM framework (Adeoye-Olatunde & Olenik, 2021).

3.3.2 Participant Selection

Participants will be selected using purposeful sampling, a strategy aimed at identifying and selecting knowledgeable and experienced individuals (Palinkas et al., 2015). The primary criteria for selection include:

- Employees involved in various offshore wind project lifecycle phases, including planning, design, construction, operation, and maintenance.
- Individuals with a minimum of two years of experience in offshore wind projects to ensure in-depth and relevant insights.
- A range of roles, including project managers, engineers, data analysts, and sustainability experts, to capture a comprehensive view of the challenges faced across the lifecycle (Adams, 2015).

This approach ensures that the selected participants provide diverse perspectives while offering detailed knowledge about the sector's challenges.

3.3.3 Design of Interview Questions

The interview guide will be developed based on established guidelines for conducting semi-structured interviews in qualitative research, ensuring that the questions are aligned with the objectives of this thesis and rooted in scientific methodology Kallio et al. (2016). The primary goal of the interviews is to explore the practical challenges faced by participants during different phases of offshore wind projects and how they use digital tools in their workflows.

Theoretical Basis for Question Design

The development of the interview questions will follow the five-phase model proposed by Kallio et al. (2016), which ensures a rigorous and structured approach to formulating semi-structured interview guides. These phases include:

1. **Identifying the prerequisites for using semi-structured interviews**: This confirms that the research topic—challenges in offshore wind projects and digital tools—requires an in-depth, qualitative understanding of participant experiences.

2. **Retrieving and using previous knowledge**: A comprehensive literature review on the challenges in offshore wind projects and digital tool usage will inform the question design. This ensures that the questions are grounded in both theoretical understanding and practical needs.

3. **Formulating the preliminary interview guide**: Based on the thesis objectives, the guide will be structured around key themes such as general challenges, data management, stakeholder communication, and the role of digital tools in project workflows.

4. **Pilot testing the interview guide**: A pilot test of the interview questions will be conducted with a small sample to ensure clarity and relevance. Feedback from the pilot will be used to refine the questions.

5. **Presenting the complete interview guide**: The final version of the guide will be prepared, ensuring that it facilitates open discussion while remaining focused on the research objectives.

Categories of Questions

The interview guide includes open-ended questions designed to elicit detailed responses, providing the flexibility to explore specific challenges, coordination practices, and tool usage in depth Adams (2015). The questions are tailored to encourage participants to reflect on their workflows, challenges, and areas for improvement. The key categories of questions are as follows:

- **Background Information**: These questions aim to understand the participant's role in offshore wind projects, focusing on their experience, specific responsibilities, and the phases or aspects of projects they are involved in. This provides context for analyzing their insights.

- **Challenges in Offshore Wind Projects**: These questions target the specific challenges participants face, such as operational, logistical, or resource issues. Participants are encouraged to provide examples of how these challenges have affected projects, offering insight into critical problem areas.

- **Coordination and Complexity Management**: This category focuses on how participants manage collaboration across teams and ensure the reliable sharing of information. The questions also explore the potential for information loss or miscommunication across project phases.

- **Digital Tools and Processes**: Participants are asked about the digital tools or systems they use to organize their tasks and manage collaboration. The questions aim to identify the effectiveness of current tools and highlight areas where improvements or new solutions could be beneficial.

- **Recommendations for Improvement**: These questions invite participants to suggest improvements in communication, tools, or processes that could enhance the efficiency and organization of offshore wind projects. Specific suggestions are encouraged to address both team-level and project-wide challenges.

- **Additional Insights**: To conclude, participants are asked if there is anything else they consider important for improving offshore wind project management, along with suggestions for other colleagues who could provide relevant insights.

Rationale for Question Design

As recommended for qualitative research, the open-ended questions allow participants to elaborate on their experiences Bryman (2016). This approach ensures the capture of rich, nuanced data highlighting common and unique challenges across different project phases. By focusing on participants' experiences with digital tools and workflow challenges, the interviews will generate data that directly informs the problem identification and development phases of the DSRM process.

3.3.4 Data Collection, Processing, and Analysis

Data Collection

Interviews will be conducted in person or via video call depending on participant availability. Each interview will last 45 to 60 minutes and be audio recorded (with participant consent) to ensure accurate data capture. Transcription will follow, and notes will be taken during each interview for immediate reflection on key insights as suggested by Adams (2015).

Data Processing

The recorded interviews will be transcribed directly, and the transcripts will be reviewed for accuracy and translated from german to english. A coding framework will then be developed to categorize and analyze the data. This framework will use inductive and deductive coding to identify recurring themes related to project challenges and BIM's potential applications Adeoye-Olatunde and Olenik (2021).

Development of the Codebook

A codebook was developed as a foundational framework to analyze the interview data systematically. The codebook categorizes the lifecycle challenges of offshore wind projects, facilitating the identification of recurring themes and patterns. The development process involved combining inductive and deductive approaches:

- **Inductive Coding:** Emerging themes were identified directly from the interview data, capturing participant-specific insights.

- **Deductive Coding:** Predefined categories, based on literature and the research focus, were used to ensure alignment with the thesis objectives.

The final codebook includes categories such as logistical challenges, data management issues, coordination challenges, lifecycle-specific obstacles, and the complexity of interdependencies. Each category is further subdivided into specific codes (e.g., planning delays, data silos, stakeholder misalignment) with definitions and example quotes to ensure consistency in analysis. This structured framework ensures comprehensive coverage of the challenges and establishes the basis for deriving actionable objectives in subsequent steps. The complete codebook is included in *Appendix B (Codebook for Problem Identification and Motivation), p. 118.*

Data Analysis

The data will be analyzed using thematic analysis, a method that allows for the systematic identification of patterns across the interview data Nowell et al. (2017). This approach is ideal for semi-structured interviews because it enables the researcher to interpret data through multiple layers of meaning, facilitating a deeper understanding of the challenges in offshore wind projects and the role BIM might play in addressing them.

3.4 Multi-Criteria Decision Analysis (MCDA)

3.4.1 Introduction to MCDA

Multi-Criteria Decision Analysis (MCDA) is a structured approach for evaluating and prioritizing alternatives in decision-making when multiple, often conflicting, criteria are involved. It provides a systematic framework for breaking down complex problems into manageable components, assigning relative importance to criteria, and deriving a transparent and justifiable ranking of alternatives. As noted by Keeney and Raiffa (1993), MCDA's foundations lie in addressing decision-making under uncertainty and balancing trade-offs across objectives. It has since been advanced to accommodate various applications, including sustainability assessments and resource planning (Greco et al., 2016).

The strength of MCDA lies in its flexibility and adaptability. Allowing decision-makers to evaluate options based on their specific objectives and constraints ensures that decisions are tailored to the unique context of the problem. MCDA methods often rely on scoring, weighting, and ranking, enabling a balanced evaluation of competing factors while accommodating subjective judgment and preferences (Belton & Stewart, 2002). This makes it particularly suitable for complex, resource-intensive sectors like offshore wind energy, where multiple stakeholders and lifecycle challenges must be considered.

This thesis uses MCDA to prioritize challenges in offshore wind projects systematically. It provides a clear basis for evaluating where BIM can deliver the most value. The thesis's structured nature ensures transparency, rigour, and a focus on actionable outcomes.

3.4.2 How MCDA Can Be Conducted

Multi-Criteria Decision Analysis (MCDA) encompasses a range of methodologies for evaluating alternatives against multiple criteria. Various approaches exist, each tailored to different decision-making contexts. This section provides an overview of key MCDA methodologies as outlined in the literature (Cinelli et al., 2014):

- **Utility-Based Methods**: Techniques such as Multi-Attribute Utility Theory (MAUT) aggregate scores across criteria using utility functions. These methods are robust but require detailed quantitative data and assume compensatory trade-offs.

- **Outranking Methods**: Approaches like PROMETHEE and ELECTRE rely on pairwise comparisons of alternatives. They handle qualitative and quantitative data effectively but may suffer from rank-reversal issues.

- **Analytical Hierarchy Process (AHP)**: A widely used method that establishes criteria weights and scores alternatives through pairwise comparisons. However, AHP can be cognitively demanding and requires consistent judgments.

- **Dominance-Based Rough Set Approach (DRSA)**: This method excels in classification tasks without requiring explicit weights or thresholds, making it intuitive but less suited for ranking.

- **Simplified Scoring Approaches**: These translate qualitative assessments into numerical scores for aggregation and ranking. This approach is commonly used in policy appraisals due to its accessibility and practical application (Government, 2009; Treasury, 2020).

3.4.3 Methodology Used in This Thesis

This thesis employs a scoring-based Multi-Criteria Decision Analysis (MCDA) approach that integrates qualitative insights with structured numerical evaluation. This hybrid approach draws from established MCDA methodologies, including the PAPRIKA method for pairwise ranking (Hansen & Ombler, 2009), the Evidential Reasoning (ER) approach for handling uncertainty (J. B. Yang & Xu, 2002), and the DEX model for qualitative multi-attribute decision-making (Bohanec et al., 2013). Combining expert insights with structured scoring and weighting allows for systematically evaluating challenges in offshore wind projects, where qualitative and quantitative data are relevant but often incomplete or inconsistent.

The justification for selecting this approach is based on its flexibility, transparency, and practical relevance for complex decision-making contexts. The structured nature of the scoring and ranking process ensures that results are transparent and traceable, aligning with decision-making guidelines established by the UK Government's Green Book (Treasury, 2020). Furthermore, expert input allows for informed judgments even without complete quantitative data. This section outlines the methodology, including developing criteria, scoring scales, weighting, and the aggregation and ranking process.

Step 1: Define Criteria and Alternatives

The criteria for evaluating BIM application challenges in offshore wind projects were identified through a comprehensive review of literature and insights from expert interviews. The requirements reflect technical, economic, and operational factors relevant to offshore wind project development and operation. The identification process ensured that the selected criteria were comprehensive, mutually exclusive, and collectively exhaustive (Belton & Stewart, 2002).

Step 2: Develop Scoring Scale and Weighting Framework

A structured scoring scale was developed to translate qualitative assessments into numerical values. Similar to the approach used in PAPRIKA (Hansen & Ombler, 2009), a 5-point scale was adopted, where 1 represents the least favourable outcome, and 5 represents the most favourable outcome. This scale allows for the consistent evaluation of each criterion while preserving the qualitative input from expert judgment.

To establish the relative importance of each criterion, weights were assigned based on insights gained from earlier interviews and the researcher's professional judgment. While the interviews were not explicitly designed for the MCDA process, the qualitative insights provided valuable context for evaluating the significance of different criteria. The resulting weights were normalized to ensure consistency and balance in the evaluation process.

Step 3: Aggregate and Rank Alternatives

The scores assigned to each criterion were aggregated using a weighted sum model, consistent with simplified MCDA methodologies (Greco et al., 2016). The aggregated scores represent the overall performance of each alternative to the defined criteria. The calculation process follows the general form:

$$S_i = \sum_{j=1}^{n} w_j x_{ij}$$

where S_i is the aggregated score for alternative i, w_j is the weight of criterion j, and x_{ij} is the score assigned to alternative i under criterion j.

The alternatives were ranked based on their aggregated scores, generating a prioritized list of challenges where BIM implementation is expected to have the most significant impact. Adjustments were made where expert feedback suggested stronger or weaker relative importance among specific factors, reflecting a structured approach to balancing trade-offs in multi-criteria evaluation.

Step 4: Expert Validation and Refinement

To improve the reliability of the results, a focus group was conducted with industry experts to validate the scoring and weighting decisions. The experts reviewed the preliminary rankings and provided feedback on their consistency and relevance. This step ensured that the final rankings reflected both the structured evaluation process and the practical experience of stakeholders.

The validation process followed an iterative structure:

1. Experts reviewed the initial rankings and scores.
2. Adjustments were made where inconsistencies or gaps were identified.
3. The final rankings were refined through consensus-based feedback.

This validation step aligns with best practices for qualitative decision analysis, where expert feedback is used to refine and improve decision models (Belton & Stewart, 2002).

Rationale for Method Selection

The scoring-based MCDA method selected for this thesis reflects a balanced trade-off between simplicity, robustness, and adaptability. Similar approaches have been successfully applied in complex decision-making contexts, including healthcare (Hansen & Ombler, 2009), environmental planning (Leopold et al., 1971), and strategic business management (Greco et al., 2016). Integrating qualitative expert feedback with structured quantitative evaluation ensures that the analysis remains grounded in theoretical rigour and practical relevance.

3.4.4 Limitations of MCDA and Mitigation Strategies

While Multi-Criteria Decision Analysis (MCDA) is a powerful tool for addressing complex decision-making challenges, it has limitations. This section discusses the main flaws of MCDA, their relevance to this thesis, and the mitigation strategies implemented to address these challenges.

Subjectivity in Scoring and Weighting

Subjectivity in scoring and weighting is a widely acknowledged limitation of MCDA, as it often relies on individual judgment to assign scores and determine the relative importance of criteria. This reliance introduces the potential for bias and inconsistency, particularly when different stakeholders have varying perspectives. Guidance from the UK Government's Green Book highlights that the absence of clear documentation and stakeholder engagement can exacerbate these challenges, leading to decisions that reflect individual preferences rather than a balanced consensus (Government, 2009; Treasury, 2020).

Similar issues arise in this thesis when qualitative insights from interviews are translated into numerical scores and weights for criteria. To address this, the research employs strategies to mitigate subjectivity. Focus groups validate scoring and weighting decisions, incorporating diverse perspectives to minimize bias. Justifications for scores and weights are thoroughly documented, with ties to evidence from interviews and literature. Additionally, iterative feedback cycles are incorporated to refine results and ensure greater reliability and transparency.

Oversimplification of Complex Problems

MCDA simplifies multi-dimensional challenges into numerical values, which, while beneficial for ranking and prioritization, can obscure critical nuances and interdependencies among factors. This limitation is acknowledged in the literature, where it is noted that reducing complex problems to a single-dimensional scoring system may mask necessary trade-offs and relationships between variables (Cinelli et al., 2014; Treasury, 2020).

In the context of this thesis, the translation of offshore wind challenges into numerical rankings may fail to adequately capture interdependencies, such as the interplay between data management, cost efficiency, and regulatory compliance. To address this, numerical results are complemented with qualitative narratives and scenarios that provide context and depth to the rankings. Additionally, iterative reflection is employed to identify and account for overlooked nuances, while the development of BIM application scenarios for high-priority factors ensures that the analysis yields actionable insights.

Dependence on Assumptions and Data Quality

MCDA is highly sensitive to the quality of input data and the assumptions underlying the analysis. Errors in data collection or flawed assumptions can lead to unreliable results, undermining the decision-making process. The UK Government's Green Book highlights that the reliability of MCDA is directly tied to the quality and completeness of data inputs, with uncertainties in assumptions posing risks to the validity of outcomes (Treasury, 2020). Similarly, Cinelli et al. (2014) emphasize that the outcomes of MCDA depend heavily on the accuracy and relevance of information available during the analysis. This thesis relies on qualitative data from interviews and literature, which inherently come with limitations such as incomplete data or subjective interpretations. Data inputs are validated by cross-referencing multiple sources, including peer-reviewed literature, industry reports, and stakeholder feedback to mitigate these challenges. Assumptions are regularly revisited and documented to align with the latest insights. Additionally, sensitivity analyses are conducted to evaluate the impact of varying inputs and assumptions, enhancing the results' robustness. These strategies aim to address the inherent sensitivity of MCDA to data quality and assumptions, improving the reliability and applicability of the findings in this thesis.

Conclusion: By acknowledging and addressing these limitations, this thesis ensures that the MCDA framework remains robust and credible. Mitigation strategies such as expert validation, iterative refinement, and qualitative contextualization enhance the analysis's reliability, aligning with established practices in decision analysis. The execution of the rating and its outcomes are described in detail and specifically for use in the thesis in *Chapter 5.2.1 (Demonstration), p. 77.*

3.5 Focus Group Methodology

3.5.1 Introduction to Focus Groups

Focus groups are a qualitative research method widely used to gather in-depth participant insights on specific topics or issues. According to Morgan (1996), focus groups involve guided discussions among a small group of individuals, facilitated by a moderator, to explore their perceptions, opinions, and experiences in a structured setting. This method is particularly valuable for uncovering nuanced viewpoints, generating ideas, and validating concepts through group interaction.

One of the primary strengths of focus groups lies in their ability to provide rich qualitative data by leveraging group dynamics. Participants can build on each other's contributions, fostering a deeper exploration of the topic (Morgan, 1996). Furthermore, focus groups allow researchers to observe non-verbal cues and group interactions, offering additional insight not typically accessible in individual interviews (Krueger & Casey, 2015). They are commonly employed in applied research to refine tools, processes, or frameworks and identify barriers and opportunities in specific contexts.

3.5.2 Application in This Research

This study will employ focus groups as a critical component of the Evaluation step in the DSRM to refine and validate the Strategic BIM Prioritization Framework for Offshore Wind Projects (SBPF-OW). The primary purpose of these focus groups is to gather expert feedback on the framework's design, the selection and weighting of criteria, and the prioritization of factors derived from previous steps, including interviews and literature.

The focus group sessions will involve EnBW stakeholders with expertise in digitization, operations and maintenance (O&M), project management, and construction. Given their practical experience in addressing the lifecycle challenges of offshore wind projects, these participants were strategically selected to ensure a comprehensive evaluation of the framework. Their input will help validate the MCDA matrix, ensuring it effectively supports the prioritization of BIM applications across project phases. The outcome of the focus group can be found in *Chapter 5.3 (Focus Group), p. 86.*

3.5.3 Focus Group Structure

According to Krueger and Casey (2015), focus groups typically follow a structured format to facilitate open and productive discussions. The session begins with an introduction where the moderator explains the purpose, establishes ground rules, and uses an icebreaker to make participants comfortable. Opening questions are general and help set the stage for the discussion. Transition questions then guide participants from general topics to the core focus of the session. The main part involves key questions addressing the central objectives and encouraging detailed, interactive dialogue. Finally, the session concludes with questions summarising insights, validating key points, and allowing participants to share final thoughts. A comfortable environment, skilled moderation, and a well-defined questioning route are essential for successful focus groups (Krueger & Casey, 2015; Morgan, 1996).

For this research, the focus group will begin with an introduction to the purpose of the session and an overview of BIM and its relevance to offshore wind projects. This will take some time due to the participants' limited knowledge of BIM. Scenarios illustrating BIM applications will serve as transition points, providing participants with context for assessing challenges and opportunities. The core discussion will centre on open-ended questions, encouraging participants to share insights and critique the scenarios. The session will conclude with a summary of the debate and an opportunity for participants to validate or refine the framework's key elements. This structure ensures alignment with best practices outlined in the literature while addressing the specific goals of this thesis.

3.5.4 Focus Group Output and Significance

The focus groups' output will provide insights into the practical applicability and refinement of the Strategic BIM Prioritization Framework for Offshore Wind Projects. Participants' feedback on the scenarios, criteria, and factors will be used to validate and adjust the MCDA matrix, ensuring that it effectively reflects real-world challenges and priorities. By incorporating expert opinions, the framework becomes more robust, actionable, and tailored to address industry-specific needs.

Additionally, the focus groups play a crucial role in mitigating subjectivity in scoring and weighting, a standard limitation in MCDA. By incorporating diverse perspectives, the focus groups ensure that scores and weights reflect a balanced consensus rather than individual biases. Justifications for these decisions are documented thoroughly, linking them to evidence from interviews and literature. This iterative feedback process enhances reliability, transparency, and alignment with stakeholder priorities, ensuring that the framework is academically rigorous and practically relevant for offshore wind projects.

4. Interview Analysis

This chapter explores the insights gained from interviews with industry stakeholders, focusing on the challenges and opportunities in offshore wind project management and the role of digital tools. These interviews signify an essential step in both the problem identification and motivation phase, as well as the execution phase, of the Design Science Research Methodology, offering practical perspectives that complement the theoretical foundations established in earlier chapters. By capturing real-world experiences, this chapter bridges the gap between academic research and the practical realities of offshore wind projects, ensuring that the proposed framework is grounded in industry needs.

The interview findings are structured around key themes such as coordination and collaboration, data management, lifecycle integration, and innovation. These themes reveal persistent challenges in project workflows and highlight areas where BIM can offer significant benefits. For example, difficulties in coordination across stakeholders and transitions between project phases emphasize the need for enhanced lifecycle management solutions. In contrast, data management issues indicate BIM's potential to streamline information flows and enable better decision-making.

The insights derived from these interviews directly inform the development of the Strategic BIM Prioritization Framework for Offshore Wind Projects (SBPF-OW). By identifying and analyzing recurring challenges, this chapter sets the stage for defining specific objectives and shaping the design of a BIM framework that addresses the most pressing industry needs. Integrating stakeholder perspectives ensures the framework aligns with practical requirements and maximizes its potential impact.

This chapter concludes by summarizing the interview findings and linking them to the next phase of the DSRM process. The themes and insights discussed here are the foundation for the framework's design and development, detailed in the following chapter. By aligning stakeholder experiences with the research objectives, this chapter ensures a clear and logical progression from problem identification to solution development.

4.1 Overview of Interview Participants

The interviews conducted for this study included a diverse cohort of professionals representing various sectors within the offshore wind industry. These participants offered critical insights into offshore wind development's logistical, data management, and coordination challenges. To maintain participant anonymity, specific roles and job titles are not associated with individual interviews, safeguarding the information's confidentiality. Nonetheless, a general overview of the participants' roles, experience levels, and areas of expertise is presented to contextualize their contributions.

4.1.1 Expertise and Project Phases

The interviewees included professionals engaged across key phases of offshore wind projects: project development, design, construction, operations, and maintenance. While some individuals specialized in specific phases, others occupied roles spanning the entire project lifecycle. Their expertise included engineering, project management, operations coordination, and quality assurance. Furthermore, the cohort included team leaders and department heads responsible for overseeing activities and ensuring alignment across teams, as well as professionals involved in organizational initiatives focused on digitalization, standardization, and process optimization. Table 4.1 summarizes the interviewees' involvement across different project phases and their years of experience within the offshore industry, illustrating the diversity of roles and expertise represented in this study. Figure 4.1 visually represents the distribution of interviewees across different project phases, highlighting the balance between various lifecycle stages.

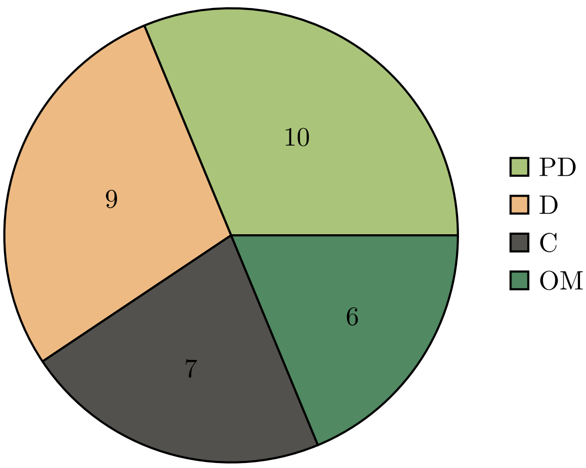


Figure 4.1: Distribution of Interviewee Involvement Across Project Phases

4.1.2 Levels of Experience

The interviewees possess varying levels of experience, encompassing early-career professionals, mid-level practitioners, and seasoned experts. This range of experience facilitates a comprehensive analysis by incorporating both innovative approaches and extensive industry expertise:

- **Less than 5 years**: Early-career professionals offering new perspectives and contributing to contemporary solutions for offshore wind project challenges.
- **5 to 10 years**: Mid-level professionals with substantial industry experience, providing valuable insights into established practices and ongoing developments within the sector.

Interview	Phase(s)	Tenure	Job Title
Interviewee 1	PD, D, C, OM	+10 Y	Technical Project Lead OWF
Interviewee 2	D	+10 Y	Construction Manager
Interviewee 3	PD	5-10 Y	Project Development Manager
Interviewee 4	OM	5-10 Y	Offshore Wind Operations Team Lead
Interviewee 5	C	+10 Y	T&I Specialist
Interviewee 6	PD, D, C, OM	+10 Y	Operational Readiness Manager
Interviewee 7	OM	0-5 Y	R&D Engineer – Structural Health Monitoring
Interviewee 8	PD, D	+10 Y	Quality Assurance Engineer – Foundations
Interviewee 9	PD	5-10 Y	Wind Turbine Engineering Specialist
Interviewee 10	OM	5-10 Y	Electrical Operations Engineer
Interviewee 11	PD	+10 Y	Head of Offshore Wind Farm Engineering
Interviewee 12	PD, D	0-5 Y	Electrical Grid Engineer
Interviewee 13	D, C, OM	+10 Y	Offshore Cable and Grid Connection Manager
Interviewee 14	PD, D, C	5-10 Y	Head of Project Intelligence
Interviewee 15	D, C	+10 Y	Manager – QHSE & Construction Management
Interviewee 16	PD, D, C	+10 Y	Senior Manager for Digital Transformation
Interviewee 17	PD	+10 Y	Project Analyst Offshore

Table 4.1: Summary of interviewees by their work phase(s) (PD: Project Development, D: Design, C: Construction, OM: Operation and Maintenance)

- **10+ years**: Highly experienced professionals, including individuals with over 25 years of expertise.

Including professionals with over 25 years of experience provides significant value to this study, as these individuals were instrumental in the early stages of offshore wind development. Their involvement in foundational projects grants them a comprehensive understanding of the industry's evolution, encompassing advancements in technology, process optimization, and the establishment of best practices. These pioneers offer critical insights into how challenges have evolved and provide a unique perspective on addressing current and future complexities within the sector. Additionally, several participants have been with EnBW for over a decade, contributing in-depth knowledge of the organization's strategic and operational adaptations. Their experiences highlight how the company has responded to shifts in market dynamics, technological progress, and regulatory frameworks. This combination of extensive professional experience and institutional knowledge ensures that the research benefits from both a historical perspective and an understanding of contemporary practices, strengthening its relevance and applicability. This distribution is visualized in Figure 4.2, illustrating the proportion of interviewees within each experience bracket.

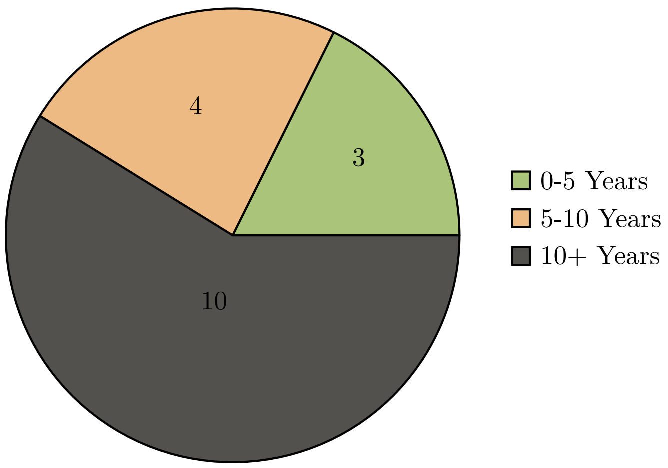


Figure 4.2: Distribution of Interviewees by Tenure

4.1.3 Relevance to Research

The expertise of the interviewees is closely aligned with the challenges explored in this research. Their knowledge spans critical areas, which include:

- **Project Coordination and Logistics**: Expertise in managing supply chains, coordinating multidisciplinary teams, and facilitating seamless transitions between different project phases.

- **Technical Design and Quality Assurance**: Proficiency in foundation design, turbine technology, cable systems, and ensuring adherence to industry standards.

- **Operations and Maintenance (O&M)**: Skills in optimizing lifecycle costs, maintaining operational efficiency, and minimizing downtime.

- **Digitalization and Standardization**: Experience in enhancing process efficiency, implementing BIM and related digital tools, and improving workflow integration.

The selection of participants ensures a comprehensive understanding of both phase-specific challenges and the broader coordination issues that span multiple phases. This diversity of expertise enables the research to approach the complexities of offshore wind projects holistically, offering practical and actionable insights that directly inform the development of a BIM-based framework.

4.2 Coding Process

Interviews fulfil multiple functions within this research, requiring a coding and analysis approach that aligns with their diverse objectives. An overview of the coding process is illustrated in Figure 4.3.

The primary function of the interview analysis is to acquire insights into the real-life challenges faced by offshore wind projects. This helps to inform the problem identification phase and substantiates the research by illustrating the necessity for solutions to current challenges. This element underpins the broader research framework, ensuring alignment with genuine industry needs.

The second function concerns the Design Science Research Methodology and the testing/ demonstration phase of the BIM framework. The interviews with EnBW employees are essential to the case study of EnBW's offshore wind department.

While the first function of the analysis aims to establish a comprehensive understanding of challenges, processes, and tools within offshore projects, the second function necessitates organizing and categorizing interview data to facilitate its use within the DSRM framework. To meet this requirement, a two-cycle coding approach was employed.

4.2.1 First Cycle Coding (Initial Coding)

The first cycle of coding represents the preliminary stage, in which labels (codes) are assigned to interview excerpts to capture key concepts, as exemplified in Figure 4.4. This process comprises multiple steps:

- **Deductive Coding:** Initially, coding was conducted based on predefined categories derived from challenges identified in *Chapter 2.1 (Offshore Wind Projects), p. 12.* Codes corresponding to these challenges were assigned to relevant interview fragments. This resulted in 20 codes across six categories, assigned to a total of 85 quotes. The outcomes are presented in Table 4.2 and further discussed in *Chapter 4.3 (Comparison of Challenges from Literature and Interview Findings), p. 64.*

- **Inductive Coding:** The second step involved an open-ended coding approach without predetermined categories. Through iterative cycles of code creation, assignment, revision, combination, and subdivision, a refined coding structure was established. This process continued until saturation was reached, yielding 43 initial codes (without predefined categories) assigned to 418 quotes.

4.2.2 Second Cycle Coding

The second coding cycle was also divided into two steps:

- **Reorganization and Categorization:** The inductive codes were systematically restructured and organised over multiple iterations, resulting in seven categories and 41 codes. An overview of these categories and their descriptions is provided in *Appendix B (Codebook for Problem Identification and Motivation), p. 118* and *Appendix C (Interview Analysis), p. 124.* The final results are presented in *Chapter 4.4 (Insights from Emerging Codes During Analysis), p. 69.* This stage laid the foundation for the comparison of literature-based challenge occurrences (as detailed in *Chapter 2.1 (Offshore Wind Projects), p. 12* and analysed via deductive coding in Table 4.2) with the challenges identified by EnBW employees across different offshore wind

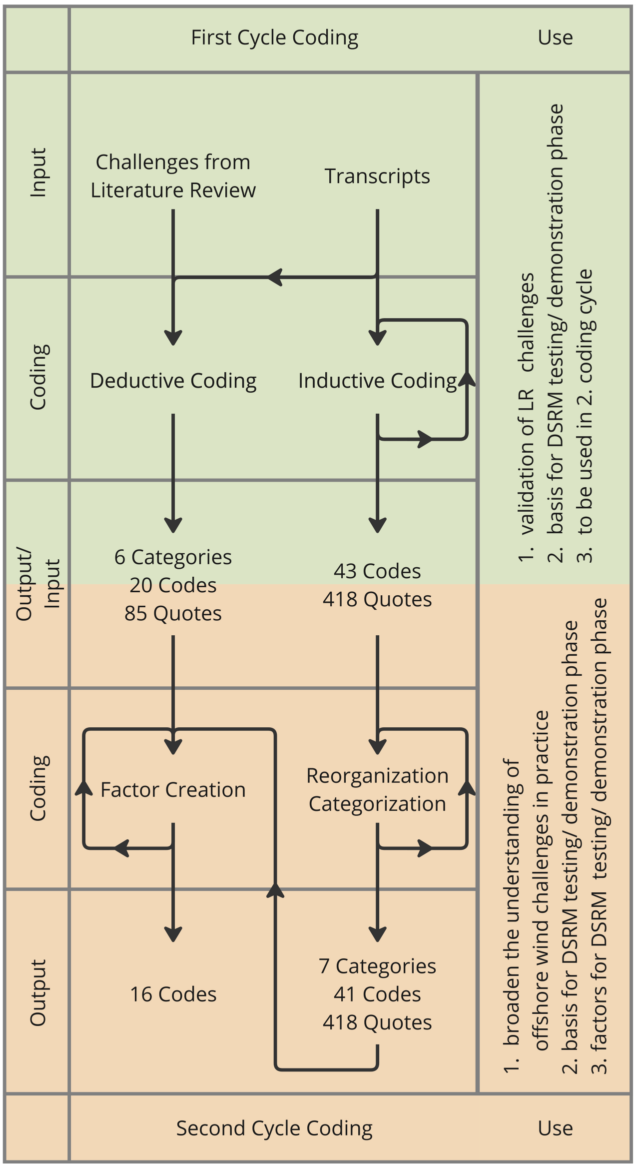
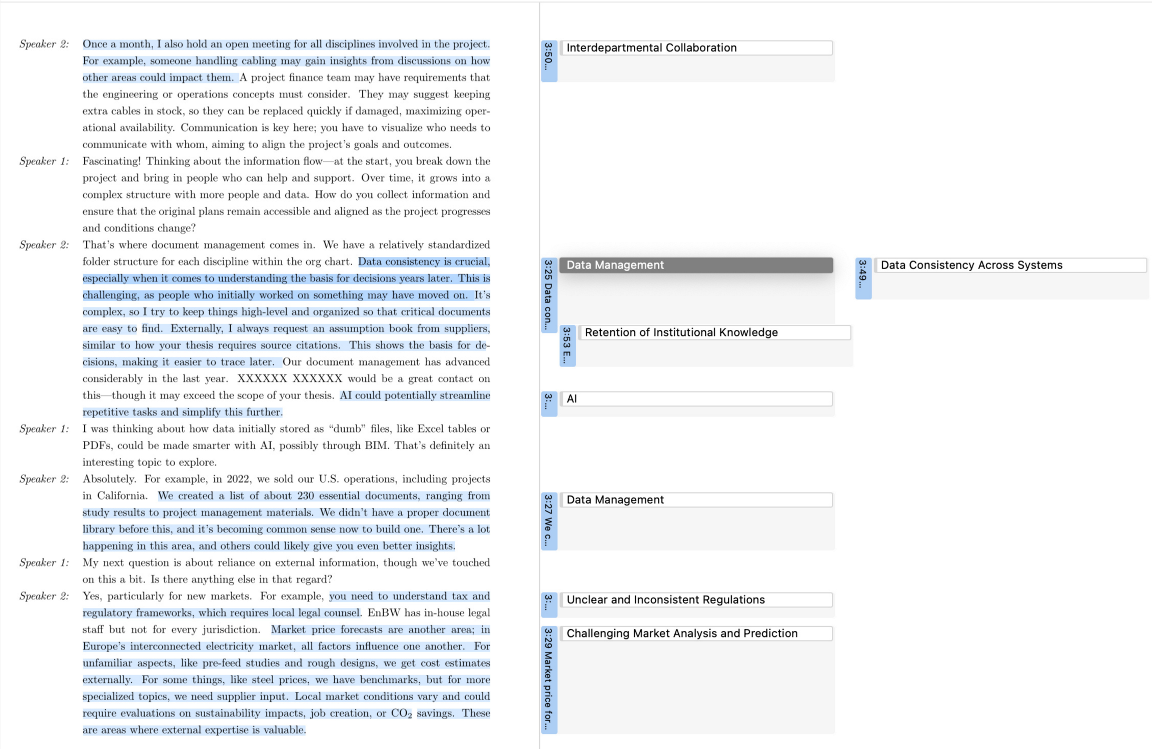


Figure 4.3: Coding Process



Speaker 2: Once a month, I also hold an open meeting for all disciplines involved in the project. For example, someone handling cabling may gain insights from discussions on how other areas could impact them. A project finance team may have requirements that the engineering or operations concepts must consider. They may suggest keeping extra cables in stock, so they can be replaced quickly if damaged, maximizing operational availability. Communication is key here; you have to visualize who needs to communicate with whom, aiming to align the project's goals and outcomes.

Speaker 1: Fascinating! Thinking about the information flow—at the start, you break down the project and bring in people who can help and support. Over time, it grows into a complex structure with more people and data. How do you collect information and ensure that the original plans remain accessible and aligned as the project progresses and conditions change?

Speaker 2: That's where document management comes in. We have a relatively standardized folder structure for each discipline within the org chart. Data consistency is crucial, especially when it comes to understanding the basis for decisions years later. This is challenging, as people who initially worked on something may have moved on. It's complex, so I try to keep things high-level and organized so that critical documents are easy to find. Externally, I always request an assumption book from suppliers, similar to how your thesis requires source citations. This shows the basis for decisions, making it easier to trace later. Our document management has advanced considerably in the last year. XXXXXX XXXXXX would be a great contact on this—though it may exceed the scope of your thesis. AI could potentially streamline repetitive tasks and simplify this further.

Speaker 1: I was thinking about how data initially stored as "dumb" files, like Excel tables or PDFs, could be made smarter with AI, possibly through BIM. That's definitely an interesting topic to explore.

Speaker 2: Absolutely. For example, in 2022, we sold our U.S. operations, including projects in California. We created a list of about 230 essential documents, ranging from study results to project management materials. We didn't have a proper document library before this, and it's becoming common sense now to build one. There's a lot happening in this area, and others could likely give you even better insights.

Speaker 1: My next question is about reliance on external information, though we've touched on this a bit. Is there anything else in that regard?

Speaker 2: Yes, particularly for new markets. For example, you need to understand tax and regulatory frameworks, which requires local legal counsel. EnBW has in-house legal staff but not for every jurisdiction. Market price forecasts are another area; in Europe's interconnected electricity market, all factors influence one another. For unfamiliar aspects, like pre-feed studies and rough designs, we get cost estimates externally. For some things, like steel prices, we have benchmarks, but for more specialized topics, we need supplier input. Local market conditions vary and could require evaluations on sustainability impacts, job creation, or CO_2 savings. These are areas where external expertise is valuable.

Figure 4.4: Example Coded Interview

project lifecycle phases. The outcomes of this comparative analysis are presented in *Chapter 4.5 (Discussion of Interview Analysis), p. 72*.

- **Application within DSRM:** The final step of the coding process was integrated into the demonstration phase of the DSRM. Offshore wind project challenges were mapped to BIM capabilities and subsequently rated based on the extent to which BIM could provide solutions. To facilitate this, a consolidated list of offshore wind project challenges was compiled. Using visualization tools such as Miro, the codes and categories from both deductive and inductive coding were reorganized and restructured into 16 key factors representing the primary challenges of offshore wind project phases. The composition of the factors based on the codes is shown in Figure 4.5. The graphical representation of this factor creation process is provided in *Appendix E (Combination of Codes to Factors), p. 130* in the form of field notes.

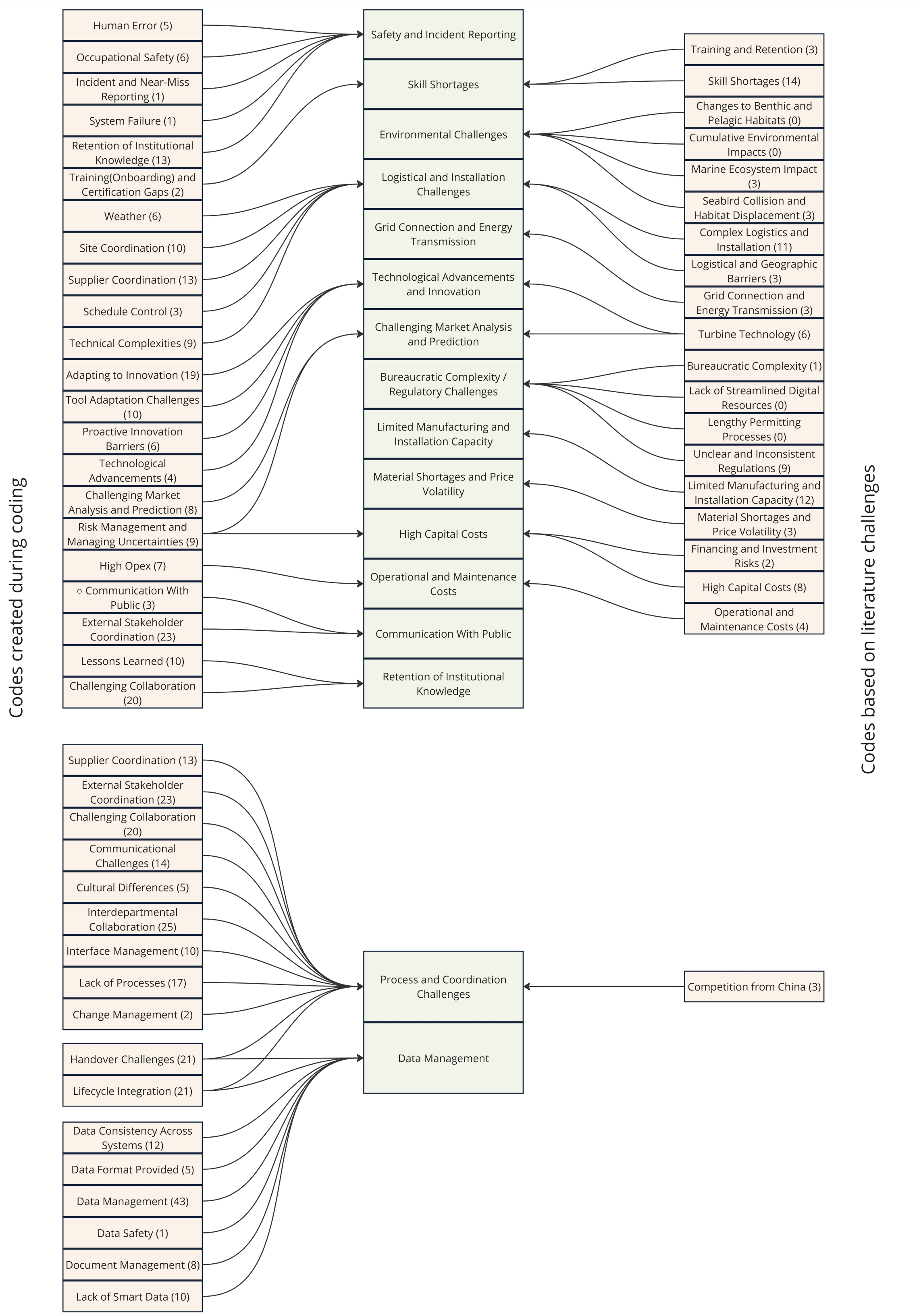


Figure 4.5: Creation of Factors

4.3 Comparison of Challenges from Literature and Interview Findings

This subsection compares the challenges identified in the literature with the findings of the interviews. The analysis focuses on significant variations in challenge occurrence, drawing attention to high and low-significance patterns and providing explanations where necessary. A detailed overview of the challenges and their occurrences during the interviews is presented in Table 4.2.

4.3.1 High Occurrence Challenges

Workforce challenges, particularly skill shortages (14 occurrences) and training and retention issues (3 occurrences), emerged as a critical concern in the interviews. These findings align with the literature, which emphasizes the growing demand for specialized labour due to the rapid expansion of the offshore wind industry. For example, one interviewee mentioned:

> “Recently, a big challenge has been finding companies with sufficient offshore-qualified personnel. For example, some firms we contact for maintenance or repairs have only three people certified to work offshore across their entire organization, which limits availability.” (Interview 10)

This highlights the acute scarcity of qualified offshore personnel, particularly for specialized roles, which is further exacerbated as the demand for wind park development increases. Another interviewee noted,

> “Organizationally, we’re always trying to get the best experts in the right roles, but we have limited resources.” (Interview 3)

This demonstrates the challenge of balancing the need for highly skilled personnel with resource constraints, especially as project teams are often stretched thin across multiple responsibilities.

Challenges related to the **Supply Chain**, such as limited manufacturing and installation capacity (12 occurrences) and material shortages and price volatility (3 occurrences), were frequently highlighted. These concerns are consistent with findings from the literature, which point to bottlenecks in turbine manufacturing, vessel availability, and raw material supply chains. For example, one interviewee noted,

> ”In 2017, when we secured nearly a gigawatt [in turbine capacity], we thought suppliers would be competing for our business. Not anymore. For turbines, there are only two major Western players, Siemens and Vestas, who are aware of their position.” (Interview 3)

This quote highlights the increasing dominance of suppliers in the offshore wind market, limiting developers’ options and creating dependencies that pose risks to project timelines and budgets. Another interviewee stated,

> “Material supply has been another concern, especially during the pandemic, with long waits for parts manufactured in Asia. Things have normalized over the past year or two, but we’ve learned to be proactive, keeping critical parts in stock. These are parts that, if needed, would cause a turbine shutdown or limited output.” (Interview 4)

Category	Specific Challenge	Occurrence
End-of-Life Challenges	Economic Viability	2
	Environmental Impact	0
	Regulatory Uncertainty	1
	Technical and Logistical Challenges	3
	Total	6
Environmental Challenges	Changes to Benthic and Pelagic Habitats	0
	Cumulative Environmental Impacts	0
	Marine Ecosystem Impact	3
	Seabird Collision and Habitat Displacement	0
	Total	3
Financial Challenges	Financing and Investment Risks	2
	High Capital Costs	8
	Operational and Maintenance Costs	4
	Total	14
Regulatory Challenges	Bureaucratic Complexity	1
	Lack of Streamlined Digital Resources	0
	Lengthy Permitting Processes	0
	Unclear and Inconsistent Regulations	9
	Total	10
Supply Chain Challenges	Competition from China	3
	Limited Manufacturing and Installation Capacity	12
	Material Shortages and Price Volatility	3
	Total	17
Technical Challenges	Complex Logistics and Installation	11
	Grid Connection and Energy Transmission	3
	Turbine Technology	6
	Total	19
Workforce-Related	Logistical and Geographic Barriers	3
	Skill Shortages	14
	Training and Retention	3
	Total	20
Totals		89

Table 4.2: Categorization of challenges and their occurrence during interviews

This demonstrates how developers have adapted to supply chain disruptions by maintaining inventories of critical components, which helps mitigate risks and increases operational costs. Additionally, vessel availability remains a significant bottleneck, as noted by an interviewee:

> "In terms of logistics, especially ships, we see an issue with large vessels, specifically Jack-Up Vessels. These are often reserved for new installations, as providers prefer longer-term contracts. It's understandable but a challenge for us, especially as older turbines require more significant interventions over time. And that competition will only intensify as more parks come online, with fewer vessels available." (Interview 4)

This emphasizes the limited capacity of specialized vessels, a critical resource for new installations and maintenance. These insights underscore the offshore wind industry's dependency on a constrained supply chain, highlighting vulnerabilities in securing key components and logistics as demand grows. Without addressing these bottlenecks, achieving ambitious expansion targets may prove increasingly difficult.

Technical Challenges such as Complex logistics and installation (11 occurrences) and turbine technology (6 occurrences) were widely discussed challenges. Interviewees echoed the literature, highlighting issues such as harsh marine environments, delays due to adverse weather, and the need for technological advancements in turbine design to address mechanical fatigue and corrosion. For example, one interviewee noted,

> "Another example was on Albatros, where TenneT connected our cable to the existing export cable for the Global Tech 1 platform, but bad weather caused delays, costing us about six months in total." (Interview 14)

This highlights how unpredictable weather conditions remain a significant logistical and scheduling challenge, especially during offshore operations, where delays can have compounding effects on project timelines. Another interviewee explained the technological advancements in turbine technology, stating,

> "When we built Baltic 1, we used 2.3 MW turbines that were essentially onshore turbines, and now we're installing 15 MW offshore turbines. It's staggering. Developing this technology is a significant challenge as it's still in its early stages." (Interview 3)

This highlights the rapid evolution of turbine technology over the past decade, moving from relatively simple adaptations of onshore turbines to highly specialized offshore turbines with significantly higher capacities. While this progress is impressive, it also underscores the engineering and logistical challenges in designing, manufacturing, and installing these advanced turbines to meet increasing energy demands.

4.3.2 Low Occurrence Challenges

End-of-Life Challenges were notably underrepresented in the interviews, with only six occurrences across all subcategories (Table 4.2). This is significantly lower than expected based on the literature's emphasis on decommissioning complexities. This can be attributed to the lack of practical experience at EnBW, as their wind parks have not yet reached the decommissioning phase. Interviewee 3 explicitly stated,

> "Financially, it's not overly critical either, since future costs are worth less today due to net present value. So, these are all manageable engineering challenges." (Interview 3)

This statement highlights that decommissioning costs are discounted heavily during project development due to their occurrence far in the future, reducing their perceived financial burden. Additionally, the interviewee noted the scrap value of recyclable materials, stating,

> “The scrap value alone is significant as most of the materials are recyclable, including the new recyclable blades we’re using. Today, over 95% of the raw materials in offshore wind turbines are already recyclable, so that’s not the main issue.” (Interview 3)

This indicates that recycling does not add complexity or pose an extra challenge, as the interviewee perceives it as a solved issue. The established recyclability of turbine materials reduces financial and logistical concerns, contributing to the perception that decommissioning is a manageable phase of the project lifecycle.

Environmental Challenges, despite being a significant concern in the literature, such as marine ecosystem impact (3 occurrences) and seabird collision and habitat displacement (0 occurrences), had a surprisingly low presence in interview data. This discrepancy suggests that these issues may be perceived as less immediate or pressing in day-to-day project management at EnBW. However, Interviewee 5 highlighted that environmental challenges can become significant when specific government criteria must be met, requiring additional process adaptations. For example, the interviewee noted,

> “The authorities set a limit of 160 decibels at a certain distance, but they don’t mandate which system to use. However, the base risk, if the noise level is exceeded and the BSH orders a stop, remains with the developer. This is one of the significant risks that cannot be fully transferred to the contractor.” (Interview 5)

This demonstrates that environmental factors often become challenges primarily through the lens of regulatory compliance, requiring modifications to the installation process, such as noise mitigation strategies. As such, the environmental impact is often seen as secondary and only becomes a tangible challenge when linked to government-mandated requirements.

4.3.3 Implications

The findings from the interviews strongly align with the literature in areas such as workforce, supply chain, and technical challenges, emphasizing the practical realities and immediate needs of offshore wind project development and operation. High-occurrence challenges, including skill shortages, constrained supply chains, and logistics and turbine technology complexities, reflect the industry’s ongoing struggles to meet increasing demands and ambitious expansion targets. Addressing these challenges will require concerted efforts to secure resources, enhance workforce capacity, and advance technological innovations.

In contrast, the low occurrence of end-of-life and environmental challenges highlights areas where EnBW’s current operational focus diverges from the broader challenges emphasized in the literature. The limited attention to decommissioning can be attributed to EnBW’s lack of practical experience in this area, as its wind parks have not yet reached the end-of-life phase. Similarly, environmental challenges appear to be perceived as secondary, emerging primarily in response to regulatory compliance rather than as intrinsic concerns. These discrepancies suggest that EnBW’s challenges are shaped significantly by its current position in the lifecycle of offshore wind projects.

This analysis underscores the importance of addressing high-priority challenges to ensure project success while proactively preparing for future concerns such as decommissioning and evolving environmental regulations. Integrating lessons from the literature into long-term strategic planning will help bridge these gaps and support EnBW's readiness to navigate the next phases of offshore wind development.

4.4 Insights from Emerging Codes During Analysis

This part explores the codes that emerged during the analysis of the interviews. The study highlights patterns and key themes relevant to offshore wind project management, particularly areas of recurring importance and notable challenges. A complete table with occurrences per code is in the appendix under C.

4.4.1 Emerging Categories and Codes

Coordination and Collaboration (148 occurrences) was the most frequently coded category, emphasizing its importance in managing offshore wind projects. Subcategories such as Interdepartmental Collaboration (25 occurrences) and External Stakeholder Coordination (23 occurrences) reflect the complexity of managing both internal teams and external relationships. Challenges related to Challenging Collaboration (20 occurrences) and Communicational Challenges (14 occurrences) further highlight the difficulties of fostering effective teamwork, particularly in the presence of Cultural Differences (5 occurrences). For instance, one interviewee observed,

> ”One person might consider a piece of information critical and feel the need to share it, while someone else thinks it’s already resolved and doesn’t mention it again.” (Interview 2)

This example underscores the challenges of ensuring consistent communication within teams, where differing perceptions of what is essential can lead to gaps in information sharing. Addressing this issue requires clear communication protocols and a shared understanding of priorities to prevent misunderstandings and inefficiencies. External stakeholder coordination also presents significant challenges, as highlighted by one interviewee:

> ”We have many touchpoints within EnBW and externally with service providers and investors. One of the biggest challenges is coordinating these different areas and securing necessary inputs while ensuring these tasks are prioritized across other departments. Since all operational matters ultimately come to us, we rely on support from various departments, which can be tricky as they have their own priorities and limited capacity. Making sure we get the support we need is an ongoing challenge.” (Interview 4)

This quote emphasizes the difficulty of balancing the needs of diverse stakeholders while managing internal resource constraints. Effective coordination requires aligning priorities across departments and stakeholders, ensuring critical tasks receive timely attention to avoid bottlenecks. The relatively high frequency of Lack of Processes (17 occurrences) underscores the need for standardized procedures, while the focus on Lessons Learned (10 occurrences) indicates ongoing efforts to improve knowledge-sharing practices. Additional themes such as Supplier Coordination (13 occurrences) and Site Coordination (10 occurrences) point to specific areas where better coordination could enhance project efficiency.

Data and Digital Systems (80 occurrences) emerged as a critical theme, reflecting the growing reliance on digital tools. Data Management (43 occurrences) dominated this category, underscoring the importance of handling large datasets effectively. Persistent challenges such as Data Consistency Across Systems (12 occurrences) and Lack of Smart Data (10 occurrences) highlight difficulties in achieving seamless integration and actionable insights. As one interviewee noted,

> "It's surprising how underdeveloped data management and control systems are. For instance, in our last project, Hohe See/Albatros, parts of the operational software were running on Windows 7, which was outdated but deemed stable enough to use without upgrades." (Interview 9)

This quote illustrates how reliance on outdated systems can hinder efficient data management and highlights the need for modernization to meet the growing complexity of offshore wind projects. The aspiration for more advanced systems was a recurring theme in the interviews. As the interviewer noted during a discussion,

> "You essentially have a 3D model with all documentation linked to each component. For example, a technician can walk through a building with an iPad, virtually locate the exact spot, and tap on the model to access the datasheet for the HVAC unit, the service hotline, and past maintenance records." (Interview 11)

This vision was met with enthusiasm by an interviewee, who replied,

> "That's the dream of my sleepless nights!" (Transcript 11)

This exchange underscores the industry's recognition of the potential for smart, integrated systems to streamline workflows and enhance accessibility. Another interviewee emphasized the challenges related to the Lack of Smart Data, stating,

> "It's [Think Project] only a document management system. If I wanted to analyze data—say, I wanted to know on how many days we had wave heights over three meters—then I'd probably have to sit someone down for four hours to sift through Excel sheets. This could be prepared and reviewed either at the end of a project or even during it. Sure, I can find all the weather reports from the past few months in Think Project, but it doesn't mean that the data is readily available at a glance." (Interview 2)

This highlights the inefficiencies in extracting actionable insights from existing data systems, often requiring manual effort to analyze and compile information for decision-making. The low frequency of Data Safety (1 occurrence) suggests that while necessary, it may not currently be a pressing concern compared to other data-related challenges. Document Management (8 occurrences) and Tool Adaptation Challenges (10 occurrences) further illustrate the need for optimized systems to manage and utilize project data efficiently.

Innovation and Market Dynamics (28 occurrences) highlights the strategic challenges of navigating a rapidly evolving industry. Codes such as Challenging Market Analysis and Prediction (8 occurrences) emphasize difficulties anticipating market trends, while Proactive Innovation Barriers (6 occurrences) reflect constraints in integrating forward-looking technologies and practices.

Operational and Lifecycle Management (65 occurrences) underscores the importance of lifecycle-focused approaches in offshore wind projects. Handover Challenges (21 occurrences) and Lifecycle Integration (21 occurrences) highlight critical pain points during transitions between project phases and the need for seamless alignment across the project lifecycle. As one interviewee noted,

> "Handovers between phases are always challenging. For instance, the auction team aims to win the bid with a viable business case, but the consequences of over-promising don't fall on the auction team—they're passed to the development or construction teams." (Interview 15)

This quote highlights how unresolved issues or over-optimistic assumptions during the bidding phase can create significant challenges for subsequent project stages, emphasizing the importance of robust handover management. Risk Management and Managing Uncertainties (9 occurrences) and High Operational Expenditures (Opex) (7 occurrences) reflect ongoing concerns about cost pressures and risk mitigation. These findings underscore the necessity of proactive lifecycle management and the integration of lessons learned to anticipate and address risks effectively across all phases of offshore wind projects.

Training and Knowledge Retention (15 occurrences) emerged as a more minor but significant theme. The emphasis on the Retention of Institutional Knowledge (13 occurrences) underscores the critical need to preserve organizational expertise. In comparison, Training (Onboarding) and Certification Gaps (2 occurrences) suggest that onboarding processes, while necessary, may not be a current priority in the industry.

4.4.2 Key Insights and Implications

The analysis highlights three central challenges in offshore wind project management: coordination and collaboration, effective data management, and lifecycle integration. Coordination emerged as a dominant theme, revealing ongoing difficulties in aligning priorities and fostering seamless communication across internal teams and external stakeholders. These challenges underscore the need for clear protocols and more robust frameworks to navigate the complexities of multi-stakeholder projects.

Data management surfaced as another critical area, with issues like outdated systems and limited accessibility to actionable insights impeding efficiency. This reflects a broader need for modernization and smarter tools to integrate and streamline workflows. The current reliance on fragmented systems indicates that investments in unified platforms could yield substantial operational benefits. Lifecycle considerations, particularly during phase transitions, remain a persistent challenge. Misalignments during handovers and inadequate integration across project phases highlight the importance of a more lifecycle-focused approach to planning and execution. Addressing these gaps could reduce risks and improve long-term project performance.

While less prominent, innovation and knowledge retention barriers reflect the industry's strategic vulnerabilities. These findings suggest that improved forecasting, adaptable frameworks, and systematic knowledge-sharing practices will be essential as offshore wind expands.

4.5 Discussion of Interview Analysis

This section builds on the findings presented in the previous chapter, which explored the challenges and opportunities in offshore wind projects through interviews with key stakeholders. Functioning as a bridge between the empirical data collected and the subsequent steps of the Design Science Research Methodology (DSRM), this chapter not only highlights the practical relevance of the interview findings but also aligns them with the overarching objectives of the thesis. It sets the stage for defining specific objectives and designing a conceptual BIM framework tailored to offshore wind challenges.

4.5.1 Insights and Emerging Themes from Interviews

The interviews reinforced key challenges within offshore wind projects, including workforce shortages, supply chain constraints, and coordination inefficiencies. These challenges reflect themes common to offshore wind and general construction, highlighting the importance of addressing these persistent barriers. However, the interviews also offered practical nuances specific to offshore wind, such as the impact of harsh marine conditions and limited supplier capacity, which add layers of complexity compared to onshore construction.

Coordination, collaboration, and lifecycle integration emerged as the most frequently discussed themes, underscoring their central role in ensuring project success. Persistent coordination challenges, particularly in managing interdepartmental workflows and external stakeholder interactions, were highlighted as critical barriers to efficiency. The need for improved collaboration frameworks was emphasized, especially in addressing competing team priorities and ensuring seamless communication among geographically dispersed stakeholders. Many interviewees stressed the importance of lifecycle integration to align project phases effectively and prevent bottlenecks during transitions.

Less-emphasized topics, such as environmental challenges and decommissioning, reflect EnBW's operational focus on earlier lifecycle phases. Ecological concerns were primarily discussed in the context of regulatory compliance rather than as intrinsic priorities, and decommissioning received limited attention due to EnBW's lack of practical experience in this phase, as its wind parks have not yet reached the end of their operational lifespan. These omissions highlight the immediate priorities shaping EnBW's challenges and suggest areas for future strategic planning and potential BIM applications.

4.5.2 Narrowing the Scope

A narrower scope is essential for a focused and in-depth exploration of BIM's potential in offshore wind projects. Given offshore wind's broad and multidisciplinary nature, attempting to address all lifecycle phases in detail would dilute the research focus and hinder actionable insights. By concentrating on specific phases where BIM adoption can deliver the most immediate and measurable benefits—design, construction, and operations—this thesis aims to provide targeted recommendations that are both practical and impactful.

After analyzing the Interviews and considering the relevant literature, the scope of this thesis is narrowed to focus on the design, construction, and operations phases of offshore wind projects, as well as their interfaces with the project development phase. This decision ensures a targeted exploration of BIM applications in areas where its adoption can deliver the most immediate and measurable benefits. EnBW has recognized the need for digitalization and optimization in the project development and bid preparation phases. The company is developing Vind AI, a specialized tool designed to streamline project development processes through advanced modelling, financial simulation, and decision-making capabilities to address this. As Vind AI is tailored to this phase, this thesis does not include a detailed analysis of BIM applications in project development. Instead, it examines potential interfaces between Vind AI's outputs and BIM applications in subsequent phases to ensure seamless integration and data continuity.

The decommissioning phase is also excluded from this study for several reasons. First, the offshore wind industry has limited experience with decommissioning, as most wind farms have not yet reached the end of their operational lifespans, resulting in a lack of empirical data and established best practices. Second, decommissioning shares many operational and logistical similarities with the construction phase, albeit in reverse. Consequently, any BIM-related benefits identified for construction are likely to apply to decommissioning as well. Finally, current digitalization efforts in the industry focus on earlier lifecycle phases, such as project development, design, and construction, where BIM can immediately address challenges and inefficiencies. While decommissioning is not directly analyzed, its potential benefits are acknowledged as part of the overall value BIM can provide across the lifecycle of offshore wind projects.

5. Framework Development

This chapter examines how BIM can address critical challenges in offshore wind projects. The chapter highlights recurring issues from industry interviews, including coordination, data management, and lifecycle integration, emphasizing BIM's potential to improve processes and decision-making. These interviews serve as a crucial link between the problem identification phase of the Design Science Research Methodology and the development of the Strategic BIM Prioritization Framework for Offshore Wind Projects (SBPF-OW).

The analysis is organized around key interview themes, such as operational inefficiencies, fragmented data systems, and better integration across project phases. Each theme provides valuable context for understanding where BIM can generate the most impact. Practical examples and participant feedback help bridge theoretical discussions with real-world applications, ensuring the framework aligns with industry needs and expectations.

This chapter also narrows the research focus, concentrating on offshore wind projects' design, construction, and operational phases, where BIM adoption is expected to yield the most immediate benefits. While acknowledging broader lifecycle considerations, the chapter underscores the importance of targeting specific areas to deliver actionable and relevant recommendations.

The findings presented here inform the design of the SBPF-OW framework and establish a foundation for its validation and refinement. This chapter sets the framework's iterative development stage by aligning stakeholder perspectives with research objectives, ensuring practical and impactful outcomes.

5.1 Problem Identification, Motivation and Objectives

5.1.1 Problem Identification and Motivation

Offshore wind energy is essential to achieving global energy transition goals, yet significant challenges impede its development. These include inefficiencies in lifecycle management, fragmented data handling, complex stakeholder coordination, and regulatory and environmental constraints, as detailed in Chapter 2.1. Addressing these issues is critical to ensuring the sector's scalability and long-term success.

BIM has demonstrated its value in the AECOO industry by enhancing project outcomes through improved data integration, collaboration, and lifecycle management. However, BIM's application in offshore wind remains underexplored and lacks a structured framework tailored to the sector's unique demands, as reviewed in Chapter 2.3. This gap leaves offshore wind stakeholders uncertain about BIM's potential effectiveness and extent of applicability.

This uncertainty was particularly evident at EnBW, whose growing exposure to BIM through various industry channels highlighted an internal knowledge gap. EnBW lacked the expertise to evaluate whether, and where, BIM could effectively support their offshore wind operations. This practical need directly motivated the research, aiming to provide EnBW with a structured basis for decision-making regarding BIM adoption.

This research addresses the lack of knowledge regarding whether and to what extent BIM can be effectively implemented in offshore wind projects to overcome existing challenges and enhance project success. It aims to develop a qualitative framework to explore BIM's applicability, providing strategic guidance for future research and resource allocation in the offshore wind sector.

5.1.2 Define Objectives for a Solution

The objectives of this research are twofold. Firstly, to develop a decision-making tool that evaluates how BIM can be utilised in offshore wind projects from a specific stakeholder's perspective. Secondly, to apply this tool to ascertain the value of BIM for EnBW, addressing their need for clarity on whether and where BIM can contribute to the delivery of their offshore wind projects.

The first objective focuses on creating a qualitative framework designed to assess BIM's applicability and potential benefits for addressing challenges in offshore wind projects. This framework will account for diverse stakeholder perspectives and consider the unique complexities of offshore wind projects across their lifecycle. It will help answer the research question.

The second objective involves applying the developed framework within the context of EnBW's operations and project environment. This application aims to identify areas where BIM can create the most value for EnBW by enhancing lifecycle efficiency, improving stakeholder collaboration, and supporting strategic decision-making processes.

Together, these objectives aim to address the knowledge gap surrounding BIM's role in offshore wind projects, provide actionable insights for industry stakeholders, and establish a foundation for EnBW to leverage BIM in meeting its strategic goals.

5.2 Iterative Development, Demonstration and Evaluation

5.2.1 1. Iteration

Development

Based on the problem statement and objectives, the initial framework was developed. The process began by deriving challenges and factors impacting project success in offshore wind projects from the literature. Semi-structured interviews with EnBW employees were conducted to validate these challenges and identify additional factors. This combined approach ensured that theoretical insights and practical expertise were incorporated into the framework.

The findings were organized into a catalogue of factors representing a comprehensive and multifaceted view of the elements influencing project success in offshore wind projects. To ensure manageability without losing depth, the factors were refined and consolidated into a final list of 16, which can be found in *Appendix F (Combined and Refines Codes for MCDA 1. Itertation), p. 133*.

To evaluate the relevance of these factors for BIM implementation in offshore wind projects, a Multi-Criteria Decision Analysis (MCDA) approach was selected. Selecting the appropriate MCDA setup was a critical step, as it determines the robustness and validity of the evaluation process. Initially, three different MCDA setups were considered, ranging from purely qualitative to mixed qualitative and quantitative approaches. A comparison of the three setups can be seen in *Appendix G (1. Iteration MCDA Setup, with/ without Codes), p. 142*:

- **Version 1** is purely qualitative, using four criteria—Technical Feasibility, Impact, Cost-Effectiveness, and Plausibility—with equal weight distribution. This version allows for a straightforward comparison of the factors based on subjective expert judgment but cannot incorporate objective, data-driven insights.

- **Version 2** introduces a mixed qualitative and quantitative approach by incorporating a fifth criterion: the occurrence of the codes. The occurrence score is factored into the weighted score, comprising 20% of the total score and carrying equal weight with the other four criteria from Version 1. The occurrence score is calculated on a linear scale where the lowest occurring factor receives a score of 1, the highest occurring factor receives a score of 5, and the remaining factors are distributed proportionally between the two extremes based on their frequency of occurrence. This setup adds a layer of objectivity by grounding part of the analysis in empirical data, thereby balancing qualitative insights with quantitative evidence.

- **Version 3** refines the mixed approach by adjusting how the Impact criterion is calculated. In this version, the requirements from Version 1—Technical Feasibility, Cost-Effectiveness, and Plausibility—are retained with the exact weights, maintaining consistency in the evaluation framework. The adjustment applies only to the Impact criterion, which is composed of two equally weighted components: (i) the qualitative rating based on expert judgment and (ii) the number of occurrences converted into a score between 1 and 5 using the same normalization process as in Version 2. This setup aims to capture the factor's perceived significance and its empirical relevance, creating a more balanced and comprehensive evaluation.

The progression from Version 1 to Version 3 reflects an effort to balance qualitative expert insights with objective, data-driven inputs. Version 1 provides a straightforward framework but may lack empirical grounding. Version 2 improves objectivity by factoring in real-world data but introduces the complexity of weighting and normalization. Version 3 attempts to strike an optimal balance by integrating qualitative and quantitative elements within the same criterion, thereby enhancing the robustness and validity of the evaluation.

Version 3 was ultimately selected because it offers the most balanced and comprehensive evaluation. By retaining the original criteria and their weights from Version 1, the framework preserves consistency while enhancing the analytical depth through the adjusted Impact criterion. This approach ensures that objective data on the occurrence of factors reinforce the subjective insights from expert judgment. This hybrid approach strengthens the analytical depth of the MCDA while maintaining empirical grounding, thereby increasing the credibility and repeatability of the results. By combining perceived importance with actual relevance, Version 3 ensures that the evaluation reflects both theoretical significance and practical applicability. This makes the framework more defensible, transparent, and adaptable for future assessments of BIM in offshore wind projects.

The selected MCDA framework is based on the following four criteria, which reflect both theoretical and practical considerations essential for BIM implementation in offshore wind projects:

- **Technical Feasibility**: This criterion evaluates BIM's ability to address the technical complexities of offshore wind projects. It investigates the extent to which BIM's capabilities (*Chapter 2.2 (BIM), p. 22*) can be mapped to the challenges of offshore wind projects (*Chapter 2.1 (Offshore Wind Projects), p. 12*).

- **Impact**: This criterion assesses the extent to which BIM can effectively address specific challenges and the significance of these challenges as identified in interviews. In the selected MCDA setup, the Impact criterion is composed of two equally weighted components: (i) a qualitative rating based on expert judgment and (ii) a quantitative score derived from the number of occurrences of the factor in the interviews. The quantitative score is normalized on a linear scale, with the lowest occurring factor receiving a score of 1 and the highest occurring factor receiving a score of 5, while the remaining scores are distributed proportionally between these extremes. This combined approach ensures that the framework prioritizes areas where BIM can deliver meaningful value, balancing perceived significance with actual relevance based on empirical data.

- **Cost-Effectiveness**: Offshore wind projects have high capital and operational costs. This criterion evaluates the economic viability of implementing BIM, ensuring it balances investment and return by addressing inefficiencies and reducing risks.

- **Plausibility**: Given the nascent application of BIM in offshore wind, this criterion examines the practicality of implementing BIM under current industry conditions.

All four criteria were assigned equal weight at this stage, reflecting an unbiased initial prioritization. Combining the refined factors with these criteria resulted in the creation of the MCDA matrix, which serves as the foundation for further evaluation and analysis in subsequent iterations.

Demonstration

The MCDA was conducted following the approach outlined in *Chapter 3.4 (Multi-Criteria Decision Analysis (MCDA)), p. 49* by rating each identified factor on a scale of 1 to 5 against the criteria of technical feasibility, impact, cost-benefit, and plausibility. The ratings were derived from insights gained during the literature review and interviews, ensuring a balanced evaluation incorporating theoretical knowledge and practical, company-specific experience. This rating process prioritised the identified factors according to their relevance for implementing BIM in offshore wind projects.

The assignment of individual ratings followed a structured approach. Each criterion was assessed as follows:

- **Technical Feasibility:** This criterion was evaluated based on the alignment between the identified factor and the core BIM capabilities outlined in *Chapter 2.2 (BIM), p. 22*. The rating reflected the degree to which existing BIM functionalities could address the specific challenge.
- **Impact:** The impact score is composed of two equally weighted components: (i) a qualitative rating based on expert judgment and (ii) a quantitative score derived from the frequency with which the factor appeared in the interviews.
- **Cost-Benefit:** This evaluation combined technical and financial considerations. High implementation costs associated with staff training or expensive software were weighed against the anticipated benefits, as highlighted in the interviews.
- **Plausibility:** Plausibility was assessed based on understanding EnBW's organisational practices, relationships with suppliers, and the general willingness to adopt digital solutions. Insights were drawn from interviews, project documentation, and the researcher's knowledge of EnBW's existing tools and processes.

In instances of conflicting information, the evaluation process prioritised insights from interviews over literature. Interviews were afforded greater significance as they mirrored EnBW's context-specific reality, whereas the literature offered a more general industry perspective that was not necessarily tailored to EnBW.

The rating procedure unfolded in several stages. First, each factor was evaluated on its own. After a preliminary set of ratings was formed, a comparative analysis followed. This revealed the factors with the lowest and highest ratings, establishing the ranges of the evaluation scale. Consequently, this facilitated a more standardised adjustment of the intermediate ratings, ensuring that the relative placement of all factors represented their true importance accurately.

The ratings underwent further refinement through a continuous process. Following the initial assessment, a comprehensive review was conducted, including bullet points that outlined the rationale for each rating within the MCDA matrix. Each score was re-evaluated, and necessary adjustments were made to ensure internal consistency across all criteria. A final review confirmed that the ratings were reasonable and aligned with the supporting evidence gathered from interviews and literature.

Certain factors, such as material shortages, price volatility, and limited manufacturing and installation capacity, posed specific challenges during the rating process. Although the theoretical application of BIM to these issues seemed feasible, quantifying the precise impact of BIM on mitigating such challenges proved difficult due to a lack of empirical data. In these instances, the ratings involved a degree of informed speculation, supported by the researcher's judgement and discussions with industry stakeholders. This highlights a known limitation of the current iteration of the framework: some ratings are necessarily tentative and would benefit from further validation through additional industry input in future applications.

The MCDA was conducted using Microsoft Excel to facilitate calculations, data visualisation, and documentation. The final weighted scores produced a ranked list of all 16 factors, prioritising them according to their relevance for BIM implementation in offshore wind projects; the outcome is depicted in Figure 5.1. This output serves as the basis for the subsequent evaluation and refinement of the SBPF-OW framework. The complete MCDA matrix is provided in *Appendix H (MCDA Matrices), p. 145*.

Ranking	Rating	Factor
1	4,45	Process and Coordination Challenges
2	4,21	Data Management
3	4,09	Technological Advancements and Innovation
4	3,97	Operational and Maintenance Costs
5	3,97	Logistical and Installation Challenges
6	3,35	Skill Shortages
7	3,23	Limited Manufacturing and Installation Capacity
8	3,10	Retention of Institutional Knowledge
9	2,98	Safety and Incident Reporting
10	2,73	High Capital Costs
11	2,73	Bureaucratic Complexity / Regulatory Challenges
12	2,61	Communication With Public
13	2,48	Environmental Challenges
14	2,11	Grid Connection and Energy Transmission
15	1,86	Material Shortages and Price Volatility
16	1,61	Challenging Market Analysis and Prediction

Figure 5.1: Ranked list of factors after the first iteration with weighted scores.

Evaluation

This subsection reflects on the first iteration of the framework development and evaluates the extent to which the objectives were fulfilled.

First Objective: The first objective focuses on creating a qualitative framework to assess BIM's applicability and potential benefits for addressing challenges in offshore wind projects. This objective was partially achieved. The rated factors provided a clear direction for identifying where BIM can be best applied, with data management and process coordination challenges emerging as the most relevant. However, the quality of the weighted scores remains questionable due to the high level of subjectivity in the ratings. Further refinement is required to enhance the reliability of the scores.

Filling in the justification for the scores was time-consuming, with 64 justifications required. To manage this workload, the justifications were broad and less grounded in literature and research than initially hoped. To address this, the number of factors will be reduced in the second iteration, focusing on the top five factors for a more detailed investigation.

Second Objective: The second objective involves applying the developed framework within the context of EnBW's operations and project environment to identify areas where BIM can create the most value. This objective was also partially achieved. The weighted and ranked factors aligned well with interview findings, with the highest scoring being data management and process coordination challenges. However, the analysis lacked practical insights, and developing more specific scenarios closer to real-life applications could improve the framework's relevance. Factors deemed less relevant to BIM adoption for EnBW will be excluded from the next iteration to streamline the process.

Key Outcomes:

- As expected, process coordination challenges and data management were identified as the primary factors for BIM implementation, reflecting both interview insights and general BIM research.
- Sensitivity analysis revealed that the framework is not overly sensitive to minor changes in the ratings, with the top five factors remaining consistent. Adjusting the weights may further refine the results and improve prioritization.

Summary and Next Steps: The next iteration will focus on fewer factors, emphasizing greater detail and specificity. Scenarios based on available software solutions and real-life challenges from EnBW will be introduced to make BIM's applicability more accessible and practical. The top five factors will be revisited, with adjusted weights and more focused ratings applied.

5.2.2 2. Iteration

Development

Following the first iteration, the framework was refined into a two-step evaluation process. The first step involved assessing all 16 factors using preliminary ratings to establish an initial ranking. The second step focused on the most promising factors by developing detailed BIM application scenarios as a basis for reassessment.

This adjustment aimed to improve the framework's practical relevance by ensuring that prioritization was based on concrete applications rather than theoretical considerations. The refined approach allowed for a more structured rating process while maintaining flexibility in addressing the challenges of offshore wind projects specific to stakeholder needs.

Demonstration

The demonstration phase began by revisiting the MCDA matrix from the first iteration. The process followed two distinct steps:

- The initial broad rating was reviewed, and the five highest-ranked factors were selected for further analysis.

- For these five factors, detailed BIM application scenarios were developed, demonstrating how BIM could be applied to address specific challenges. The scenarios were compiled through online research on existing software solutions and BIM applications in other areas of the AEC industry. This was further informed by revisiting the literature on BIM capabilities (*Chapter 2.2 (BIM), p. 22*) and BIM in offshore engineering (*Chapter 2.3 (Literature Review on BIM and Offshore Engineering), p. 31*). The resulting scenarios were documented in detailed descriptions and visual representations, focusing on the practical applicability of BIM to specific offshore wind challenges. *Appendix I (Creation Scenarios 2.Iteration), p. 181* gives an example of these detailed scenarios.

The MCDA ratings were revised using these refined scenarios to provide a more practical assessment. This second iteration of the matrix, which incorporates scenario-based justifications, is included in *Appendix H (MCDA Matrices), p. 145*. The second MCDA builds upon the first iteration and features explanations for why the rating was altered (or remained unchanged) based on the additional research outlined previously. The weights have also been slightly adjusted upon review, with explanations in the same appendix. Unlike the first iteration, the second MCDA does not include the occurrence of qualitative codes in the scoring process. This adjustment was made to avoid overemphasising frequently mentioned factors, which may reflect respondent bias or differences in interview scope rather than actual project relevance. By excluding code occurrence, the second iteration focuses more on the factors' substantive relevance and practical impact, ensuring that the evaluation reflects a balanced and scenario-driven analysis rather than simply the frequency of mentions.

Evaluation

The second iteration resulted in a more refined prioritization of factors and a clearer understanding of BIM's applicability to EnBW's offshore wind projects. The key improvements over the first iteration included:

- More substantiated ratings, as they were now based on defined BIM application scenarios rather than abstract assessments.
- A structured assessment of how BIM could be effectively implemented in EnBW's specific operational and project environment.

Despite these improvements, the evaluation remained limited by the subjectivity of the scoring process. Since the ratings were still based on the researcher's judgment, further validation was necessary to enhance the credibility and robustness of the findings.

Next Steps: To address the subjectivity of the assessment, the next iteration introduced an external validation step. The refined framework retained the two-step evaluation process from this iteration but incorporated a focus group with EnBW experts. The goal was to present the second iteration's findings, validate the scoring methodology, and refine the final prioritization based on expert input.

5.2.3 3. Iteration

Development

Building on the refinements of the second iteration, the framework was expanded into a three-step evaluation process. The first two steps, consisting of an initial broad rating followed by a refined assessment based on detailed BIM application scenarios, remained unchanged. The third step introduced an expert focus group to validate the framework's structure, factor prioritization, and overall methodology.

This iteration aimed to enhance the framework's general applicability by incorporating external validation from industry professionals. By engaging domain experts, the framework moved beyond theoretical assessments and researcher-driven justifications, ensuring that the evaluation approach and prioritization of BIM applications aligned with real-world project conditions and industry expectations.

The focus group method, detailed in *Chapter 5.3 (Focus Group), p. 86*, was chosen to provide qualitative insights on the framework's structure, particularly regarding the feasibility and scalability of BIM adoption across offshore wind projects. This step reinforced the methodology by capturing stakeholder perspectives, validating key assumptions, and identifying areas where refinements were necessary.

Demonstration

The three-step process was executed as follows:

- The initial broad rating was conducted using the MCDA matrix from the second iteration.
- The top five factors were reassessed, integrating scenario-based justifications for improved accuracy.
- The focus group reviewed the refined ratings, discussing the feasibility and practical relevance of BIM applications at EnBW.

During the discussion, participants validated the selection of factors, confirming that they represented the most pressing areas where BIM could be applied. The consensus was that BIM could offer substantial benefits, particularly in data management, process coordination, and O&M. However, the focus group also highlighted a key limitation in the framework's current approach:

> "The MCDA fractures the BIM application over individual factors, but many of these factors are interconnected. Centralized data management would benefit not just O&M, but also collaboration, certification, and lessons learned." (Focus Group, Speaker 3)

This feedback underscored the need to consider BIM's broader impact across multiple project areas rather than viewing its benefits separately for each factor.

The final MCDA rankings, adjusted based on focus group feedback, are included in *Appendix H (MCDA Matrices), p. 145*. The outcomes of this iteration provide a structured assessment of where BIM can be most effectively applied at EnBW.

Evaluation

The third iteration addressed the limitations of the previous iterations by incorporating stakeholder validation into the rating process. The focus group discussion reinforced the credibility of the MCDA rankings and provided practical insights into how BIM should be implemented. Key takeaways included:

- The focus group confirmed that BIM should be prioritized in data management, O&M, and process coordination, validating the weightings assigned in the previous iteration.
- The need for a more integrated perspective was emphasized, as BIM benefits multiple factors simultaneously, requiring an approach that accounts for its broader impact.
- While the impact and technical feasibility were widely accepted, the focus group stressed that plausibility should be weighted more heavily, as implementation challenges vary significantly across different project phases.
- Cost-effectiveness remains a concern, particularly regarding resource constraints and the personnel required for BIM adoption.

5.2.4 Outcome Framework Development

MCDA Outcomes and Factor Rating Development

Throughout the three implementations of the MCDA, the ratings for the top five prioritized factors—Data Management, Process and Coordination Challenges, Operational and Maintenance Costs, Technological Advancements and Innovation, and Logistical and Installation Challenges—underwent notable refinements. These adjustments reflect the increasing depth of analysis, the integration of scenario-based evaluations, and the incorporation of practitioner validation during the focus group.

O&M emerged as the highest-priority factor in the final iteration, with its rating increasing from 3.97 to 4.8 and ultimately to 5.0. This steady upward adjustment reflects the growing recognition of BIM's potential to enhance O&M efficiency, mainly through improved access to accurate as-built data and digitalized maintenance processes. The focus group confirmed that BIM could significantly reduce operational downtime, facilitate predictive maintenance, and enhance overall lifecycle performance, solidifying O&M as the most critical area for BIM application in offshore wind projects.

Data Management was consistently rated as a high-priority factor across all iterations (4.21 – 4.8 – 4.5), reflecting broad agreement on its importance for improving project success. Data fragmentation and document-heavy processes were repeatedly highlighted as key pain points during interviews and the focus group. Although O&M overtook Data Management as the top factor in the final ranking, Data Management remains foundational, as a well-structured data environment is seen as the backbone enabling all other BIM applications, including O&M improvements.

Process and Coordination Challenges started with a strong rating (4.45) but declined slightly in the second (4.3) and further in the third iteration (3.9). This reflected a more cautious stance from the focus group, who acknowledged BIM's potential to improve collaboration but stressed that existing organizational silos and interface challenges at EnBW would complicate implementation. Concerns about the cultural shift needed for cross-departmental data-sharing led to a lower plausibility rating, ultimately reducing its priority compared to O&M and Data Management.

Technological Advancements and Innovation saw its rating decrease from 4.09 to 3.7 in the second iteration, before rebounding slightly to 4.0 in the third. The initial drop resulted from skepticism about EnBW's readiness to implement cutting-edge digital solutions. At the same time, the partial recovery in the final iteration stemmed from the focus group recognizing that BIM adoption could act as a catalyst for future innovations. Innovation was ultimately viewed as a secondary benefit dependent on establishing robust data management processes.

Logistical and Installation Challenges experienced the most significant decline (3.97 – 3.6 – 2.8). While initially viewed as an area where BIM might enhance planning and reduce installation risks, subsequent evaluations—particularly the focus group—revealed a more nuanced reality. These challenges were increasingly seen outside EnBW's core sphere of influence, primarily managed by contractors responsible for transportation, installation, and vessel logistics. Factors like supply chain constraints, vessel availability, and port capacity were identified as external dependencies where BIM's direct value to EnBW would be limited. As a result, this factor was ultimately assigned the lowest priority in the final evaluation, with the consensus being that BIM's most significant potential lies in areas more closely tied to EnBW's internal processes and lifecycle management responsibilities.

The progression of these ratings across the three MCDAs is visualized in Figure 5.2, illustrating the increasing priority of O&M, the sustained importance of Data Management, and the diminishing relevance of Logistical and Installation Challenges.

Overall, the evolution of the ratings underscores a growing convergence between theoretical expectations and practical feasibility, with O&M and Data Management emerging as the two primary areas where BIM can unlock significant value. Notably, the final evaluation emphasized that these two factors are closely interlinked—effective data management is seen as a prerequisite for maximizing BIM's benefits in O&M and other project phases.

Final Statement on BIM Implementation at EnBW:

Applying the Strategic BIM Prioritisation Framework to EnBW's offshore wind projects underscores the necessity for BIM-enabled data management to supplant the existing document-centric approach, thereby unlocking the full potential of digital workflows. A consistent, structured, and centralised BIM-based data environment should be the foundation for all other applications, ensuring seamless access to project information, minimising inefficiencies, and facilitating automation.

By shifting from document-based practices to a data-driven BIM ecosystem, EnBW can enhance operations and maintenance (O&M), streamline project execution, and improve adaptability to technological innovations. A well-structured BIM data model would enable real-time updates, reducing reliance on scattered files and manual input. This transition is not solely about improving

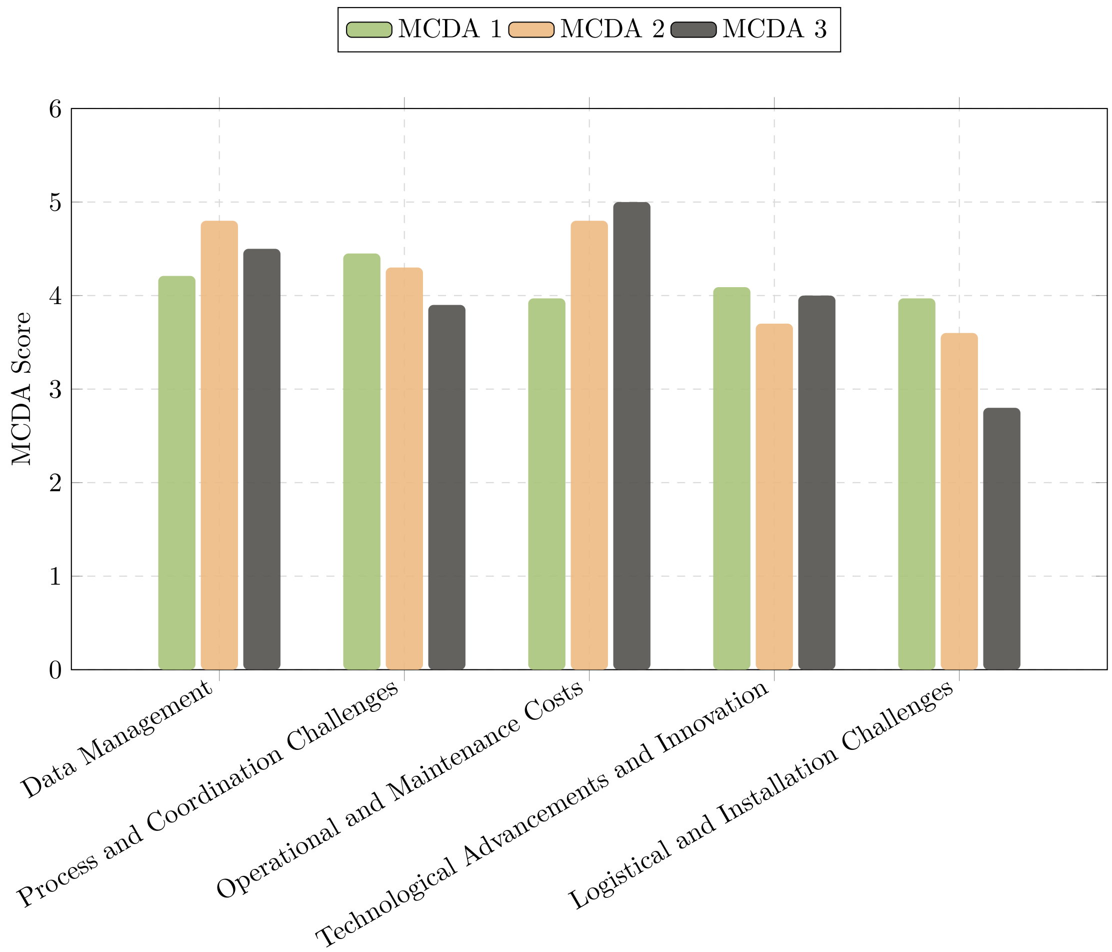


Figure 5.2: Comparison of MCDA Scores for Key Challenges in Offshore Wind Projects

data accessibility—it is about facilitating smarter, automated, and integrated processes that support predictive maintenance, resource optimisation, risk mitigation, and continuous innovation.

However, successfully adopting BIM-based data management requires more than mere technical implementation—it necessitates a cultural shift within the organisation. Employees must transition from document-driven workflows like those in Think Project to a more dynamic and structured approach. The next step should involve evaluating existing software solutions and engaging with software developers to identify the most user-friendly, automated, intuitive, and flexible system that enhances efficiency and makes working with BIM enjoyable and engaging.

Beyond software selection, change management and cultural adaptation must be integral to this transition. A clear adoption strategy should be developed, focusing on training, user support, and phased implementation to ease the shift from traditional practices. Employees need to see tangible benefits in their daily work, ensuring that the new system is not perceived as an additional burden but as an empowering tool. The next phase should therefore focus on designing an implementation roadmap, combining technological evaluation, software selection, and organizational change management to ensure a smooth and sustainable transition towards a BIM-driven future for EnBW's offshore wind operations.

Future Considerations:

The framework provides a structured approach to evaluating BIM use cases and their general applicability in offshore wind projects. It offers a solid foundation for decision-making on BIM adoption and ensures its implementation is based on clear priorities. However, while the framework identifies where BIM creates value, it does not assess the combined impact of BIM's capabilities across project phases or how they influence business strategy. The focus remains on individual factors rather than an integrated perspective on BIM's full potential.

This highlights the next step: developing a methodology to determine the best-combined value of BIM applications and creating a roadmap for their adoption based on industry needs. While this is beyond the scope of this thesis, further testing with other industry players will be essential to assess the framework's scalability and refine its application.

5.3 Focus Group

5.3.1 Introduction

A focus group discussion was conducted to refine and validate the framework as part of the iterative evaluation of the Strategic BIM Prioritization Framework for Offshore Wind Projects (SBPF-OW). The session gathered expert insights on BIM's applicability in offshore wind and its potential impact on EnBW's operations, particularly in data management and O&M.

5.3.2 Participants and Setup

The focus group was conducted with professionals from EnBW who have extensive experience across the entire offshore wind project lifecycle. The participants were personally invited via email in collaboration with the EnBW supervisor, ensuring they had relevant expertise and prior involvement in the research process. The selection criteria focused on professionals with at least 10 years of experience in offshore wind, familiarity with various project phases (from development to operation and maintenance), and a balance between senior management and hands-on project involvement. The intent was to capture holistic perspectives on BIM's potential in offshore wind projects.

Participant Profiles

The focus group was designed to include four participants from EnBW, carefully selected to represent different areas of expertise across the offshore wind project lifecycle. Regrettably, the group was limited to just three participants because of illness. The participants were:

- **Expert 1 (Project Development & Engineering):** Head of Offshore Wind Farm Engineering, responsible for preparing bids for new offshore wind projects and planning their implementation after successful auction.
- **Expert 2 (Construction):** Construction Manager for He Dreiht, with experience coordinating offshore wind construction activities, including foundation, cable, and turbine installations.
- **Expert 3 (Operations & Maintenance):** A manager in Wind Offshore Operations who plays a key role in developing a digital twin for O&M at EnBW. Expert 3 was approached instead of the initially chosen O&M specialist who participated in the interviews.

These participants represented various disciplines, covering digital transformation, project development, construction execution, and operational management, ensuring that insights were gathered across the entire offshore wind lifecycle. Their prior exposure to BIM varied: while some had limited direct experience, others had interacted with BIM in experimental settings, such as research test tunnels or through contractors utilizing BIM-based simulations.

Focus Group Structure & Content Development

The session was designed to refine and validate the Strategic BIM Prioritization Framework for Offshore Wind Projects (SBPF-OW), with a specific focus on:

- Assessing the practicality and usefulness of the developed BIM scenarios for offshore wind applications.
- Evaluating the ranking of key factors using the MCDA approach and obtaining participant feedback on the factor prioritization and weight distribution.

- Understanding expert perspectives on BIM's feasibility and adoption challenges within EnBW.

Since BIM knowledge varied among participants, the session began with a structured BIM introduction, ensuring all experts had a shared foundational understanding before moving into the discussion. The focus group was semi-structured, with predefined topics but open-ended talks. The five BIM application scenarios were presented sequentially, followed by guided questions to steer the conversation. Once all scenarios were discussed, a general open discussion was held to reflect on the overall feasibility of BIM in EnBW's offshore wind operations.

Data Collection & Analysis

The session was audio-recorded, transcribed, and translated from German to English for analysis. Additional notes were taken during the discussion to capture key observations. While there was no formal coding process, responses were systematically analyzed for each factor and integrated into the outcome of the DSRM framework development. This analysis directly informed the final iteration of the SBPF-OW framework, refining the criteria weighting and practical considerations for BIM implementation in offshore wind projects.

5.3.3 Key Findings and Insights

BIM Awareness and Initial Perception

Before the session, BIM was largely unfamiliar to the participants, except for one individual who had encountered it two decades ago in an experimental context on a complex research infrastructure project. However, after the introduction of BIM, participants demonstrated a solid understanding of its principles, with several drawing parallels to digital twin technology, which was more widely recognized. One participant had even been involved in digital twin development for O&M applications.

Validation of BIM Application Scenarios

The third section of the focus group focused on presenting real-world BIM applications for EnBW's offshore wind projects. These scenarios were illustrated using existing software solutions, including tools currently in use at He Dreiht. Key considerations included:

- The necessity of a cultural shift to encourage adoption, particularly regarding discipline in maintaining an updated data environment.
- Ease of use as a critical factor: Adoption will be low if a system increases workload rather than reducing it.
- Positive reception of visual navigation through 3D models for document retrieval and interaction with project data.

Data Management as the Central Theme

A recurring theme in the discussion was the necessity of a centralized data repository—a single source of truth that integrates structured data and facilitates streamlined access to critical project information. Participants repeatedly pointed to the inefficiencies in current document management systems and difficulty retrieving relevant information when needed. As one participant noted,

> "We have endless amounts of data and documents, but the challenge is locating what you need when you need it." (Focus Group, Expert 3)

This difficulty is compounded by inconsistent storage conventions and the varying interpretations of where specific documents should reside. A participant explained:

> "You need to decide in advance which documents belong in which category. There are different opinions with some documents—one person might think it belongs in one folder, while another thinks it belongs elsewhere." (Focus Group, Expert 2)

To address these issues, several solutions were discussed, including AI-powered categorization tools and dropdown menus to ensure consistent document classification. This was necessary to prevent ambiguities and reduce inefficiencies in searching for information.

Another major concern was access rights management, particularly the difficulty of modifying permissions once large volumes of data have already been uploaded. One participant explained:

> "During the project, we suddenly realized we needed to restrict access to about half of the documents. But once you have uploaded hundreds of thousands of documents, making retroactive changes to permissions is nearly impossible." (Focus Group, Expert 2)

This highlighted the importance of flexible access control mechanisms that allow for bulk modifications and adaptable permission structures to accommodate the dynamic nature of offshore wind projects.

A particularly compelling use case for BIM in operations and maintenance was raised—integrating BIM with inventory management systems to streamline procurement processes. The envisioned workflow would enable maintenance personnel to interact with a digital model, select a component, verify its availability in storage, and, if necessary, trigger an automated reorder. One participant outlined the potential efficiency gains:

> "If you need a specific component, the system could check whether it's in stock. If it isn't, you could directly place an order based on the specifications already stored in the system. That way, you wouldn't need to enter specifications like size or material manually—it would all be prefilled, reducing errors and streamlining the process." (Focus Group, Expert 3)

Beyond procurement, the ability to visually navigate and interact with the BIM model as an intuitive interface for data retrieval was widely regarded as beneficial. This approach was seen as particularly valuable in minimizing human error and improving documentation accessibility:

> "Looking at what you're showing here, it would be great if I could just click on a turbine or a rotor blade and automatically access all related data and documents." (Focus Group, Expert 1)

Ultimately, the discussion underscored that BIM's most significant potential lies in its ability to centralize, structure, and simplify data access, transforming fragmented and document-heavy workflows into an integrated and intuitive system. However, participants also cautioned that its success hinges on ensuring ease of use and demonstrating clear benefits to end users, as one participant emphasized:

> "People need to see the direct benefit. If a system makes their work harder instead of easier, they won't use it." (Focus Group, Expert 3)

Existing Digitalization Efforts and BIM's Role

Participants highlighted that contractors already use BIM-based simulations for lifting operations and installation planning. EnBW also employs VR and AR for safety training, site inspections, and drone-based monitoring. One participant noted,

> "At Vestas, this is a standard application. They didn't just use BIM for collision checks but also for simulating workflows in advance." (Focus Group, Expert 1)

BIM was seen as a way to unify these digital efforts, integrating real-time operational data into a structured model rather than using isolated tools. Another participant emphasized the value of simulation-driven planning, stating,

> "Herema used a simulator to run through the entire foundation installation process before the crane operator even stepped onto the vessel. In my opinion, this was highly beneficial." (Focus Group, Expert 1)

Additionally, EnBW itself actively employs VR and AR for:

- Safety training and operational simulations.
- Digital site inspections, replacing traditional in-person safety walkthroughs.
- Experimental use of drones for data collection and monitoring.

BIM was seen as a potential enabler that could unify these efforts, ensuring that real-time operational data is seamlessly integrated into a structured model.

Refinements to the SBPF-OW Framework

The focus group validated the selected factors and BIM application scenarios but emphasized key refinements to improve the framework's practicality. One significant adjustment was increasing the weight of plausibility, as participants stressed that real-world implementation challenges—such as organizational resistance and workflow integration—are critical to BIM adoption. While impact and technical feasibility remained central, greater emphasis was placed on evaluating whether BIM solutions could realistically be implemented within EnBW's existing structures.

Resource constraints, mainly cost and personnel availability, were also highlighted. While financial feasibility was already considered, the focus group noted that procedural and cultural barriers often outweigh cost concerns. Demonstrating tangible short-term benefits was key to justifying investment and overcoming resistance.

Several factor ratings were refined based on these discussions. Logistical and installation challenges were deprioritized, as these are mainly contractor-driven and beyond EnBW's control. Technological advancements and innovation saw a slight feasibility reduction due to concerns about added complexity and cost. Conversely, operational and maintenance costs were reinforced as a high-priority factor, with participants emphasizing BIM's role in predictive maintenance and asset management. Process and coordination challenges were adjusted downward due to scepticism about overcoming entrenched organizational barriers. However, data management remained a top priority, as persistent data consistency and classification issues hinder seamless information exchange despite existing digitalization efforts.

These refinements have been incorporated into the updated MCDA, ensuring a more balanced evaluation of BIM's applicability by integrating technical feasibility and practical implementation challenges. The revised MCDA ratings and weight adjustments reflecting these refinements can be found in *Appendix H (MCDA Matrices), p. 145.*

5.3.4 Conclusion

The focus group reinforced BIM's potential in offshore wind, particularly for O&M and data management, while emphasizing that its success depends on practical implementation strategies. Participants did not question BIM's relevance but instead focused on how to ensure effective adoption. The discussion underscored that BIM's most significant value lies in structured data integration, making data accessibility, usability, and maintainability critical for success. These insights directly inform the refinement of the MCDA matrix and the next iteration of the SBPF-OW framework.

5.4 Final Artefact: Strategic BIM Prioritization Framework for Offshore Wind Projects (SBPF-OW)

The DSRM result is the Strategic BIM Prioritization Framework for Offshore Wind Projects (SBPF-OW), a decision-making tool designed to systematically assess and prioritize the application of IMBIM in offshore wind projects. This artefact synthesizes insights from literature, interviews, and focus group discussions to address the critical challenges identified throughout this research. Its dual purpose is to provide actionable guidance for stakeholders while contributing to the academic understanding of BIM's potential role in the offshore wind sector. The framework is depicted in Figure 5.3.

5.4.1 Framework Structure and Components

The SBPF-OW framework consists of two integrated components: the Static Framework and the Dynamic Application Process. These components work together to identify and prioritize key challenges, map BIM capabilities to those challenges, and evaluate BIM's feasibility and impact.

Static Framework: MCDA Matrix

The static framework is represented by a Multi-Criteria Decision Analysis (MCDA) matrix, which evaluates challenges based on pre-defined criteria:

- **Technical Feasibility**: The practicality of implementing BIM to address a specific challenge.
- **Impact**: The significance of the improvement BIM can offer to project outcomes.
- **Cost-Effectiveness**: The balance between investment and the anticipated benefits of BIM.
- **Plausibility**: The likelihood of successful implementation within the constraints of the offshore wind environment.

These criteria are weighted and scored to create a ranked list of challenges, highlighting areas where BIM has the highest potential to deliver value. This ranking ensures that resources are focused on addressing the most critical issues.

Dynamic Application Process

The dynamic process operationalizes the static framework, enabling iterative refinement and practical application. Key steps include:

1. **Criteria Weighting and Scoring**: Stakeholders assign weights to criteria and score challenges based on their relevance and importance.
2. **Challenge Prioritization and BIM Mapping**: Challenges are mapped to BIM functionalities, identifying potential applications such as enhanced data visualization, digital twins, or lifecycle management.
3. **Scenario Development**: High-level scenarios are created to outline how BIM can address prioritized challenges, including the required tools, processes, and expected outcomes.
4. **Iterative Refinement**: Feedback from stakeholders is incorporated to adjust and improve the framework, ensuring its adaptability to specific project needs.

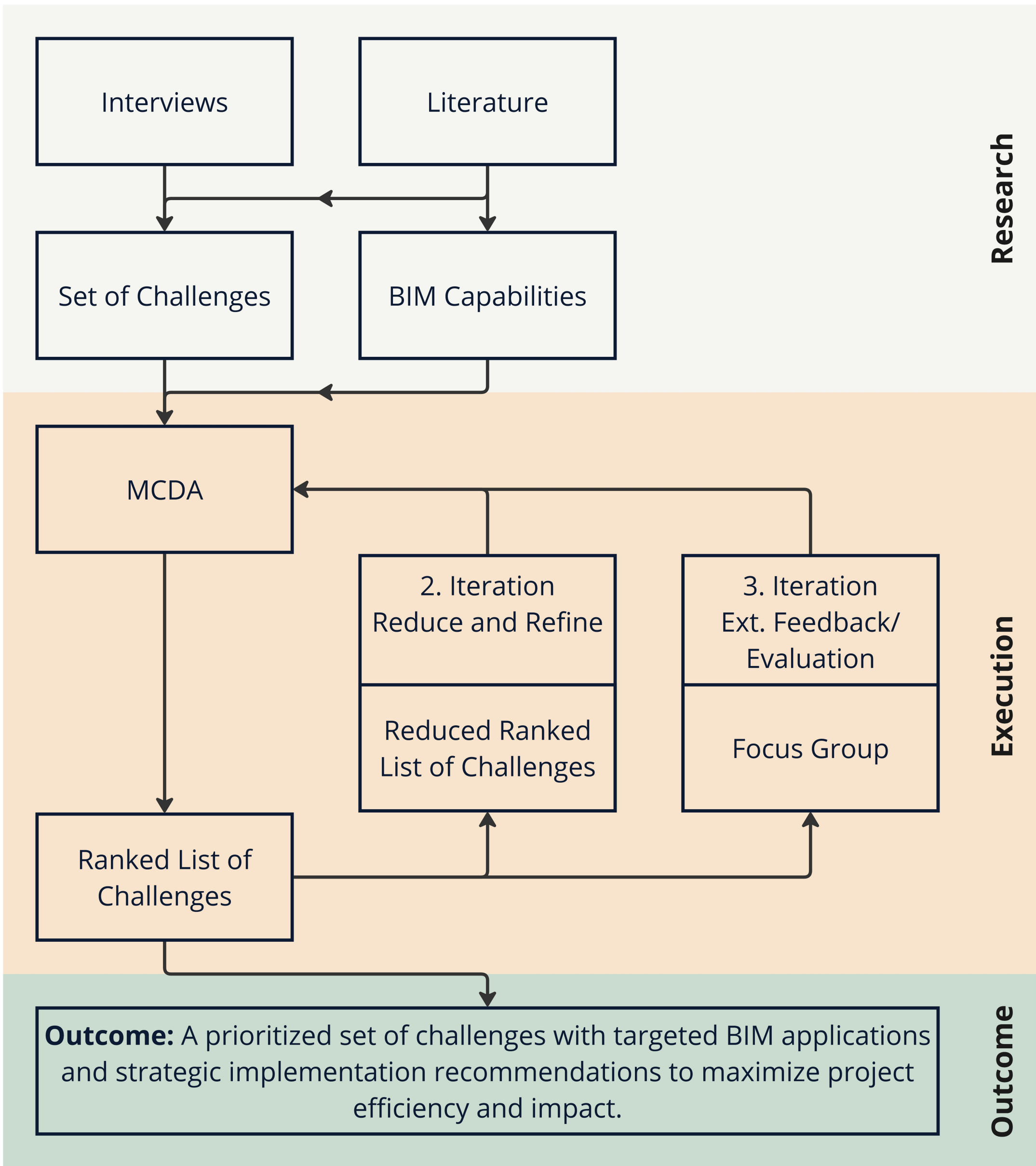


Figure 5.3: Final Framework

6. Discussion

The discussion chapter critically reflects on the findings of this study, assessing the viability of BIM for offshore wind projects and its potential impact on industry practices. This chapter synthesizes insights from the literature review, semi-structured interviews, and the focus group to evaluate whether BIM provides a viable solution for offshore wind project challenges.

The analysis is structured into four key sections. First, the study's findings are interpreted to determine how BIM addresses challenges in offshore wind development, particularly in the case of EnBW. Second, the Strategic BIM Prioritization Framework for Offshore Wind Projects (SBPF-OW) is critically assessed to examine its effectiveness in evaluating BIM applications, strengths, and areas for refinement. Third, the broader implications of BIM adoption for the offshore wind industry include how digitalization, cultural shifts, and changing stakeholder dynamics influence BIM implementation. Finally, the chapter acknowledges the limitations of this study and outlines directions for future research to validate and enhance the framework.

This discussion ultimately aims to answer the research question: To what extent can BIM be effectively implemented in offshore wind construction projects to overcome existing challenges and enhance project success? The chapter comprehensively assesses BIM's role in offshore wind and its future trajectory by integrating theoretical and empirical findings.

6.1 Interpreting Key Findings

6.1.1 BIM's Role in Offshore Wind Project Execution

Applying the Strategic BIM Prioritization Framework for Offshore Wind Projects (SBPF-OW) at EnBW has provided valuable insights into the potential and limitations of BIM adoption in offshore wind. The findings suggest that BIM is well-suited to addressing key operational challenges, particularly in data management, operations and maintenance (O&M), and cross-phase collaboration. While EnBW has not implemented a fully centralized BIM solution, elements of BIM—including digital twins, workflow simulations, and safety training applications—have already been integrated into offshore wind processes. These existing use cases underscore a latent readiness for BIM adoption within the sector.

However, fragmentation remains a core issue. Offshore wind projects operate across multiple stakeholders, each using disparate digital tools, leading to data silos, inefficiencies, and limited interoperability. EnBW's efforts to improve data accessibility through a Common Data Environment (CDE) demonstrate a partial solution. Still, the study highlights that a more structured and holistic BIM implementation could yield more significant benefits. These findings confirm that BIM has a strong theoretical foundation in offshore wind, but its practical success depends on addressing industry-wide digital integration challenges. Many of the issues identified at EnBW—such as unstructured data handovers, limited standardization, and reliance on document-based workflows—likely reflect the broader offshore wind industry.

6.1.2 Key Insights from the SBPF-OW Framework

The SBPF-OW framework played a critical role in evaluating BIM's applicability at EnBW. Utilizing a multi-criteria decision analysis (MCDA) approach, the framework systematically prioritises BIM use cases, balancing technical feasibility, impact, cost-effectiveness, and plausibility factors. The results demonstrated that BIM's most substantial contributions lie in enhancing data continuity across lifecycle phases, reducing inefficiencies in handovers, optimizing O&M workflows through improved asset information management, and supporting simulation-driven decision-making, particularly in construction and risk management.

Despite these strengths, the structured evaluation method also introduced some limitations. The framework's factor-based approach tended to separate BIM functionalities into discrete categories rather than fully capturing its ability to integrate processes across different project stages. For example, the framework's prioritization method did not fully represent BIM's potential to seamlessly link design, construction, and maintenance data. While effective in structuring the assessment, this segmentation may not fully reflect the interconnected nature of BIM's benefits when implemented across an entire project lifecycle.

The findings suggest that while the SBPF-OW framework is practical for structured evaluation, future iterations should consider a more holistic assessment of BIM's integrated benefits rather than isolating individual factors. Additionally, validating the framework across multiple stakeholders and project settings would strengthen its robustness and generalizability beyond EnBW.

6.1.3 Understanding BIM's Broader Industry Relevance

While this study focuses on EnBW's specific case, the findings suggest that BIM's applicability extends to the broader offshore wind sector. EnBW's challenges—fragmented data management, inefficient workflows, and inconsistent information handovers—are standard across offshore wind projects. The reliance on document-based workflows rather than structured, data-driven processes remains a significant constraint to efficiency and interoperability across stakeholders.

BIM's value proposition varies across lifecycle phases. Early-stage project development enhances planning accuracy and design coordination through visualization and clash detection. It enables workflow optimization, real-time coordination, and improved scheduling during construction, reducing interface clashes and delays. In O&M, BIM provides a structured data repository for predictive maintenance and asset management, preventing data loss over time and ensuring that crucial information is carried forward from earlier phases.

Despite these benefits, widespread BIM adoption requires a shift from fragmented digital tools toward integrated workflows. Offshore wind relies largely on unstructured data systems, and industry-wide standardization remains weak. This structural incompatibility with centralized digital workflows is a fundamental barrier to BIM's large-scale implementation. However, the findings suggest that this digital transition is already happening incrementally, as demonstrated by the increasing use of digital twins for real-time monitoring, the adoption of BIM-based simulations in construction planning, and the implementation of CDEs to improve data access. While these developments indicate a growing shift toward data-driven workflows, they remain largely isolated and uncoordinated across different stakeholders.

The industry must now determine how to bridge the gap between existing digital tools and a truly integrated BIM workflow. The study highlights that although offshore wind stakeholders recognize the benefits of BIM, its adoption remains uneven and largely dependent on individual project needs rather than a unified industry-wide approach.

6.1.4 Bridging the Research Gap: BIM's Lifecycle-Wide Potential

While BIM's benefits for individual offshore wind stakeholders have been explored in prior research, most studies have focused on specific applications, such as installation planning, digital twins, or O&M workflows. However, these fragmented assessments fail to capture BIM's full potential across the offshore wind project lifecycle. The existing research landscape has not yet provided a comprehensive understanding of how BIM can function as an integrated tool across all phases of offshore wind development, construction, and operations.

This study addresses this gap by developing a structured prioritization framework tailored to offshore wind. By integrating MCDA methods with industry expert insights, this research moves beyond theoretical discussions and provides a decision-support tool for targeted BIM implementation. Unlike prior studies that examined isolated use cases, this study offers a structured, phase-specific approach to assessing BIM's feasibility, prioritizing implementation areas, and strategically guiding decision-makers in evaluating BIM adoption.

The findings emphasize that BIM's full value cannot be realized through piecemeal adoption alone. Instead, offshore wind projects require a structured implementation strategy that aligns with specific industry needs while ensuring cross-phase data continuity. The SBPF-OW framework provides a foundation for structured evaluation. Still, future work should explore how different industry stakeholders—developers, contractors, suppliers, and regulators—can collaboratively implement BIM to ensure more seamless data integration and workflow standardization.

6.2 Limitations of the Study

While this study provides valuable insights into the applicability of BIM in offshore wind projects, several methodological limitations must be acknowledged, as they affect the generalizability and scope of the findings.

One key limitation is the reliance on a single stakeholder, EnBW, for primary data collection. The research framework, interviews, and focus groups were all conducted within EnBW's operational environment. While EnBW faces common challenges across the offshore wind industry and operates from a central position within the industry, interacting with most other stakeholders directly, different developers, contractors, and suppliers may have distinct workflows, digital strategies, and priorities. This means that while the framework developed in this study is applicable within EnBW, its adaptability to other industry players remains untested.

Another limitation stems from the subjectivity inherent in the MCDA process. Despite efforts to systematically evaluate factors influencing BIM adoption, the scoring process ultimately depended on the researcher's interpretation, supplemented by interview and focus group insights. While the focus group helped refine the factor prioritization, some subjectivity remains, particularly in assigning numerical values to qualitative assessments. This subjectivity affects the precision of the rankings and highlights the need for further validation through broader expert input.

Additionally, the study's limited real-world validation constrains its applicability. While the framework offers a structured approach to assessing BIM's potential, it was not tested through actual BIM implementation within an offshore wind project. The findings are based on expert discussions and theoretical evaluations rather than empirical performance data from ongoing or completed projects. As a result, the study provides strong indications of BIM's relevance but does not provide conclusive evidence of its long-term impact in practice.

A further limitation is the fragmentation of BIM capabilities across different factors. The MCDA framework evaluates BIM applications by ranking individual factors, yet BIM's real-world benefits often arise from its integrated use across multiple areas. For instance, centralized data management not only improves O&M processes but also enhances collaboration and compliance documentation. The factor-based evaluation method does not fully capture the synergies of combined BIM capabilities, meaning that the total benefit of BIM adoption may be greater than the sum of its individually assessed parts.

Despite these limitations, the study successfully demonstrates the viability of BIM for addressing critical offshore wind challenges, particularly for EnBW. However, future research should focus on validating the framework across multiple industry stakeholders, refining the MCDA methodology, and testing BIM applications in real project environments to provide a more comprehensive understanding of its effectiveness.

6.3 Future Research Directions

6.3.1 Implications for EnBW and Future Implementation

The findings of this study indicate that while BIM is highly relevant for EnBW's offshore wind operations, its effective implementation requires addressing both technical and organizational challenges. EnBW's current approach to digital workflows, including the use of a Common Data Environment (CDE), has demonstrated partial success in improving collaboration and data accessibility. However, the absence of a fully integrated and interactive BIM system limits the potential benefits. Future research should focus on defining a phased BIM implementation roadmap tailored to EnBW's specific project structure and operational requirements. Key aspects include identifying optimal software solutions, ensuring interoperability with existing workflows, and developing training programs to facilitate adoption. Additionally, research should explore strategies for overcoming organizational resistance to transitioning from document-heavy workflows to fully data-driven BIM environments.

Beyond internal implementation, further investigation is required into how BIM can enhance EnBW's interactions with contractors and suppliers. Offshore wind project execution involves multiple stakeholders, many of whom operate in siloed digital environments with varying degrees of BIM maturity. A structured strategy for enforcing standardized BIM requirements in supplier contracts, particularly regarding data exchange formats such as IFC, could improve project efficiency and reduce miscommunication-related risks. Future research should examine the feasibility of such an approach and assess how BIM's integration into EnBW's broader supply chain could streamline data exchange and decision-making.

A crucial next step for EnBW is conducting a cost-benefit analysis of BIM adoption over the short, mid, and long term, evaluating its financial impact across different project phases. This would provide quantitative insights into the return on investment and help guide decision-making regarding the depth and scale of BIM integration. Additionally, EnBW should initiate the development of a prototype for a central data management system, designed with a primary focus on usability in the operations and maintenance (O&M) phase. However, for such a system to be effective, it must be actively used and populated with relevant data throughout the entire project lifecycle. The needs and functional requirements for this prototype can be derived from the findings of this thesis, particularly the insights gained from interviews and the focus group discussions. As a first step, EnBW should conduct targeted workshops and further interviews to refine the specific requirements of such a system, ensuring alignment with operational workflows. Testing and iterative refinement will be necessary to optimize usability, functionality, and integration into EnBW's broader digital infrastructure. Further research should also explore whether an existing software solution could be adapted to meet these needs or whether a tailored, purpose-built solution is required for optimal implementation.

6.3.2 Implications for the BIM Evaluation Framework

The framework developed in this study provides a structured approach to evaluating BIM's applicability in offshore wind projects. However, its current iteration remains focused on assessing individual factors rather than BIM's combined impact across multiple domains. This fragmented perspective limits the ability to capture the full scope of BIM's transformative potential, as interactions between different BIM-enabled processes are not fully accounted for. Future research should explore methodologies for assessing BIM more holistically, incorporating cross-functional dependencies and lifecycle-wide applications.

A critical next step is expanding the framework's validation by engaging a broader range of industry stakeholders, including contractors, suppliers, regulatory bodies, and policymakers. While the current study primarily focuses on the perspective of a project developer, assessing BIM's relevance and applicability from the standpoint of different actors in the offshore wind value chain will provide a more comprehensive evaluation. This broader testing will help refine the framework's adaptability and ensure its applicability across diverse organizational structures and project settings.

Additionally, incorporating quantitative data into the framework could enhance its decision-making utility. Future research should explore using structured surveys and questionnaires to collect data on stakeholder needs, financial considerations, and perceived benefits of BIM implementation. Capturing cost-benefit metrics in monetary terms would provide more substantial evidence for BIM's economic impact, supporting more data-driven investment decisions. Integrating these quantitative elements would improve the framework's robustness and facilitate more precise comparisons between different levels of BIM adoption.

6.3.3 Broader Implications for the Offshore Wind Industry

While this study has primarily focused on EnBW's perspective, the findings indicate that BIM's potential extends beyond a single organization. Many of the challenges identified—fragmented data management, inefficient collaboration, and difficulties in maintaining structured project information over the wind farm lifecycle—are industry-wide issues. Like much of the construction and energy sectors, offshore wind projects continue to rely on document-based workflows rather than structured, data-driven processes, which contributes to inefficiencies and lack of interoperability across stakeholders.

A key implication for the broader industry is the need for a unified, standardized approach to BIM adoption that extends beyond individual project developers. The offshore wind sector involves multiple entities—including project developers, contractors, equipment manufacturers, and regulatory bodies—all must interact seamlessly for projects to succeed. Research should explore how cross-industry BIM standardization, mainly through initiatives like buildingSMART's ongoing development of IFC extensions, could enhance interoperability and efficiency.

Integrating BIM with emerging technologies such as AI, IoT, and digital twins could enable a more connected and predictive project management approach. AI, in particular, plays a critical role in transitioning from document-based workflows to data-driven BIM environments by automating data input, reducing manual efforts, and improving model accuracy. AI-driven tools can assist in extracting relevant information from existing documents, identifying missing data fields, and ensuring consistency across project phases. Additionally, AI-powered predictive analytics can enhance maintenance planning by leveraging real-time performance data, ultimately reducing operational costs and improving asset longevity. Future research should explore how these technologies can be effectively integrated into BIM processes to maximize their benefits.

Future research should also examine how policymakers and regulatory bodies can support industry-wide BIM adoption through incentives and standardization mandates. While some countries have implemented BIM requirements in the construction sector, similar directives are lacking in offshore wind. Understanding how regulatory frameworks could encourage BIM adoption while balancing cost implications for stakeholders would provide valuable insights into the industry's long-term digital transformation.

Ultimately, while this study provides a strong foundation for evaluating BIM's role in offshore wind, its broader success depends on continued research, industry collaboration, and a willingness to embrace data-driven project execution at scale.

7. Conclusion

This chapter consolidates the key insights gained throughout the research, synthesizing the findings into a structured conclusion. It reflects on the study's contributions, assesses its broader implications for industry stakeholders, and evaluates the effectiveness of the proposed framework in addressing challenges in offshore wind project execution. Additionally, it considers the research process and discusses its limitations.

The chapter begins by analysing the findings and explaining how BIM can enhance offshore wind projects and where its implementation shows the most potential. It then highlights the Strategic BIM Prioritization Framework (SBPF-OW) as a key research outcome. The chapter provides a structured approach for evaluating BIM adoption using MCDA. The discussion extends to the industry level, emphasizing the role of BIM in improving data management, project coordination, and lifecycle efficiency.

Furthermore, this chapter explores the implications of these findings for different stakeholders, including developers, operators, and contractors, outlining practical considerations for integrating BIM within existing workflows. It also reflects on the research methodology, addressing its strengths and limitations, particularly regarding data collection, expert input, and the MCDA evaluation process.

This chapter consolidates theoretical insights, industry perspectives, and methodological considerations to ensure a structured and meaningful conclusion, reinforcing the relevance of BIM as a strategic tool for executing offshore wind projects.

7.1 Answering the Research Question

7.1.1 Main Research Question

This thesis set out to answer the question:

To what extent can BIM be implemented in offshore wind construction projects to address existing challenges and improve project outcomes?

The findings demonstrate that the answer to this question depends on the stakeholder's perspective, as different entities within the offshore wind industry have distinct operational needs and priorities. While BIM presents substantial benefits, its implementation must be assessed based on the specific challenges and requirements of the adopting organization.

The framework developed in this thesis provides a structured approach for industry stakeholders to assess the extent to which BIM should be applied in their operations. By systematically evaluating technical feasibility, impact, cost-effectiveness, and plausibility, the framework offers a decision-making tool that enables organizations to tailor BIM adoption to their unique circumstances.

From EnBW's perspective, the findings suggest that BIM can be implemented extensively, particularly in centralized data management, process optimization, and operations and maintenance (O&M). Fragmented data systems, inefficient collaboration, and document-based workflows currently hinder these aspects of offshore wind project execution, all of which BIM can effectively address.

On a broader industry level, there are strong indicators that BIM has the potential to improve project execution across stakeholders, as digital twin applications, simulation-based planning, and structured data environments are already being adopted in specific areas. However, the fragmented nature of offshore wind project execution remains a significant barrier. Various stakeholders operate in siloed environments, leading to persistent inefficiencies that could be mitigated through a more holistic, lifecycle-oriented application of BIM.

In summary, BIM can be transformative in offshore wind project execution, but its full potential can only be realized through a comprehensive and coordinated approach. While this study provides a validated method for assessing BIM adoption, industry-wide benefits will depend on how much stakeholders integrate BIM across the entire lifecycle rather than in isolated applications. Addressing fragmentation and ensuring cross-phase data continuity will be crucial in maximizing the value of BIM for the offshore wind industry.

7.1.2 Research Sub-Questions

1. **What are the key challenges faced by offshore wind construction projects?**
   Offshore wind construction projects face key technical, financial, supply chain, regulatory, environmental, and workforce challenges. Technical challenges include complex logistics, grid connection failures, and turbine fatigue. Financial barriers stem from high capital costs, uncertain returns, and rising operational expenses. Material shortages, limited manufacturing capacity, and vessel availability drive supply chain issues. Regulatory hurdles, such as lengthy permitting and inconsistent requirements, complicate project execution. Environmental concerns, including marine ecosystem disruption and seabird collisions, add further complexity. Workforce challenges hinder project efficiency, including skill shortages, retention issues, and logistical barriers. These challenges were identified through literature and expert interviews at EnBW and are ranked based on their weighted impact in *Chapter 2.1 (Offshore Wind Projects),*

p. 12, *Chapter 4 (Interview Analysis), p. 55*, and *Chapter 5.2 (Iterative Development, Demonstration and Evaluation), p. 76*.

2. **What capabilities does BIM offer for addressing complex project requirements?**
BIM offers powerful capabilities for addressing complex project requirements by providing a centralized platform for managing project data throughout the lifecycle. Key BIM functions include 3D modelling for enhanced design visualization, clash detection to prevent design conflicts, 4D modelling for time-based scheduling, and 5D modelling for real-time cost estimation. BIM also supports 6D modelling for improved facility management and end-of-life planning to optimize decommissioning. Advanced capabilities, such as AI integration for predictive analysis, GIS for environmental modelling, and VR/AR for enhanced stakeholder engagement, further extend BIM's utility. These capabilities improve coordination, reduce errors, and enhance decision-making by enabling real-time collaboration and integrated data management. The role of BIM in addressing offshore wind challenges is explored in *Chapter 2.2 (BIM), p. 22*.

3. **What research exists on the application of BIM within the offshore wind sector, and what gaps remain?**
Research on the application of BIM in offshore wind projects remains limited and fragmented, with most studies focusing on individual lifecycle phases rather than a comprehensive framework. Existing research highlights BIM's potential to improve design accuracy, construction efficiency, and predictive maintenance through real-time data integration and digital twins. However, many studies are focused on the oil and gas sector, raising questions about the direct transferability of findings to offshore wind. Key gaps include the lack of empirical validation, limited real-world implementation, and the absence of a fully integrated framework covering all lifecycle stages. This thesis addresses these gaps by systematically analyzing BIM's applicability to offshore wind projects and developing a structured evaluation framework. The research basis is outlined in *Chapter 2 (Literature Review), p. 11*.

4. **How can organizations in offshore wind evaluate where and to what extent BIM should be integrated into their workflows?**
Organizations in offshore wind can evaluate where and to what extent BIM should be integrated into their workflows using the Strategic BIM Prioritization Framework for Offshore Wind Projects (SBPF-OW) developed in this thesis (*Chapter 5.2 (Iterative Development, Demonstration and Evaluation), p. 76*). The evaluation process involves a structured Multi-Criteria Decision Analysis (MCDA), where factors influencing project success are rated based on technical feasibility, impact, cost-effectiveness, and plausibility. These factors were identified through literature and validated by semi-structured interviews and a focus group with EnBW experts. The MCDA matrix provides a ranked list of factors, highlighting where BIM can deliver the most value. Refinements through multiple iterations, including scenario-based justifications and focus group feedback, ensured that the evaluation reflects both theoretical insights and practical industry conditions (*Chapter 5.2 (Iterative Development, Demonstration and Evaluation), p. 76*, *Chapter 5.3 (Focus Group), p. 86*).

5. **What is the added value of BIM for offshore wind construction projects across different lifecycle phases?**
BIM could add value to offshore wind projects, particularly for project developers like EnBW, by improving data management, predictive maintenance, and construction efficiency (*Chapter 5.2 (Iterative Development, Demonstration and Evaluation), p. 76*). The SBPF-OW framework identifies where BIM might deliver the most impact, especially in enhancing data con-

tinuity across lifecycle phases and reducing inefficiencies in handovers and scheduling. While the findings are specific to EnBW, they reflect broader industry challenges such as fragmented data management and weak standardization (*Chapter 6.1.3 (Understanding BIM's Broader Industry Relevance), p. 94*). The growing use of digital twins, BIM-based simulations, and CDEs suggests a shift toward data-driven workflows, but adoption remains uneven and uncoordinated across stakeholders.

7.2 Key Contributions of the Thesis

This thesis contributes to the ongoing discourse on digitalization in offshore wind by providing a structured approach to evaluating BIM's applicability within the industry. While BIM has been widely explored in traditional construction, its role in offshore wind has remained largely unexamined. This research addresses this gap by systematically assessing BIM's relevance, identifying critical areas for application, and proposing a framework that enables stakeholders to make informed decisions regarding its adoption.

A primary contribution of this study is the development of the Strategic BIM Prioritization Framework for Offshore Wind Projects (SBPF-OW). This framework introduces a structured evaluation method based on Multi-Criteria Decision Analysis, allowing industry stakeholders to systematically assess BIM's feasibility and potential benefits. By incorporating technical feasibility, impact, cost-effectiveness, and plausibility as decision criteria, the framework provides a replicable approach for determining BIM's suitability in different project contexts.

Beyond the framework itself, this thesis offers new insights into the role of BIM in offshore wind, particularly in addressing long-standing challenges such as fragmented data management, inefficiencies in operations and maintenance, and the lack of lifecycle continuity in project execution. The findings demonstrate that while elements of the BIM ecosystem, such as digital twins and simulation tools, have already been adopted in isolated use cases, a more centralized and integrated approach is necessary to leverage BIM's capabilities fully.

Furthermore, this research contributes practical recommendations for BIM implementation, emphasizing the need for a holistic approach that aligns digital workflows with organizational and operational structures. The study highlights the importance of overcoming cultural and structural barriers to adoption, ensuring that BIM is not merely introduced as a technology but integrated as a fundamental change in project execution strategies.

In summary, this thesis advances the theoretical and practical understanding of BIM in offshore wind by introducing a structured evaluation framework, providing industry-specific insights into BIM's potential, and outlining strategic considerations for its successful adoption.

7.3 Reflections on the Research Process

The research process undertaken in this thesis aimed to provide a comprehensive evaluation of the applicability of BIM in offshore wind projects. It integrated multiple methodologies to ensure a well-rounded analysis. The study captured theoretical perspectives and industry-specific expertise by incorporating insights from literature, semi-structured interviews, and a focus group discussion. This multi-method approach enabled a deeper understanding of the challenges faced in executing offshore wind projects and how BIM could serve as a solution.

A key strength of the research lay in the iterative development of the Strategic BIM Prioritisation Framework. The structured evaluation process, refined through multiple iterations, ensured the systematic improvement of the framework based on new insights. This approach allowed for a more nuanced prioritisation of BIM applications, ensuring the framework remained practical and relevant for industry stakeholders. Multi-criteria decision analysis provided a structured method for assessing the feasibility of BIM, balancing qualitative and quantitative aspects of evaluation.

However, several limitations must be recognised. As discussed in *Chapter 6 (Discussion), p. 93*, the research was confined to a single industry stakeholder, EnBW, which limits the broader applicability of the findings. While EnBW's position as a project developer makes its challenges and requirements representative of the sector, other stakeholders—such as suppliers, contractors, and regulatory bodies—may offer different perspectives on BIM adoption. Future research should strive to validate the framework across a broader range of industry players to ensure its scalability and adaptability.

Another limitation arises from the inherent subjectivity in the MCDA scoring process. While informed by expert insights, the researcher's interpretation ultimately shaped the factor evaluations. The focus group discussion helped mitigate this by incorporating additional stakeholder perspectives, but the results still reflect a degree of individual judgment. Further validation through real-world application and broader industry engagement would enhance the framework's robustness.

Additionally, the study's scope was limited to evaluating BIM's potential without implementing a pilot application. While the research strongly indicates that BIM could address key offshore wind challenges, its effectiveness in practice remains to be tested. Future work should focus on real-world case studies where BIM is actively deployed, providing empirical evidence of its long-term impact.

Despite these limitations, the research achieved its objectives by developing a structured decision-making framework for BIM adoption. The findings provide a strong foundation for further exploration and industry engagement, highlighting the opportunities and challenges of integrating BIM into offshore wind project execution.

7.4 Closing Remarks

This study has demonstrated that BIM holds significant potential for improving offshore wind project execution, particularly in data management, operational efficiency, and collaboration across project phases. By addressing key lifecycle challenges, BIM can serve as a powerful enabler of digital transformation within the sector. The findings from EnBW's case indicate that a structured approach to BIM adoption can lead to meaningful improvements, and the developed framework provides a systematic method for evaluating and prioritizing BIM use cases.

While the framework is a strong foundation, its full potential can only be realized through further refinement and real-world application. Integrating BIM into offshore wind requires overcoming organizational, operational, and cultural barriers. Future work must focus on developing actionable strategies to implement BIM holistically, ensuring its benefits extend beyond isolated use cases to drive broader industry-wide improvements.

Beyond its technical and operational implications, BIM represents a shift toward more structured and data-driven decision-making in offshore wind. Maintaining fragmented workflows will become increasingly unsustainable as the sector grows in scale and complexity. A comprehensive, collaborative approach—supported by industry-wide engagement and ongoing research—will be essential for unlocking BIM's full potential.

Ultimately, the successful adoption of BIM in offshore wind will depend on technological advancements. Stakeholders' willingness to embrace new working methods research, cross-industry collaboration, and a long-term commitment to digitalization will be critical in ensuring that BIM becomes a key enabler of efficiency, transparency, and innovation in the sector.

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A. Interview Guide

Participant Information

Name: ______________________________
Date: ______________________________
Role: ______________________________
Years of Experience: ______________________________

Introduction / Participant Information

- Briefly introduce yourself and explain the goal of the research, focusing on the challenges in managing offshore wind projects.
- Explain the confidentiality of the interview and request consent for recording.
- Example introduction: *"The goal of this interview is to better understand your experiences and challenges in offshore wind projects, particularly regarding the tasks and processes you manage."*

Part 1: Background Information

1. Can you tell me about your responsibilities in offshore wind projects?
    - How long have you been involved in offshore wind projects?
    - Which phases or aspects of the project do you primarily focus on (e.g., turbine design, planning, project management)?

Part 2: Key Challenges in Offshore Wind Projects

2. What are the biggest challenges you face in your role in offshore wind projects?
    - Can you provide specific examples of how these challenges have impacted the project (e.g., delays, cost overruns, resource issues)?
    - Are there specific tasks or project phases in your role that are particularly challenging? Why do you think these challenges are particularly demanding?

Part 3: Handling Complexities and Coordination

3. How do you coordinate collaboration with other teams in offshore wind projects?

- Can you share an example where coordination (or the lack thereof) impacted your work or the project?

4. How do you ensure that critical information is reliably shared between teams or departments?
5. Do important pieces of information sometimes get lost or misunderstood between teams or project phases?
6. To what extent do you rely on information from outside the organization?

Part 4: Tools and Processes

7. What (digital) tools or systems do you use to manage your part of the project?
   - How well do these tools support you in managing your tasks and collaborating with other teams?
8. Are there tasks where the current tools or processes fall short? What improvements could help?

Part 5: Improvements and Recommendations

9. What improvements would you suggest to optimize the organization and execution of offshore wind projects?
   - Are there specific improvements in communication, tools, or processes that you think would significantly impact your work or the project as a whole?
   - Are there particular processes or tools that you believe should be prioritized to enhance team-wide execution of offshore wind projects?

Part 6: Conclusion

10. Is there anything we haven't covered that you think is important for better managing or supporting offshore wind projects?
11. Are there other colleagues in the organization you think I should interview on this topic?

Summary

- Thank the participant for their time and contribution.
- Explain how the insights will contribute to the research.

B. Codebook for Problem Identification and Motivation

Introduction

- This codebook focuses on the thesis's Problem Identification and Motivation step, emphasizing lifecycle challenges in offshore wind projects.
- The following section outlines codes derived from the literature on offshore wind project development, operation, and decommissioning.
- These codes provide a foundational understanding of the complex challenges across the lifecycle phases, guiding the analysis of empirical data.

Code from Literature

Origin of Codes

- The codes presented in this section are derived from an extensive academic and industry literature review.
- They address critical challenges identified in offshore wind projects, ranging from economic viability to environmental and logistical concerns.
- Grouping the codes into thematic categories ensures a structured approach to understanding these multifaceted issues.

Code from Literature

- **End-of-Life Challenges**
  - Economic Viability
  - Environmental Impact
  - Regulatory Uncertainty
  - Technical and Logistical Challenges
- **Environmental Challenges**
  - Changes to Benthic and Pelagic Habitats
  - Cumulative Environmental Impacts
  - Marine Ecosystem Impact
  - Seabird Collision and Habitat Displacement

- **Financial Challenges**
  - Financing and Investment Risks
  - High Capital Costs
  - Operational and Maintenance Costs
- **Regulatory Challenges**
  - Bureaucratic Complexity
  - Lack of Streamlined Digital Resources
  - Lengthy Permitting Processes
  - Unclear and Inconsistent Regulations
- **Supply Chain Challenges**
  - Competition from China
  - Limited Manufacturing and Installation Capacity
  - Material Shortages and Price Volatility
- **Technical Challenges**
  - Complex Logistics and Installation
  - Grid Connection and Energy Transmission
  - Turbine Technology
- **Workforce-Related Challenges**
  - Logistical and Geographic Barriers
  - Skill Shortages
  - Training and Retention

Conclusion

- This codebook section categorizes the primary challenges identified in the literature, forming a basis for further empirical analysis.
- It ensures a systematic approach to capturing the complexities of offshore wind project lifecycles.

Digital Tools and Software

Origin of Codes

- These codes were created during the coding phase of the research, based on mentions of digital tools and software by interview participants.
- They capture the diverse range of applications and systems used across the lifecycle of offshore wind projects.
- This provides insights into the technological landscape and helps identify gaps or opportunities for improvement.

Digital Tools and Software

- 4C Offshore
- Aegir
- AI
- Asset Radar
- Construction Reporting Tool
- Digital Twin
- Excel
- HSE Database Application
- JIRA
- Meister Plan
- Microsoft 365
- Navisworks
- Panda Power
- Permit-To-Work-Tool
- PowerFactory
- Primavera
- SAP
- Shoreline
- Think Project
- Vind AI

Conclusion

- This section of the codebook highlights the digital tools and software utilized in offshore wind projects, as revealed through interviews.
- It provides a reference for understanding the digital ecosystem and supports further exploration of its role in enhancing project outcomes.

Lifecycle Phase Coding

Origin of Codes

- These codes were developed during the coding process to identify the specific lifecycle phases in which interview participants are actively involved.
- By categorizing responses according to lifecycle phases, the research highlights phase-specific challenges and practices within offshore wind projects.

- The codes facilitate a structured analysis of the roles and focus areas of interview participants.

Lifecycle Phases

- Construction
- Design
- O&M (Operations and Maintenance)
- Project Development

Conclusion

- This section of the codebook categorizes the lifecycle phases that interviewees are associated with, ensuring clarity in analyzing phase-specific insights.
- It supports a detailed understanding of how different phases impact the challenges and practices in offshore wind projects.

Emergent Themes from Interview Analysis

Origin of Codes

- These codes emerged during the analysis of interview data, highlighting recurring themes and patterns across responses.
- The themes provide insights into common challenges, practices, and opportunities in offshore wind projects.
- By categorizing these themes, the research ensures a focused approach to addressing key areas of interest and concern.

Themes and Codes

- **Coordination and Collaboration**
  - Adapting to Innovation
  - Challenging Collaboration
  - Communication With Public
  - Communicational Challenges
  - Cultural Differences
  - External Stakeholder Coordination
  - Interdepartmental Collaboration
  - Interface Management
  - Lack of Processes
  - Lessons Learned
  - Site Coordination
  - Supplier Coordination
- **Data and Digital Systems**

  - Data Consistency Across Systems
  - Data Format Provided
  - Data Management
  - Data Safety
  - Document Management
  - Lack of Smart Data
  - Single Source of Truth
  - Tool Adaptation Challenges
  - Innovation and Market Dynamics

- **Innovation and Market Dynamics**
  - Challenging Market Analysis and Prediction
  - Everything Regarding BIM
  - Proactive Innovation Barriers

- **Operational and Lifecycle Management**
  - Handover Challenges
  - High Opex
  - Lifecycle Integration
  - Occupational Safety
  - Project Phase
  - Risk Management and Managing Uncertainties
  - Schedule Control
  - Timing of Deliveries

- **Safety and Incident Reporting**
  - Human Error
  - Incident and Near-Miss Reporting

- **Technical and Logistical Challenges**
  - Change Management
  - Congested Seabed Use
  - System Failure
  - Technical Complexities
  - Technological Advancements
  - Unique Features of Offshore Wind
  - Weather

- **Training and Knowledge Retention**
  - Retention of Institutional Knowledge

    - Training (Onboarding) and Certification Gaps

Conclusion

- This codebook section captures the emergent themes identified during the analysis, providing a framework for understanding common challenges and opportunities in offshore wind projects.
- These themes form the basis for targeted recommendations and insights presented in the thesis.

C. Interview Analysis

	Codes	Quotations	Interview (17 documents, 496 quotations)
End-of-Life Challenges	4	6	6
Economic Viability		2	2
Environmental Impact		0	
Regulatory Uncertainty		1	1
Technical and Logistical Challenges		3	3
Environmental Challenges	4	3	3
Changes to Benthic and Pelagic Habitats		0	
Cumulative Environmental Impacts		0	
Marine Ecosystem Impact		3	3
Seabird Collision and Habitat Displacement		0	
Financial Challenges	3	14	14
Financing and Investment Risks		2	2
High Capital Costs		8	8
Operational and Maintenance Costs		4	4
Regulatory Challenges	4	10	10
Bureaucratic Complexity		1	1
Lack of Streamlined Digital Resources		0	
Lengthy Permitting Processes		0	
Unclear and Inconsistent Regulations		9	9
Supply Chain Challenges	3	17	17
Competition from China		3	3
Limited Manufacturing and Installation Capacity		12	12
Material Shortages and Price Volatility		3	3
Technical Challenges	3	19	19
Complex Logistics and Installation		11	11
Grid Connection and Energy Transmission		3	3
Turbine Technology		6	6
Workforce-Related Challenges	3	20	20
Logistical and Geographic Barriers		3	3
Skill Shortages		14	14
Training and Retention		3	3
Totals			**180**

Figure C.1: Challenges from Literature Occurring during the Interviews

Code			Interview 17 496
Coordination and Collaboration	12	148	148
Adapting to Innovation		19	19
Challenging Colaboration		20	20
Communication With Public		3	3
Communicational Challenges		14	14
Cultural Differences		5	5
External Stakeholder Coordination		23	23
Interdepartmental Collaboration		25	25
Interface Management		10	10
Lack of Processes		17	17
Lessons Learned		10	10
Site Coordination		10	10
Supplier Coordination		13	13
Data and Digital Systems	8	80	80
Data Consistency Across Systems		12	12
Data Format Provided		5	5
Data Management		43	43
Data Safety		1	1
Document Management		8	8
Lack of Smart Data		10	10
Single Sourthe of Truth		7	7
Tool Adaptation Challenges		10	10
Innovation and Market Dynamics	3	28	28
Challenging Market Analysis and Prediction		8	8
Everything Regarding BIM		15	15
Proactive Innovation Barriers		6	6
Operational and Lifecycle Management	7	65	65
Handover Challenges		21	21
High Opex		7	7
Lifecycle Integration		21	21
Occupational Safety		6	6
Risk Management and Managing Uncertainties		9	9
schedule control		3	3
Timing of Deliveries		2	2
Safety and Incident Reporting	2	6	6
Human Error		5	5
Incident and Near-Miss Reporting		1	1
Technical and Logistical Challenges	7	31	31
Change Management		2	2
Congested Seabed Use		2	2
System Failure		1	1
technical complexities		9	9
Technological Advancements		4	4
Unique Features OW		10	10
Weather		6	6
Training and Knowledge Retention	2	15	15
Retention of Institutional Knowledge		13	13
Training(Onboarding) and Certification Gaps		2	2
Totals			791

Figure C.2: Challenges emerging during the Interviews

D. Vind AI Tool Description

Introduction

- Vind AI is a software platform developed to support project development and bid preparation in offshore wind projects.
- The tool centralizes data, enables simulations, and facilitates collaboration, enhancing efficiency and decision-making in the early phases of offshore wind project planning.
- Vind AI is specifically designed to streamline workflows during the pre-construction stages of offshore wind projects.

Key Features and Capabilities

Core Functionalities

- **Project Development and Bid Preparation**
  - Vind AI facilitates project assessment, including site evaluation, feasibility studies, and resource allocation.
  - It provides tools for bid preparation by simulating costs, financing requirements, and operational expenses.
- **Simulation and Modeling**
  - Users can model wind farm layouts, including turbine placement and monopile foundations, to optimize energy yield and cost efficiency.
  - Simplified engineering equations are utilized to enable rapid estimations of metrics such as energy output and installation costs.
- **Financial Optimization**
  - The platform supports financial modeling to estimate Levelized Cost of Energy (LCOE) and Internal Rate of Return (IRR).
  - It provides tools for simulating operational expenditures (OPEX) and capital expenditures (CAPEX) to refine bid proposals.
- **Collaboration and Data Management**
  - Vind AI centralizes project data, allowing seamless collaboration among engineering, financial, and operational teams.
  - Data security features ensure the confidentiality of sensitive project information.

Planned Development

- Vind AI is currently focused on the project development and bid preparation phases. While there is potential for future expansion into other phases, such as construction and operations, these are not yet part of its core functionality.
- Future updates may include enhanced predictive analytics and additional features tailored to support strategic decision-making during the pre-construction phases.

Use Cases

- Vind AI is used to model wind farm layouts, assess financial and operational metrics, and simulate project outcomes to support competitive bid preparation.
- The tool helps identify optimal site configurations and cost structures, enabling more accurate and efficient project planning.

Conclusion

- Vind AI is a specialized tool for managing the early phases of offshore wind projects, focusing on project development and bid preparation.
- Its combination of simulation, financial modeling, and data management features provides developers with a comprehensive solution to optimize planning and bidding processes.

Vind.AI alignment with the principles and scope of Building Information Modeling

Building Information Modeling (BIM) is widely recognized as a methodology standard in digital project management. It provides shared digital representations of assets across the lifecycle of construction projects. Comparing the BIM definitions in the literature to the functionalities of Vind.AI, it becomes evident that while Vind.AI aligns with some BIM principles, it is not a comprehensive BIM system.

Comparison with BIM Definitions

- **ISO 19650-1:2018:** BIM is defined as the "use of a shared digital representation of a built asset to facilitate design, construction, and operation processes to form a reliable basis for decisions" (for Standardization, 2018). Vind.AI aligns with this definition's ability to facilitate decision-making through centralized digital representations of wind farm layouts. However, it currently focuses only on early project phases, without extending to construction or operation.
- **National BIM Standard (U.S.):** BIM is a "digital representation of physical and functional characteristics of a facility, forming a reliable basis for decisions during its lifecycle from conception to demolition" (Committee, 2007). Vind.AI supports conceptualization and feasibility studies for offshore wind projects but does not span the entire lifecycle, particularly construction and decommissioning.

- **Succar (2009):** BIM comprises "a set of interacting policies, processes, and technologies generating a methodology to manage essential building design and project data in digital format throughout the building's lifecycle" (Succar, 2009). Vind.AI integrates processes and technologies for early-stage data management and decision-making. However, it lacks lifecycle-wide applicability and standardized BIM policies.
- **Eastman et al. (2011):** BIM refers to "tools, processes, and technologies facilitated by digital, machine-readable documentation about a building, its performance, its planning, its construction, and later its operation" (Eastman et al., 2011). Vind.AI meets this definition by using machine-readable data to generate performance metrics and planning outputs. However, it does not extend to construction or operational documentation.
- **Van Nederveen and Tolman (1992):** BIM involves "a modeling technology and associated processes to produce, communicate, and analyze building models" (G. van Nederveen & Tolman, 1992). Vind.AI's modelling technology aligns with this definition, enabling the creation and analysis of wind farm layouts.

Limitations of Vind.AI as a BIM System

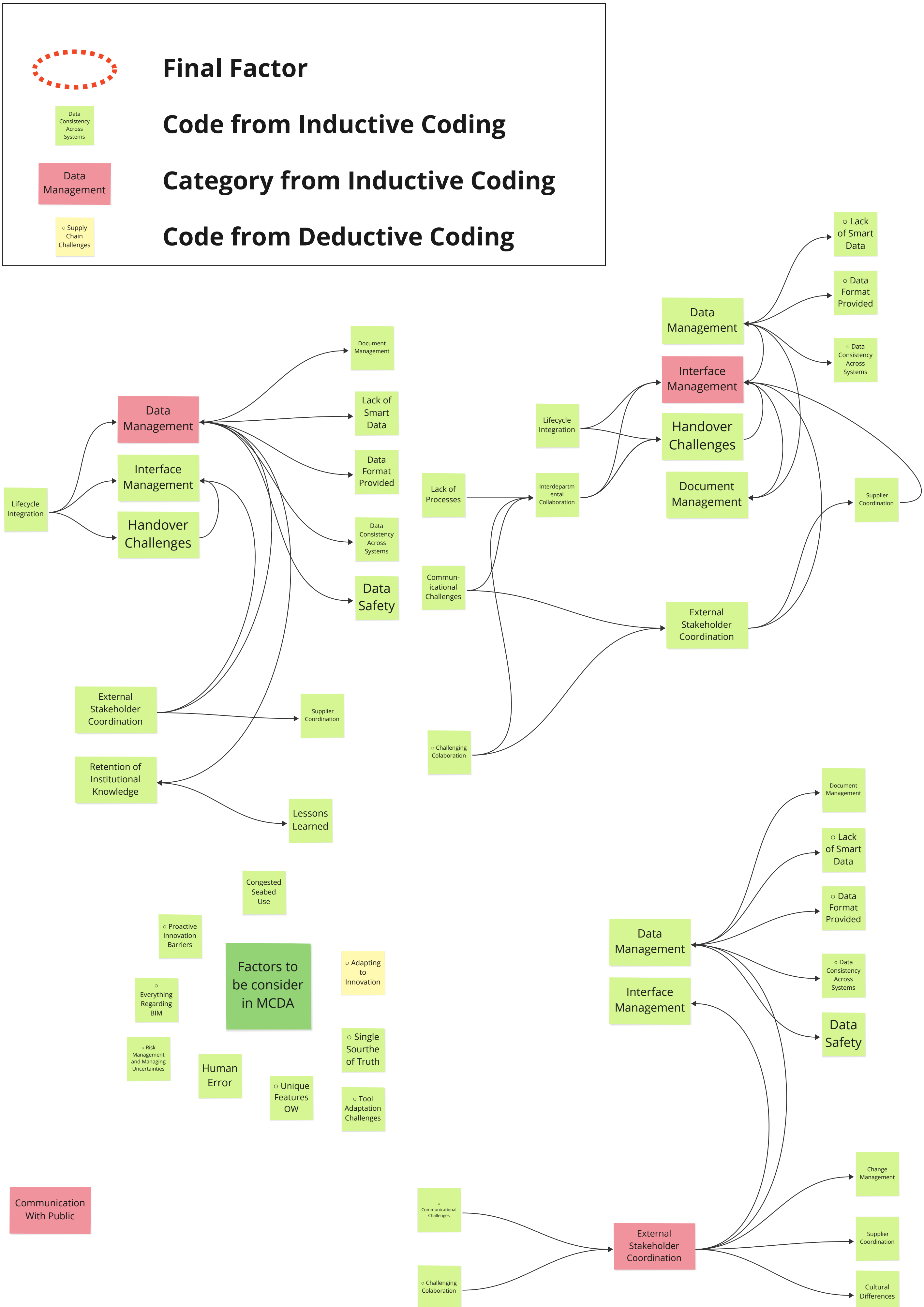
While Vind.AI embodies BIM principles such as centralized data management, real-time decision-making, and modelling capabilities, it lacks several critical BIM attributes:

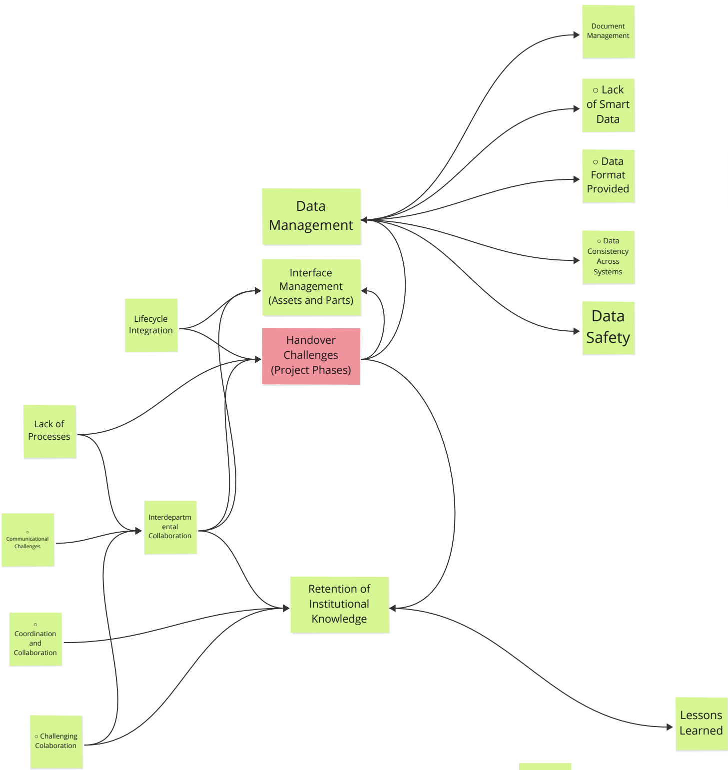
- **Lifecycle Integration:** BIM spans the entire lifecycle of assets, including construction, operation, and decommissioning. Vind.AI focuses solely on early development phases.
- **Parametric Modeling:** BIM incorporates comprehensive models detailing physical and functional characteristics, while Vind.AI focuses on scenario modelling and financial metrics rather than detailed asset representation.
- **Collaboration Across Phases:** BIM facilitates collaboration throughout all project phases, whereas Vind.AI emphasizes early-stage interdisciplinary cooperation.

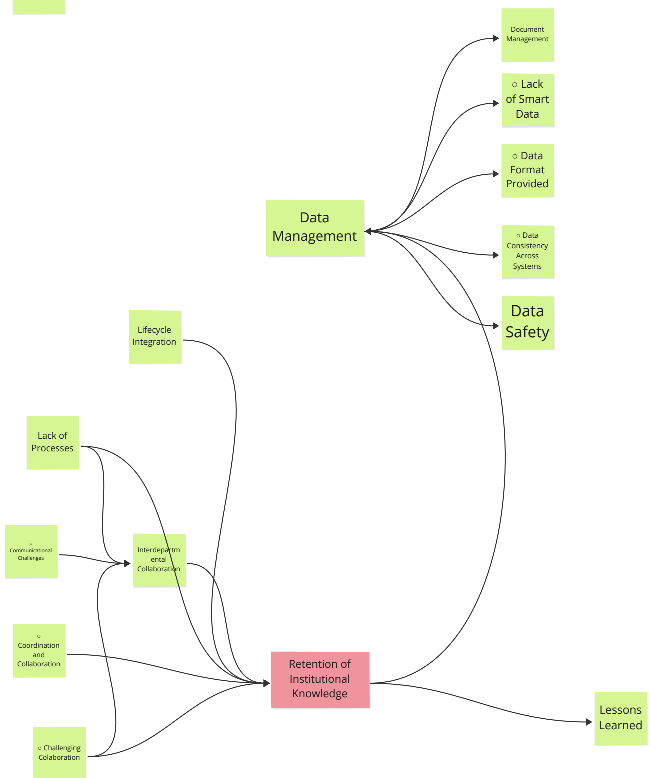
Conclusion

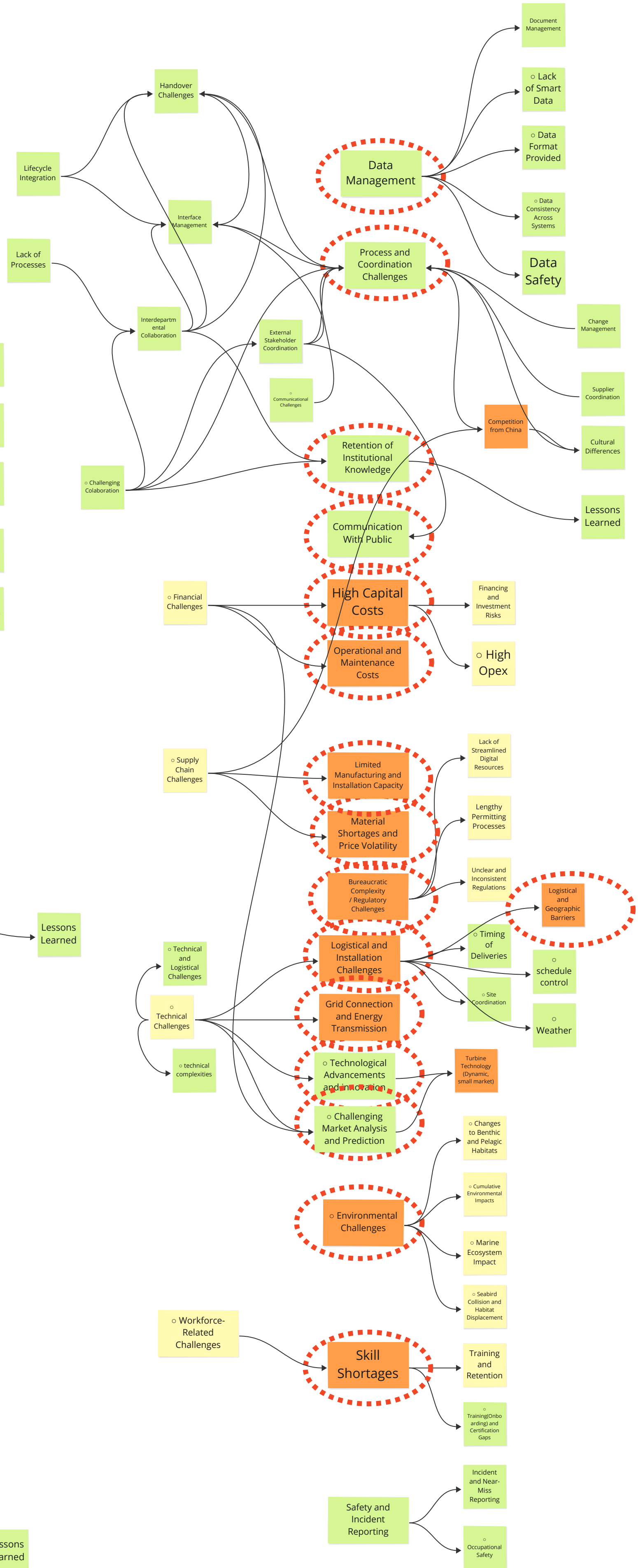
Vind.AI integrates several BIM principles in data centralization, decision-making, and scenario modelling for early-stage offshore wind project development. However, it does not fully align with BIM's definition, which emphasises lifecycle integration, parametric modeling, and cross-phase collaboration. Vind.AI should be considered a complementary tool to BIM rather than a substitute for its comprehensive lifecycle capabilities.

E. Combination of Codes to Factors


Final Factor
Data Consistency Across Systems
Code from Inductive Coding
Data Management
Category from Inductive Coding
Supply Chain Challenges
Code from Deductive Coding
Lifecycle Integration
Data Management
Interface Management
Handover Challenges
Document Management
Lack of Smart Data
Data Format Provided
Data Consistency Across Systems
Data Safety
External Stakeholder Coordination
Supplier Coordination
Retention of Institutional Knowledge
Lessons Learned
Lack of Processes
Commun-icational Challenges
Challenging Colaboration
Lifecycle Integration
Interdepartmental Collaboration
Data Management
Interface Management
Handover Challenges
Document Management
Lack of Smart Data
Data Format Provided
Data Consistency Across Systems
Supplier Coordination
External Stakeholder Coordination
Congested Seabed Use
Proactive Innovation Barriers
Everything Regarding BIM
Risk Management and Managing Uncertainties
Factors to be consider in MCDA
Human Error
Unique Features OW
Adapting to Innovation
Single Sourthe of Truth
Tool Adaptation Challenges
Data Management
Interface Management
Document Management
Lack of Smart Data
Data Format Provided
Data Consistency Across Systems
Data Safety
Communication With Public
Communicational Challenges
Challenging Colaboration
External Stakeholder Coordination
Change Management
Supplier Coordination
Cultural Differences


Data Management
Interface Management (Assets and Parts)
Handover Challenges (Project Phases)
Lifecycle Integration
Lack of Processes
Interdepartmental Collaboration
Communicational Challenges
Coordination and Collaboration
Challenging Collaboration
Retention of Institutional Knowledge
Lessons Learned
Document Management
○ Lack of Smart Data
○ Data Format Provided
○ Data Consistency Across Systems
Data Safety


Data Management
Document Management
○ Lack of Smart Data
○ Data Format Provided
○ Data Consistency Across Systems
Data Safety
Lifecycle Integration
Lack of Processes
Interdepartmental Collaboration
Communicational Challenges
Coordination and Collaboration
○ Challenging Collaboration
Retention of Institutional Knowledge
Lessons Learned


Handover Challenges
Lifecycle Integration
Interface Management
Lack of Processes
Interdepartmental Collaboration
External Stakeholder Coordination
Communicational Challenges
Challenging Collaboration
Data Management
Process and Coordination Challenges
Document Management
○ Lack of Smart Data
○ Data Format Provided
○ Data Consistency Across Systems
Data Safety
Change Management
Supplier Coordination
Competition from China
Cultural Differences
Retention of Institutional Knowledge
Lessons Learned
Communication With Public
○ Financial Challenges
High Capital Costs
Operational and Maintenance Costs
Financing and Investment Risks
○ High Opex
○ Supply Chain Challenges
Limited Manufacturing and Installation Capacity
Material Shortages and Price Volatility
Bureaucratic Complexity / Regulatory Challenges
Lack of Streamlined Digital Resources
Lengthy Permitting Processes
Unclear and Inconsistent Regulations
Logistical and Geographic Barriers
○ Technical and Logistical Challenges
○ Technical Challenges
○ technical complexities
Logistical and Installation Challenges
Grid Connection and Energy Transmission
○ Technological Advancements and Innovation
○ Challenging Market Analysis and Prediction
○ Timing of Deliveries
○ schedule control
○ Site Coordination
○ Weather
Turbine Technology (Dynamic, small market)
○ Environmental Challenges
○ Changes to Benthic and Pelagic Habitats
○ Cumulative Environmental Impacts
○ Marine Ecosystem Impact
○ Seabird Collision and Habitat Displacement
○ Workforce-Related Challenges
Skill Shortages
Training and Retention
○ Training(Onboarding) and Certification Gaps
Safety and Incident Reporting
Incident and Near-Miss Reporting
○ Occupational Safety

F. Combined and Refines Codes for MCDA 1. Itertation

Combined Codes for MCDA

Safety and Incident Reporting

This factor addresses the critical importance of maintaining safety standards and implementing effective incident and near-miss reporting systems in offshore wind projects. Offshore wind environments are inherently hazardous, requiring rigorous planning, specialized training, and compliance with strict safety regulations to protect personnel and assets.

Occupational safety involves preventive measures such as hazard meetings, detailed risk assessments, and mandatory training tailored to specific roles and environments. For example, contractors working in wind parks must complete multiple offshore-specific training courses to prepare for the unique challenges of the marine environment.

Incident and near-miss reporting systems are essential for identifying risks and enabling proactive responses. These systems facilitate the documentation and analysis of safety incidents, allowing project managers to track patterns, assess the effectiveness of safety protocols, and make informed decisions to prevent future occurrences. Regular reporting not only enhances transparency but also helps maintain operational efficiency by ensuring risks are addressed promptly.

By integrating comprehensive safety protocols with reliable reporting mechanisms, offshore wind projects can reduce accidents, improve worker confidence, and ensure compliance with regulatory standards.

Skill Shortages

Skill shortages represent a critical challenge for offshore wind projects, impacting the sector's ability to meet growing demands for specialized labor. This factor includes issues related to training and retention, onboarding processes, and certification gaps, all of which are closely tied to workforce-related challenges.

Ensuring a skilled workforce involves addressing gaps in training programs and onboarding procedures. Offshore wind operations require employees to undergo extensive and role-specific training, including multiple offshore certifications tailored to the marine environment. However, gaps in these programs can lead to delays and inefficiencies during project execution. Certification processes must be robust and streamlined to ensure personnel meet the stringent safety and operational standards required for offshore environments.

Retention of trained personnel is equally critical, as high turnover rates and competition from other renewable energy sectors or traditional industries like oil and gas exacerbate workforce shortages. Long-term campaigns often lead to fatigue and diminished focus among contractors, increasing the likelihood of errors or incidents, which further highlights the need for workforce stability and support systems.

Skill shortages also impact the scalability of offshore wind projects, as a lack of trained workers limits the sector's ability to deliver projects on time and within budget. By improving training, onboarding, and retention strategies, offshore wind developers can address workforce challenges and enhance operational resilience.

Environmental Challenges

Environmental challenges encompass the wide-ranging impacts offshore wind projects can have on marine ecosystems and wildlife. This factor includes changes to benthic and pelagic habitats, cumulative environmental impacts, marine ecosystem impacts, and seabird collision and habitat displacement.

The construction and operation of offshore wind farms can significantly alter benthic and pelagic habitats. The introduction of large structures like turbine foundations creates artificial reefs, which may attract new species but also disrupt existing habitats and food webs. These changes can result in habitat loss for some marine species while providing opportunities for others, underscoring the complex ecological trade-offs.

Cumulative environmental impacts are another critical concern. Offshore wind farms often coexist with other marine activities, such as shipping and fishing, leading to overlapping pressures on ecosystems. Noise from pile driving during construction and ongoing operational sounds from turbines can further exacerbate these impacts, requiring detailed assessments to mitigate long-term ecological damage.

Marine ecosystem impacts include the disruption of species sensitive to electromagnetic fields generated by underwater cables, as well as increased turbidity and sedimentation during construction. Such disturbances can alter migration patterns, breeding, and feeding behaviors of marine species.

Seabird collisions with turbine blades and habitat displacement present additional challenges. Offshore wind farms situated in migratory pathways or feeding grounds can increase mortality rates for seabirds, particularly for vulnerable populations. Moreover, displacement from critical habitats can force seabirds to expend more energy and reduce their reproductive success.

Addressing these challenges requires comprehensive environmental assessments, adaptive management strategies, and mitigation measures to minimize ecological harm and ensure the sustainable development of offshore wind projects.

Logistical and Installation Challenges

This factor highlights the complexities involved in the logistics and installation phases of offshore wind projects. It encompasses logistical and geographic barriers, timing of deliveries, schedule control, site coordination, and weather-related constraints, all of which are closely tied to technical challenges.

Logistical and geographic barriers include the challenges of transporting large turbine components and equipment to offshore sites, often over considerable distances and through difficult marine environments. The remote locations of offshore wind farms further complicate the logistics, requiring specialized vessels and infrastructure to support transportation and installation.

Timing of deliveries and schedule control are critical aspects of project planning. Delays in the arrival of key components, such as turbines or foundations, can lead to significant setbacks in project timelines. Effective schedule control is essential to coordinate multiple stakeholders and ensure smooth workflows during installation.

Site coordination involves managing multiple on-site activities, such as positioning foundations, cable installation, and turbine assembly. This requires seamless communication between teams and precise execution to avoid delays and minimize risks.

Weather conditions, including high winds, strong waves, and storms, present additional challenges during the installation phase. Adverse weather can delay operations, increase costs, and pose safety risks to workers. Advanced forecasting and contingency planning are critical to mitigating weather-related disruptions.

By addressing these logistical and installation challenges, offshore wind projects can improve efficiency, reduce delays, and ensure the successful deployment of critical infrastructure.

Grid Connection and Energy Transmission

Grid connection and energy transmission represent critical technical challenges in offshore wind projects, as they are fundamental to delivering generated power to the mainland grid reliably and efficiently. This factor is inherently connected to technical challenges due to the complex infrastructure and technologies required.

One of the primary issues involves the installation and maintenance of subsea cables, which are essential for transmitting electricity from offshore turbines to onshore substations. Subsea cables are prone to damage from various sources, including fishing activities, anchor dragging, and natural movements of the seabed. Repairs can be costly and time-intensive, often requiring specialized vessels and equipment.

The integration of offshore wind power into existing energy grids poses another significant challenge. Grids must be upgraded to handle fluctuating energy outputs from wind farms, requiring advanced grid management systems and energy storage solutions to maintain stability and prevent overloads.

Additionally, the geographic distance between offshore wind farms and onshore substations increases transmission losses, which can impact the overall efficiency of energy delivery. High-voltage direct current (HVDC) systems have been increasingly used to minimize these losses, but their deployment and maintenance add further complexity and cost to projects.

Addressing these challenges involves detailed site surveys, advanced cable protection measures, and ongoing collaboration with grid operators to ensure seamless integration. By tackling these issues, offshore wind developers can enhance grid reliability and optimize the energy output from wind projects.

Technological Advancements and Innovation

This factor focuses on advancements in turbine technology within a dynamic and relatively small market, a critical area connected to technical challenges in offshore wind projects.

Turbine technology is rapidly evolving, with manufacturers continuously innovating to develop larger, more efficient turbines capable of operating in harsh offshore environments. These advancements aim to maximize energy output while minimizing costs, but they also introduce complexities. The dynamic nature of the market often results in uncertainties, as new turbine models are frequently announced with changing specifications and timelines. For instance, a turbine initially marketed as an 18 MW model may be delayed and replaced with a 19 MW variant, causing disruptions in project planning and procurement.

The integration of innovative materials and design improvements in turbine components, such as blades and generators, enhances performance but requires specialized manufacturing and installation processes. Additionally, ensuring the durability and reliability of turbines in extreme marine conditions, including high winds and saltwater exposure, remains a significant technical challenge.

The small and competitive market for offshore turbine technology further complicates the situation. Limited suppliers and increasing global demand can lead to supply chain bottlenecks, delaying project timelines and escalating costs.

Addressing these challenges involves close collaboration with turbine manufacturers, early engagement in the procurement process, and adopting flexible project planning strategies to accommodate technological advancements and market dynamics.

Challenging Market Analysis and Prediction

This factor focuses on the complexities of analyzing and predicting market trends in the offshore wind industry, particularly in the context of turbine technology within a dynamic and relatively small market. It is connected to both technical and financial challenges, given the critical role of market analysis in project success.

The offshore wind market is characterized by rapid technological advancements and fluctuating demand. Turbine manufacturers frequently update their offerings, introducing larger and more efficient models, often with shifting specifications and timelines. For example, a turbine initially planned as an 18 MW model may later be replaced with a 19 MW version, altering project planning and procurement strategies. These uncertainties complicate forecasting efforts, as developers must account for evolving technological landscapes.

Financial challenges are amplified by market dynamics. Cost predictions for turbine manufacturing and installation often fluctuate due to changes in raw material prices, supply chain disruptions, and competition among global suppliers. Developers face difficulties in estimating project budgets and securing financing when market conditions remain volatile.

Additionally, the small and competitive nature of the market restricts the availability of suppliers, which can lead to delays and increased costs. Developers must engage in early and collaborative planning with suppliers to mitigate these risks and adapt to changing market conditions.

Addressing these challenges requires robust market analysis tools, close collaboration with manufacturers, and flexible project planning to accommodate technological and financial uncertainties. This ensures that projects remain feasible and align with evolving market trends.

Bureaucratic Complexity / Regulatory Challenges

This factor highlights the bureaucratic and regulatory hurdles faced by offshore wind projects. It includes a lack of streamlined digital resources, lengthy permitting processes, and unclear or inconsistent regulations, all of which contribute to delays and increased costs. These challenges are closely connected to financial issues, as they often lead to project inefficiencies and budget overruns.

The lack of streamlined digital resources complicates coordination and information sharing between regulatory bodies and developers. Many permitting systems still rely on outdated, paper-based processes, which delay approvals and create redundancies. Modernizing these systems with centralized, digitized platforms could significantly improve efficiency and transparency.

Lengthy permitting processes are another major issue. Offshore wind projects often require approvals from multiple regulatory authorities, each with its requirements and timelines. These fragmented processes can stretch over several years, delaying project timelines and increasing costs. Inconsistent application of environmental and legal standards across jurisdictions further exacerbates these delays.

Unclear and inconsistent regulations create additional uncertainty for developers. Rules adapted from other industries, such as oil and gas, are often unsuitable for offshore wind, leading to misinterpretations and prolonged negotiations. The lack of regulatory clarity hinders long-term planning and complicates compliance efforts.

Addressing these challenges requires the harmonization of regulations, the establishment of centralized permitting authorities, and the integration of digital tools to streamline workflows. By overcoming bureaucratic complexity, offshore wind projects can reduce delays, lower costs, and achieve smoother implementation.

Limited Manufacturing and Installation Capacity

This factor highlights the challenges associated with the limited manufacturing and installation capacity in the offshore wind industry. As the demand for offshore wind energy grows, the capacity of manufacturers and installers to meet these needs remains constrained, leading to project delays and increased costs. This issue is closely connected to financial challenges, as supply shortages and rising prices impact project budgets and timelines.

Manufacturing capacity is particularly strained due to the specialized nature of offshore wind components. Turbines, foundations, and subsea cables require advanced production facilities, many of which are concentrated in a few regions. The increasing global demand for these components has resulted in bottlenecks, with manufacturers struggling to scale up production.

Installation capacity is similarly limited, with a shortage of specialized vessels and skilled personnel to carry out offshore installations. The logistical complexity of transporting and installing massive turbines in challenging marine environments further exacerbates this issue. Delays caused by limited installation capacity can have a cascading effect on project schedules, increasing costs and reducing profitability.

Addressing these challenges requires strategic investments in expanding manufacturing and installation infrastructure, as well as fostering innovation in production processes to improve efficiency. Collaborative efforts between developers, manufacturers, and policymakers can help alleviate these constraints and ensure the sustainable growth of the offshore wind industry.

Material Shortages and Price Volatility

This factor addresses the challenges posed by material shortages and price volatility in the offshore wind sector, which are directly connected to financial challenges. Offshore wind projects rely heavily on critical raw materials such as steel, copper, and rare earth elements, all of which are subject to global supply constraints and fluctuating prices.

Material shortages often arise from high global demand and limited supply chains, particularly for specialized components like turbine magnets that depend on rare earth elements. The reliance on a small number of suppliers, particularly from regions like China, increases vulnerability to geopolitical risks and trade restrictions, which can disrupt supply and delay projects.

Price volatility is another critical issue, with material costs frequently fluctuating due to inflation, energy crises, and shifts in global market dynamics. For instance, steel prices have seen significant increases in recent years, directly impacting the cost of turbine manufacturing and installation infrastructure. These rising costs place additional financial pressure on developers, increasing the levelized cost of energy (LCOE) for offshore wind projects.

To mitigate these challenges, developers must adopt strategies such as long-term contracts with suppliers, diversifying sourcing options, and investing in innovative technologies that reduce material dependence. Policymakers can also play a role by ensuring stable supply chains and incentivizing local production to minimize reliance on imports.

High Capital Costs

This factor highlights the significant financial challenges associated with high capital costs in offshore wind projects. It includes financing and investment risks as well as high operational expenditures (OPEX), making it a critical component connected to financial challenges.

Financing and investment risks arise from the substantial upfront capital required for project development, including turbine manufacturing, installation infrastructure, and grid connection. Offshore wind projects are characterized by long payback periods, which increase their risk profile for investors, especially in a competitive and uncertain market. The withdrawal of government subsidies in some regions has further compounded these risks, leaving developers reliant on private financing under less favorable terms.

High OPEX is another significant concern, driven by the operational and maintenance costs associated with offshore wind farms. The remote locations of these projects and the need for specialized vessels and equipment for maintenance activities contribute to elevated costs. Additionally, unplanned maintenance due to equipment failures or adverse weather can further strain project budgets.

Addressing high capital costs requires innovative financing mechanisms, such as public-private partnerships and green bonds, to reduce reliance on traditional investment models. Developers can also focus on cost-reduction strategies, including technological innovation and efficiency improvements, to lower both upfront and operational expenses.

Operational and Maintenance Costs

This factor addresses the significant challenges posed by high operational and maintenance (O&M) costs in offshore wind projects, which are closely connected to financial challenges. O&M costs account for a substantial portion of the total lifecycle cost of offshore wind farms, driven by their remote locations, harsh environmental conditions, and the need for specialized equipment and skilled personnel.

Maintenance activities for offshore wind farms are inherently complex and expensive. The remote nature of these sites requires the deployment of specialized vessels and helicopters to transport workers and equipment. Additionally, adverse weather conditions can delay or complicate maintenance operations, increasing both time and costs.

Unplanned maintenance due to equipment failures, such as turbine breakdowns or subsea cable faults, adds another layer of financial risk. These unexpected events often require immediate attention, further straining project budgets. The unpredictability of these costs highlights the importance of robust maintenance planning and predictive maintenance technologies.

Operational costs are also impacted by the need to ensure reliable energy generation over the project's lifespan. Regular inspections, cleaning, and performance monitoring are necessary to maintain turbine efficiency and mitigate risks associated with wear and tear or environmental factors like biofouling.

Reducing operational and maintenance costs requires advancements in remote monitoring technologies, predictive analytics, and automation. Additionally, optimizing vessel usage and improving access systems can help streamline maintenance processes and reduce associated expenses.

Communication With Public

This factor addresses the challenges involved in communicating with the public and coordinating with external stakeholders during offshore wind project development. Effective external stakeholder coordination is essential for fostering understanding, gaining support, and managing the expectations of various parties, including regulatory bodies, local communities, and environmental organizations.

Public communication challenges include raising awareness about the benefits of offshore wind energy and addressing misconceptions or concerns about its potential impacts. Transparent and proactive communication is crucial to building trust and ensuring public acceptance of these projects.

Coordination with regulatory bodies and other external stakeholders involves navigating complex approval processes, balancing competing interests, and integrating feedback into project planning. Misaligned priorities or a lack of clear communication can lead to delays, conflicts, or increased costs.

Collaborative efforts between developers, policymakers, and local communities are necessary to address these challenges. Establishing clear communication channels, leveraging digital platforms for stakeholder engagement, and prioritizing transparency can improve the efficiency and effectiveness of external stakeholder coordination.

Retention of Institutional Knowledge

This factor focuses on the importance of retaining institutional knowledge through lessons learned processes and effective collaboration. It is closely connected to interdepartmental collaboration and challenging collaboration, as knowledge retention relies on efficient communication and integration across teams.

Lessons learned play a critical role in improving future project performance by capturing insights and best practices from completed tasks and addressing past mistakes. Offshore wind projects, with their complexity and long lifecycles, benefit greatly from systematic documentation and analysis of experiences to enhance planning, execution, and operations.

Interdepartmental collaboration is essential for sharing institutional knowledge effectively. Ensuring that information flows seamlessly between departments, such as engineering, procurement, and operations, prevents knowledge silos and reduces the risk of repeating errors. Similarly, overcoming challenging collaboration between external and internal stakeholders ensures that valuable insights are captured and applied across project phases.

To improve knowledge retention, offshore wind projects should implement robust systems for recording and disseminating lessons learned. These systems should promote collaboration, leverage digital tools for knowledge sharing, and ensure accessibility to all relevant stakeholders. By fostering a culture of continuous learning and collaboration, organizations can enhance efficiency and resilience in future projects.

Process and Coordination Challenges

Process and coordination challenges encompass a wide range of issues that impact the smooth execution of offshore wind projects. These challenges include change management, supplier coordination, handover challenges, interface management, competition from China, and cultural differences. They are deeply connected to external stakeholder coordination and communicational challenges, highlighting their importance in project success.

Change management is a critical aspect of offshore wind projects, as iterative processes often necessitate adjustments to design, procurement, or operations. These changes frequently occur late in the project cycle, introducing risks and delays. Ensuring that all stakeholders are informed and aligned when changes are implemented is essential to minimize disruptions.

Supplier coordination poses another significant challenge, given the reliance on specialized equipment and components. Variations in quality, delays in delivery, and misaligned expectations can disrupt project schedules and budgets. Establishing clear contracts and maintaining close collaboration with suppliers are key strategies for mitigating these risks.

Handover challenges often emerge during transitions between project phases, such as moving from design to construction or construction to operations. Inadequate documentation or inconsistent communication between teams can result in inefficiencies and errors, emphasizing the need for structured and comprehensive handover processes.

Interface management adds complexity, as offshore wind projects involve multiple departments and external partners with differing priorities, technical standards, and workflows. Misaligned goals and poor communication can lead to delays and cost overruns. Structured coordination frameworks are essential to streamline collaboration and ensure alignment.

The growing competition from Chinese manufacturers presents both opportunities and challenges. While lower-cost components can reduce material expenses, there are concerns about over-reliance on foreign suppliers, potential quality issues, and the erosion of domestic technological leadership. Balancing cost efficiency with supply chain resilience is crucial.

Cultural differences further complicate coordination, particularly in projects involving international teams and stakeholders. These differences can lead to misunderstandings, inefficiencies, and conflicts, especially in decision-making and communication. Promoting cultural awareness and providing training can help bridge gaps and improve collaboration.

These process and coordination challenges are intrinsically linked to other factors, such as handover challenges, interface management, interdepartmental collaboration, and external stakeholder coordination. They also amplify communicational challenges, as effective information exchange is critical for resolving coordination issues. Addressing these multifaceted challenges is essential for enhancing efficiency, reducing delays, and fostering collaboration across all levels of offshore wind projects.

Data Management

Data management is a critical component of offshore wind projects, encompassing a range of challenges such as document management, the lack of smart data systems, discrepancies in data formats, inconsistencies across systems, and concerns over data safety. This category is closely connected to process and coordination challenges, as efficient data handling is fundamental to seamless project execution and collaboration.

Effective document management is essential in projects that generate extensive records, including design specifications, operational plans, and compliance documentation. Poorly organized or inaccessible documentation can lead to delays, errors, and inefficiencies, especially during critical project phases such as handovers or audits.

Another significant challenge is the lack of smart data systems capable of providing actionable insights. Offshore wind projects involve complex datasets that, when analyzed effectively, can optimize decision-making, identify trends, and predict potential risks. Without smart data tools, teams are often left with fragmented or incomplete information, limiting their ability to make informed decisions.

Data format discrepancies across teams and systems also hinder collaboration and integration. Standardizing data formats is vital to ensure that information flows smoothly between different stakeholders, reducing misunderstandings and errors. Similarly, ensuring data consistency across various platforms is crucial. Offshore wind projects often involve multiple software systems, and inconsistencies can lead to conflicting reports, duplication of work, and delays.

Data safety is an increasingly critical concern, given the sensitive nature of project information and the growing threat of cyberattacks. Protecting project data through secure storage, encryption, and robust access controls is essential to safeguarding intellectual property and maintaining stakeholder trust.

Strong data management practices are integral to overcoming process and coordination challenges. Clear, consistent, and secure data enables better communication, minimizes errors, and fosters collaboration across departments and external partners. Addressing these challenges will allow offshore wind projects to harness the full potential of their data, improving efficiency, reducing risks, and enhancing overall project success.

G. 1. Iteration MCDA Setup, with/ without Codes

Version 1 - without codes

	Technical Feasibility 25%	Impact 25%	Cost-Effectiveness 25%	Plausibility 25%
Factor 1	*Rating 1-5*	*Rating 1-5*	*Rating 1-5*	*Rating 1-5*
Factor 2	*Rating 1-5*	*Rating 1-5*	*Rating 1-5*	*Rating 1-5*
Factor ...	*Rating 1-5*	*Rating 1-5*	*Rating 1-5*	*Rating 1-5*
Factor 16	*Rating 1-5*	*Rating 1-5*	*Rating 1-5*	*Rating 1-5*

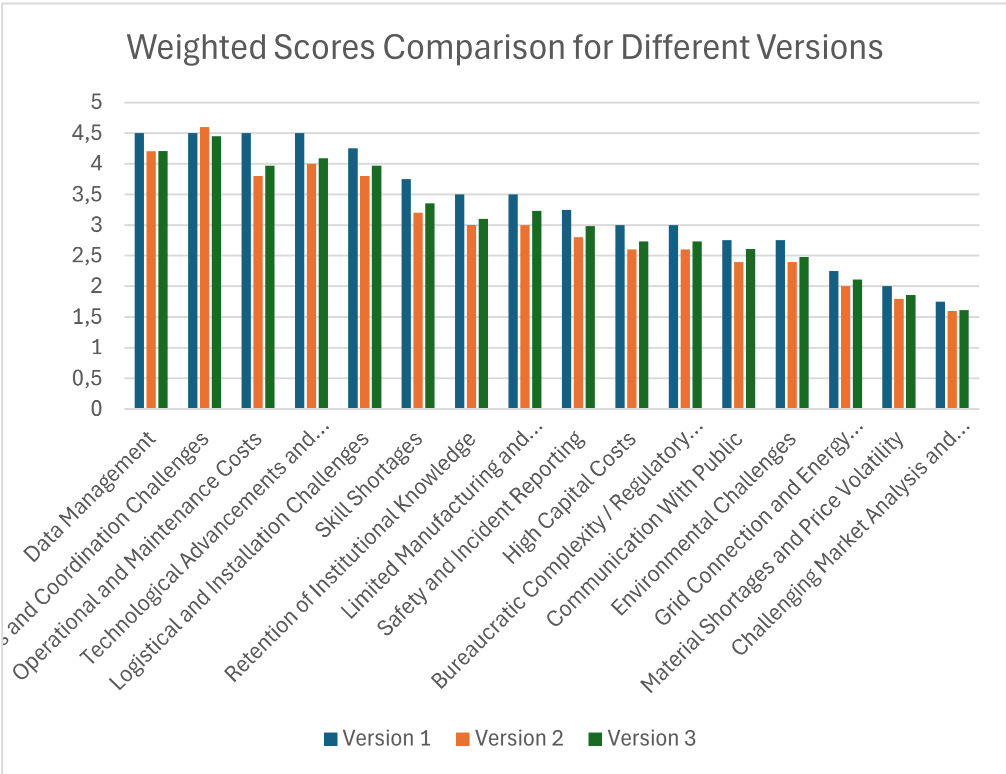
Version 2 - codes as separate criterion

	Technical Feasibility 20%	Impact 20%	Cost-Effectiveness 20%	Plausibility 20%	Code Occurrence 20%
Factor 1	*Rating 1-5*	*Rating 1-5*	*Rating 1-5*	*Rating 1-5*	*Score 1-5 I # Codes*
Factor 2	*Rating 1-5*	*Rating 1-5*	*Rating 1-5*	*Rating 1-5*	*Score 1-5 I # Codes*
Factor ...	*Rating 1-5*	*Rating 1-5*	*Rating 1-5*	*Rating 1-5*	*Score 1-5 I # Codes*
Factor 16	*Rating 1-5*	*Rating 1-5*	*Rating 1-5*	*Rating 1-5*	*Score 1-5 I # Codes*

Version 3 - codes as part of Impact criterion

	Technical Feasibility 25%	Impact 25%	Cost-Effectiveness 25%	Plausibility 25%
Factor 1	*Rating 1-5*	*Rating 1-5 I Codes*	*Rating 1-5*	*Rating 1-5*
Factor 2	*Rating 1-5*	*Rating 1-5 I Codes*	*Rating 1-5*	*Rating 1-5*
Factor ...	*Rating 1-5*	*Rating 1-5 I Codes*	*Rating 1-5*	*Rating 1-5*
Factor 16	*Rating 1-5*	*Rating 1-5 I Codes*	*Rating 1-5*	*Rating 1-5*

Factor	Version 1	Version 2	Version 3
Data Management	4,50	4,20	4,21
Process and Coordination Challenges	4,50	4,60	4,45
Operational and Maintenance Costs	4,50	3,80	3,97
Technological Advancements and Innovation	4,50	4,00	4,09
Logistical and Installation Challenges	4,25	3,80	3,97
Skill Shortages	3,75	3,20	3,35
Retention of Institutional Knowledge	3,50	3,00	3,10
Limited Manufacturing and Installation Capacity	3,50	3,00	3,23
Safety and Incident Reporting	3,25	2,80	2,98
High Capital Costs	3,00	2,60	2,73
Bureaucratic Complexity / Regulatory Challenges	3,00	2,60	2,73
Communication With Public	2,75	2,40	2,61
Environmental Challenges	2,75	2,40	2,48
Grid Connection and Energy Transmission	2,25	2,00	2,11
Material Shortages and Price Volatility	2,00	1,80	1,86
Challenging Market Analysis and Prediction	1,75	1,60	1,61



H. MCDA Matrices

This appendix includes the Multi-Criteria Decision Analysis (MCDA) matrices used in the framework development. The matrices, which are presented as PDF documents, serve as a comprehensive reference for the factors, criteria, and prioritization process discussed in the thesis.

Overview of Included MCDA Matrices

The following table provides an overview of the included MCDA matrices and their corresponding starting pages in this appendix:

MCDA 1 – Factor Evaluation

This section includes the outcome matrix, weighting matrix, and ratings matrix for the first MCDA iteration.

Rating	Factor
4,45	Process and Coordination Challenges
4,21	Data Management
4,09	Technological Advancements and Innovation
3,97	Operational and Maintenance Costs
3,97	Logistical and Installation Challenges
3,35	Skill Shortages
3,23	Limited Manufacturing and Installation Capacity
3,10	Retention of Institutional Knowledge
2,98	Safety and Incident Reporting
2,73	High Capital Costs
2,73	Bureaucratic Complexity / Regulatory Challenges
2,61	Communication With Public
2,48	Environmental Challenges
2,11	Grid Connection and Energy Transmission
1,86	Material Shortages and Price Volatility
1,61	Challenging Market Analysis and Prediction

Criteria	Weight (%)	Explenation
Technical Feasibility	25	Definition: The practicality of implementing BIM to address specific offshore wind project challenges. Key Considerations: – Availability of tools and technologies: Are there BIM-compatible tools to address the factor (e.g., for logistics, data management)? – Required skills and expertise: Does the team have the technical know-how to implement BIM for this factor? – Infrastructure readiness: Can the current digital infrastructure support BIM implementation? Example: For data management, BIM's ability to centralize and standardize data can be technically feasible, while for limited manufacturing capacity, its feasibility might be lower.
Impact	25	Definition: The potential extent to which BIM can improve outcomes for a given factor. Key Considerations: – Reduction of costs or delays: Does BIM significantly mitigate financial or time inef ficiencies? – Quality improvements: Can BIM improve project quality (e.g., fewer errors, better designs)? – Risk mitigation: Does BIM reduce risks associated with the factor (e.g., safety incidents, data errors)? Example: For process and coordination challenges, BIM's impact may be high due to its ability to facilitate communication across stakeholders and prevent clashes during construction. Compostion: 50% expert rating, 50% code occurance
Cost-Effectiveness	25	Definition: The balance between the costs of implementing BIM and the benefits it provides. Key Considerations: – Initial investment: How expensive is it to implement BIM for this factor? – Long-term savings: Does BIM reduce operational or lifecycle costs? – Return on Investment (ROI): Do the benefits outweigh the financial and time costs? Example: For operational and maintenance costs, BIM's ability to streamline asset management might make it cost-effective, whereas for communication with the public, the return on investment may be less evident.
Plausability	25	Definition: The likelihood of successfully implementing BIM in practice for a given factor. Key Considerations: – Stakeholder readiness: Are key parties (e.g., contractors, engineers, clients) willing to adopt BIM? – Organizational alignment: Does BIM align with the existing processes and workflows? – Cultural and regulatory acceptance: Are there regulatory or cultural barriers to implementing BIM for the factor? Example: For bureaucratic complexity and regulatory challenges, the plausibility may be lower due to stakeholder resistance or policy constraints.

	Technical Feasibility Weight: 25 %	Impact Weight: 12,5 %
Safety and Incident Reporting	Score = 3 BIM demonstrates strong technical feasibility for improving safety planning and hazard identification in offshore wind projects. Tools like 4D-BIM and automated, rule-based safety checks enhance the ability to anticipate risks and prevent accidents before construction begins, making these functionalities practical and achievable with existing technology. However, when it comes to incident and near-miss reporting systems, BIM's feasibility is limited. These systems often rely on real-time, human-driven inputs such as manual reporting through databases or dedicated safety tools, which are not inherently enhanced by BIM integration. Existing systems already fulfill reporting needs effectively, reducing the necessity for BIM involvement in this area. Additionally, advanced solutions like VR/AR for reporting and visualization hold potential but face significant costs and implementation complexity, which further limits their practical adoption. These challenges highlight a gap in BIM's technical feasibility for incident reporting compared to its success in proactive safety planning. Overall, while BIM excels in specific areas of safety management, its feasibility for incident and near-miss reporting remains uncertain, resulting in a score of 3.	Score = 3 Offshore wind projects already maintain a high baseline for safety through rigorous training, detailed risk assessments, and robust incident reporting systems, which are critical for managing inherently dangerous marine environments. This strong foundation limits the additional impact BIM can have on existing safety measures. BIM can, however, contribute positively by enhancing proactive safety planning through tools like 4D-BIM for hazard identification and rule-based site checks. As highlighted by Cheng et al., 2018, BIM-integrated approaches can improve evacuation planning and emergency management using dynamic escape path simulations and real-time environment sensing. While this methodology stems from oil and gas platforms, it can be adapted to offshore wind projects to optimize emergency preparedness, albeit with fewer hazards compared to oil and gas operations. Despite this potential, the existing systems for incident and near-miss reporting in offshore wind projects are already well-developed, which reduces BIM's overall impact in this area. Additionally, the added value of BIM for incident reporting remains uncertain, as current tools may suffice for tracking and documenting incidents.
Skill Shortages	Score = 4 BIM cannot replace personnel directly, but it can significantly enhance the efficiency of the existing workforce, helping to address skill shortages indirectly. By enabling predictive maintenance and improving maintenance planning, BIM reduces the labor needed for routine tasks and minimizes unexpected repairs, which optimizes resource allocation. Additionally, BIM can streamline collaboration and interface management between teams, lowering the time and effort required to coordinate across different project stakeholders. This, in turn, allows the workforce to focus on critical tasks, reducing overall labor demands. While BIM cannot solve certification gaps or replace specialized offshore training, it provides tools to make personnel more productive and effective, especially in areas like planning, coordination, and maintenance. Given its strong alignment with existing workflows and technologies, the implementation of BIM in this context is highly feasible.	Score = 4 Skill shortages present a critical challenge in offshore wind projects, and BIM can have a significant impact in mitigating their effects. While BIM cannot directly solve workforce shortages, its ability to optimize efficiency makes the challenge more manageable. Specifically, BIM can reduce the number of labor hours required by improving interface management and data management. By streamlining workflows, automating repetitive tasks, and enhancing collaboration, BIM minimizes the effort needed to coordinate between stakeholders. This allows existing personnel to focus on critical tasks, maximizing their productivity and reducing the overall burden caused by workforce gaps. If applied correctly, BIM's tools and processes can have a huge impact on alleviating skill shortages, even if they do not address root causes like training and retention. The improvements in operational efficiency make the challenge more manageable without requiring significant increases in personnel.

	Cost-Effectiveness Weight: 25 %	Plausability Weight: 25 %	Number of Mentions Weight: 12,5%		Weighted Score
Safety and Incident Reporting	Score = 3 While implementing advanced technologies like VR/AI in BIM involves significant upfront costs (e.g., software, hardware, and training), the value of improved safety outcomes cannot always be reduced to monetary terms. Safety incidents in offshore wind projects can have severe consequences, including loss of life, injury, and operational delays, which far outweigh the initial financial investment. BIM's ability to enhance hazard prevention and emergency preparedness, such as through dynamic escape route planning (as noted in \citet{Cheng2018}) and real-time safety visualizations, can make a critical difference in preventing accidents. Even if existing systems are functional, the added capabilities BIM offers—such as predictive planning through 4D-BIM—can justify the costs by potentially saving lives, improving worker confidence, and minimizing severe disruptions. Although the return on investment (ROI) is difficult to measure directly, the long-term benefits of enhanced safety planning and risk mitigation elevate BIM's cost-effectiveness.	Score = 4 The plausibility of implementing BIM-driven safety solutions, particularly through VR/AR-based training and simulations, is high under the right conditions. These technologies can replace traditional safety training methods by offering interactive, realistic scenarios that improve engagement and retention. Workers may view such tools as engaging and immersive—similar to "gaming"—which can enhance their willingness to participate and improve overall acceptance. Importantly, the successful implementation of these solutions primarily relies on internal support from organizational stakeholders, such as project managers, engineers, and HSE teams. Since safety improvements are driven largely within the organization, the role of external stakeholders is minimal, reducing resistance and simplifying adoption. The technological readiness of VR/AR tools aligns with growing digitalization trends in offshore wind projects. However, their success depends on quality execution and overcoming challenges such as high development costs and potential resistance to workflow changes. Given the critical focus on safety, internal stakeholders are likely to support technologies that demonstrate clear benefits for risk mitigation and training outcomes.	Weight: 1,72	Codes:28	2,98
Skill Shortages	Score = 4 BIM offers significant long-term cost-effectiveness in addressing skill shortages by enhancing the efficiency of the existing workforce. While initial implementation costs can be high, once the system is fully operational, the reduction in required personnel and the optimization of workflows can lead to substantial savings. BIM’s ability to streamline interface management and data management reduces the labor hours needed for repetitive or coordination-heavy tasks. Even minor improvements in team effectiveness, achieved through better planning, predictive maintenance, and collaboration tools, can result in enormous cumulative benefits over time. By enabling existing personnel to work more effectively and reducing the reliance on additional workforce, BIM provides long-term value that outweighs the upfront investment. The scalability of these improvements across multiple teams and project phases further amplifies cost savings.	Score = 3 Implementing BIM to address skill shortages is plausible but comes with notable challenges. While BIM introduces a shift in skill demands—requiring more IT and BIM experts rather than traditionally hard-to-find offshore wind specialists—its successful implementation also demands a paradigm shift in how work is approached. To fully realize the benefits of BIM, organizations need to undergo significant changes in workflows, processes, and collaboration methods. This transition can be complex, as it requires not only new skills but also a cultural shift toward digital tools and integrated ways of working. Without strong organizational alignment and willingness to adopt new practices, BIM’s effectiveness may be limited. Although the current market conditions favor the availability of IT and digital specialists, integrating these roles into offshore wind workflows still poses challenges in terms of training, adoption, and ensuring seamless collaboration between traditional and digital teams.	Weight: 1,40	Codes:17	3,35

	Technical Feasibility Weight: 25 %	Impact Weight: 12,5 %
Environmental Challenges	Score = 4 BIM demonstrates strong technical feasibility for addressing environmental challenges in offshore wind projects through its capabilities for sustainability assessments and lifecycle analysis. BIM supports tools for conducting energy performance simulations, tracking material usage, and evaluating the carbon footprint across the project lifecycle. These features enable offshore wind developers to make data-driven decisions that reduce energy consumption, minimize material waste, and lower ecological impacts during design, construction, and operations. BIM can further facilitate Lifecycle Assessments (LCA) and help align projects with sustainability standards (e.g., LEED) by providing accurate data and real-time optimization of environmental performance. This is particularly valuable for mitigating impacts like turbidity, sedimentation, and energy-related emissions. While marine-specific challenges—such as seabird collisions, habitat displacement, and underwater noise—may require integration with specialized ecological models and environmental monitoring systems, this does not reduce BIM's feasibility. Such integrations are technically achievable and complement BIM's core strengths in sustainability assessments.	Score = 3 BIM can have a huge overall impact on addressing environmental challenges by enabling detailed assessments of ecosystems and conducting advanced simulations to evaluate project impacts. Tools for sustainability assessments, energy performance modeling, and lifecycle analysis help optimize material use, reduce energy demands, and simulate long-term ecological impacts—key considerations for offshore wind projects. However, in EnBW's context, the impact of BIM may be somewhat reduced because environmental challenges are often addressed as technical requirements set by government regulations. For EnBW, meeting these requirements is a necessary step rather than an area for transformative improvement through BIM. That said, BIM can still serve as a valuable tool for mitigating public concerns. By showcasing simulations of future ecosystems that develop around turbine foundations (e.g., artificial reefs attracting marine life), BIM can help communicate the project's ecological benefits to stakeholders and the public, improving transparency and acceptance.
Logistical and Installation Challenges	Score = 5 BIM demonstrates high technical feasibility for addressing logistical and installation challenges in offshore wind projects. It has already been successfully implemented by contractors such as Heerema and extensively used in other construction sectors. BIM's capabilities, such as dock layouts, logistical planning, and lifting simulations, directly support critical tasks in these phases. These tools are not only established in traditional construction but are also easily adaptable to the offshore wind context, offering precise site coordination and workflow optimization. Additionally, research by \citet{Liu2024} highlights the integration of BIM with Radio Frequency Identification (RFID) technology to improve crane positioning accuracy during offshore construction. This method reduces positioning errors to within 0.4 meters, significantly improving the precision of hoisting operations compared to traditional methods like laser ranging. While this represents only a small fraction of BIM's broader potential, it underscores the system's technical feasibility for enhancing logistical accuracy in offshore wind projects. Given BIM's alignment with existing tools and the growing integration of complementary technologies like RFID, its feasibility for logistical and installation challenges is not only proven but also scalable.	Score = 4 BIM has a high impact on addressing logistical and installation challenges, particularly due to its ability to optimize processes like dock layouts, lifting simulations, and assembly planning. These tools are highly valuable for projects involving large components, where every operation is resource-intensive and costly. By improving precision and reducing the need for physical adjustments, BIM simulations can significantly lower risks, costs, and delays during logistics and installation phases. In the current market, developers like EnBW face increasing risks, particularly as floating wind projects emerge. In these scenarios, advanced simulations of component handling, positioning, and lifting operations become even more critical. BIM helps anticipate potential issues, enhances coordination, and ensures smooth execution, which is essential for project success. While BIM's highest impact may be seen by contractors, developers like EnBW can also benefit indirectly by reducing risks, improving schedule control, and ensuring efficient resource utilization. The ability to simulate complex operations before execution can lead to substantial savings and improved project outcomes.

	Cost-Effectiveness Weight: 25 %	Plausability Weight: 25 %	Number of Mentions Weight: 12,5%		Weighted Score
Environmental Challenges	Score = 2 The cost-effectiveness of applying BIM to address environmental challenges is relatively low, as many of these issues—such as noise mitigation or habitat displacement—do not fundamentally require BIM. While BIM can assist in sustainability assessments and lifecycle simulations, it is not the primary solution for challenges like underwater noise, seabird collisions, or habitat disruptions. Given BIM's limited direct impact on these issues, the return on investment (ROI) is questionable. The added costs of implementing BIM for environmental purposes, including developing simulations or integrating specialized models, may not deliver substantial benefits that justify the expense. Moreover, since many environmental challenges are addressed as regulatory requirements for EnBW, the role of BIM becomes supplementary rather than essential, further reducing its cost-effectiveness.	Score = 2 The plausibility of implementing BIM to address environmental challenges is relatively low in EnBW's current context. Solutions for these challenges, such as noise mitigation or habitat disruptions, typically require engineering-based approaches rather than BIM-driven solutions. While BIM can assist with advanced simulations and sustainability assessments, these tools do not directly address EnBW's most pressing environmental concerns, which are often resolved through technical solutions. However, BIM's plausibility may increase in the future if governments begin requiring more advanced simulations of ecosystems to demonstrate compliance with environmental standards. For now, this is not a high priority for EnBW, but it could play a larger role for governments or other stakeholders in the sector who focus on public transparency and ecosystem modeling.	Weight: 1,09	Codes:6	2,48
Logistical and Installation Challenges	Score = 4 BIM offers high cost-effectiveness for addressing logistical and installation challenges. While initial investments in software and personnel training are required, the benefits far outweigh these costs. Existing BIM solutions, such as tools for lifting simulations, dock layouts, and assembly planning, are readily available and do not require extensive development, reducing implementation expenses. The effect BIM can have in this area is substantial. By improving precision in site coordination, scheduling, and resource utilization, BIM reduces costly errors, delays, and inefficiencies. The ability to simulate operations involving large, resource-intensive components ensures that physical resources are used efficiently, saving time and money. Given the availability of off-the-shelf BIM solutions and their proven effectiveness, the overall costs are manageable, while the long-term savings through optimized operations make BIM a financially viable investment.	Score = 4 Implementing BIM for logistical and installation challenges is highly plausible, particularly due to its ability to be adopted in small, incremental steps. Many BIM applications, such as lifting simulations, dock layouts, and basic site coordination, can be implemented with low effort and investment as part of a testing phase. For example, initial use of BIM to create simple logistical plans or simulate crane positioning can deliver immediate benefits without requiring significant upfront investments or organizational changes. This phased approach allows EnBW to scale up BIM use gradually over time, avoiding the need for a massive paradigm shift or high initial costs. Over time, BIM applications can evolve into more complex tools, such as advanced assembly simulations or fully integrated logistical planning systems, as experience grows and processes mature. However, challenges remain, such as the need for personnel training or outsourcing to handle BIM tools effectively. Additionally, the dependence on external stakeholders for standardized data formats can hinder smooth integration. While solutions exist, these barriers require proactive collaboration to address.	Weight: 2,50	Codes:55	3,97

	Technical Feasibility Weight: 25 %	Impact Weight: 12,5 %
Grid Connection and Energy Transmission	Score = 3 BIM's technical feasibility for addressing grid connection and energy transmission challenges is moderate in the context of EnBW. While BIM provides capabilities for tasks such as infrastructure planning, site surveys, and cable route optimization, these tools are similar to those already applied in other areas of offshore wind projects, such as turbine layout and installation. BIM does not introduce new or unique technical aspects specific to grid connection and energy transmission that would significantly benefit EnBW. However, for Transmission System Operators (TSOs) and government agencies, BIM could offer greater value by improving grid integration planning, enabling simulations of fluctuating energy outputs, and supporting HVDC infrastructure development. If EnBW applies BIM extensively for its own projects, these stakeholders could indirectly benefit from the improved data management, visualization, and collaborative capabilities BIM provides. Given BIM's existing capabilities and the lack of additional technical benefits specifically for EnBW, its feasibility remains moderate but proven for general use in offshore infrastructure planning.	Score = 2 The impact of BIM on grid connection and energy transmission is relatively low in the context of EnBW. While BIM can offer benefits similar to its applications in logistics and installation—such as improved planning, visualization, and site coordination—it does not provide any unique or transformative advantages specific to grid connection. Grid-related challenges, such as subsea cable installation and energy transmission losses, primarily require engineering solutions and specialized technologies like HVDC systems. BIM's role here is supplementary at best, as it cannot directly address critical issues such as cable maintenance, protection, or integration with onshore grids. Additionally, these challenges are less central for EnBW compared to other stakeholders like Transmission System Operators (TSOs) or government agencies, where advanced grid integration planning and energy output simulations would have greater relevance.
Technological Advancements and Innovation	Score = 4 BIM demonstrates high technical feasibility for addressing challenges related to technological advancements and innovation in offshore wind projects. Advanced BIM tools are already standard practice for extraordinary and cutting-edge construction projects worldwide, particularly those involving large-scale investments and high technical complexity. These tools enable detailed simulations and planning for evolving turbine technologies, supporting tasks such as: Integration of new turbine models with varying specifications, Planning for the use of innovative materials and design improvements, Optimizing processes for specialized installation of larger and more advanced components. The proven success of BIM in managing complex projects makes it highly adaptable to offshore wind technology advancements. However, the marine environment introduces unique challenges, such as the unpredictability of weather conditions, which can complicate the reliability of construction schedules and simulations. This factor becomes even more relevant when considering climate change, which may exacerbate weather variability and increase planning uncertainties. Despite these challenges, BIM remains a highly feasible solution for supporting technological advancements, providing tools to simulate scenarios, optimize workflows, and address uncertainties during planning and execution.	Score = 5 The impact of BIM on managing technological advancements and innovation in offshore wind projects is very high. As manufacturers and designers continually push the boundaries of turbine technology—introducing larger, more efficient, but increasingly complex components—developers face mounting challenges. At the same time, profit margins for developers are shrinking, leaving little room for errors during planning, construction, and operations. BIM's ability to facilitate digitalized construction and operations planning and conduct advanced simulations is critical for ensuring these projects remain financially viable. By enabling early detection of errors and providing precise visualizations within the context of ever-narrowing margins, BIM reduces risks, prevents costly mistakes, and supports efficient execution. This level of optimization can be the decisive factor in keeping offshore wind projects on schedule and within budget, ensuring their overall feasibility. Given the increasing complexity of turbine technology and the financial pressures faced by developers, BIM offers solutions that are not just beneficial but potentially indispensable for sustaining project success.

	Cost-Effectiveness Weight: 25 %	Plausability Weight: 25 %	Number of Mentions Weight: 12,5%		Weighted Score
Grid Connection and Energy Transmission	Score = 2 The cost-effectiveness of applying BIM to grid connection and energy transmission challenges is relatively low in EnBW's context. While BIM tools can assist with planning and coordination tasks, these benefits are not unique and largely mirror its contributions to logistics and installation. The core challenges of grid connection, such as subsea cable maintenance, energy losses, and grid upgrades, require engineering solutions and technologies beyond BIM's capabilities. Given the limited added value of BIM for this factor, the costs associated with software implementation, personnel training, or integration efforts are harder to justify. BIM might enable incremental improvements, such as better visualization or route planning, but these benefits do not deliver significant financial returns for EnBW compared to the investment required.	Score = 2 While the implementation of BIM for grid connection and energy transmission is technically plausible, it has low relevance for EnBW's specific sector and business area. The primary challenges in this domain, such as grid upgrades, subsea cable maintenance, and energy integration, typically fall under the responsibilities of Transmission System Operators (TSOs) or government agencies, where BIM's capabilities—such as advanced planning and simulations—are more applicable. For EnBW, these tasks are peripheral to their core operations, reducing the motivation to invest in BIM solutions for this purpose. Although technically feasible, the lack of immediate value and alignment with EnBW's priorities limits its overall plausibility within their business scope.	Weight: 1,00	Codes:3	2,11
Technological Advancements and Innovation	Score = 5 The cost-effectiveness of BIM in managing technological advancements and innovation is high, particularly because many of the necessary models and tools are already available in the market. While BIM implementation requires processing capabilities, such as specialized software and skilled personnel, these costs are relatively minor compared to the high costs of turbine components, installation, and O&M operations in offshore wind projects. BIM can deliver significant savings by optimizing construction planning, identifying potential errors early, and streamlining operations. These savings can help offset implementation costs and provide long-term value. Given the scale of investment in offshore wind projects and the increasing complexity of turbine technologies, the potential financial benefits far outweigh the initial investments in BIM infrastructure.	Score = 4 While BIM is highly plausible for managing technological advancements and innovation due to the availability of high-quality BIM models from manufacturers, its successful implementation still requires a paradigm shift and significant organizational acceptance. For BIM to be fully effective, there needs to be a cultural shift within EnBW and its contractors toward digital-first workflows, emphasizing collaboration and data-sharing across all stakeholders. Additionally, the willingness of contractors to collaborate and adopt BIM-compatible processes is a critical factor. Without alignment between developers, contractors, and manufacturers, the integration of advanced BIM models into project workflows could face delays or inefficiencies. While these barriers are not insurmountable, they do reduce the immediate ease of implementation. Despite these challenges, BIM's ability to handle innovative materials and technologies, particularly where past experience is unavailable, provides significant advantages. Simulations allow teams to build virtual expertise and address uncertainties in planning, making the approach more attractive over time.	Weight: 2,12	Codes:42	4,09

	Technical Feasibility Weight: 25 %	Impact Weight: 12,5 %
Challenging Market Analysis and Prediction	Score = 2 BIM is not inherently designed to address market analysis and prediction challenges in the offshore wind industry. While BIM excels in managing project-specific data and facilitating planning, its core capabilities do not include advanced market forecasting or trend analysis. Insights derived from previous projects stored within BIM systems could potentially aid in some aspects of market analysis, but this application is indirect and not a core function of the tool. Other technologies, such as Vind AI or specialized AI-driven analytics tools, are better suited for market analysis and trend prediction. These tools can leverage big data, machine learning, and predictive modeling to provide a more accurate understanding of market conditions, such as pricing trends, supply chain dynamics, and technological advancements. While BIM can be coupled with AI technologies to expand its analytical potential, this integration is beyond its primary scope and would require additional tools, expertise, and development efforts. Given that BIM's role in market analysis is limited and requires substantial external enhancements, its technical feasibility for this factor remains low.	Score = 2 The impact of BIM on market analysis and prediction is on the lower end because this functionality is not a core capability of BIM. While BIM might provide limited insights from data on previous projects, it is not inherently designed to handle market trends, supply chain dynamics, or cost fluctuations. Other technologies, such as Vind AI and AI-driven predictive tools, are far better suited to these tasks due to their ability to analyze and model large datasets for forecasting. Although it is possible to couple BIM with AI technologies to enhance its capabilities, this integration is complex and outside the typical scope of BIM's core strengths. As such, the contribution BIM makes to addressing market analysis challenges is minimal and supplementary, rather than central or transformative.
Bureaucratic Complexity / Regulatory Challenges	Score = 3 While BIM offers strong potential for streamlining certain aspects of bureaucratic complexity, such as improving communication with regulatory bodies through simulations and visualizations, it is not a comprehensive solution for all regulatory challenges. BIM can facilitate processes like permitting by replacing lengthy text-based reports with method statements and dynamic visualizations, which help avoid misunderstandings and save time. These capabilities are straightforward for BIM to handle and align with its core strengths. However, many regulatory challenges—such as defining project requirements, managing contractual obligations, and ensuring compliance with environmental and legal standards—fall outside BIM's scope. These issues typically require legal expertise, policy alignment, and tools tailored specifically to regulatory compliance, rather than BIM's design and planning-oriented functionalities. Additionally, slow adoption of digital tools by governmental agencies and regulatory bodies remains a barrier, further limiting the feasibility of BIM addressing regulatory challenges holistically.	Score = 3 The impact of BIM on addressing bureaucratic complexity and regulatory challenges is moderate but has the potential to be high if used correctly. BIM's capabilities for visualization and simulation can streamline certain regulatory processes, such as permitting and compliance reporting, by replacing lengthy documentation with clear, interactive visual representations of planned work. This can save time, reduce misunderstandings, and improve communication between developers and regulatory bodies. However, the extent of BIM's impact depends on how it is applied. Many contractual requirements and regulatory compliance topics may not be easily visualized or simulated, limiting BIM's effectiveness in those areas. Additionally, while BIM can simplify processes like method statements and site layouts, it may not significantly influence areas like policy alignment or contractual negotiations, which are core components of regulatory challenges. More assessment is needed to determine which aspects of regulatory processes BIM can realistically address and where its limitations lie. While it offers clear advantages in some areas, its overall impact remains constrained by its inability to tackle the broader scope of regulatory compliance.

	Cost-Effectiveness Weight: 25 %	Plausability Weight: 25 %	Number of Mentions Weight: 12,5%		Weighted Score
Challenging Market Analysis and Prediction	Score = 2 While BIM could utilize data from other projects to provide limited insights into market trends, this is a relatively low-cost approach but with equally low impact. The ability to repurpose existing BIM data for market analysis does not require significant additional investments, but the effectiveness of these insights in addressing market dynamics is minimal. Given that BIM is not inherently designed for market analysis and prediction, and specialized tools like Vind AI are better suited for this purpose, the return on investment (ROI) for using BIM in this context is likely to be poor. The costs saved by reusing BIM data are outweighed by the low relevance and limited utility of its outputs in managing the complexities of market prediction.	Score = 1 If Vind AI was specifically developed for market analysis and prediction in offshore wind projects, the plausibility of using traditional BIM for this purpose becomes extremely low. Vind AI and similar tools are designed to directly address market trends, cost fluctuations, and supply chain dynamics, making them far more suitable and efficient than BIM, which was not created for these functions. Although BIM could theoretically be integrated with AI or other tools to support market analysis, this would require significant customization and still fall short compared to the capabilities of purpose-built solutions like Vind AI. Furthermore, if Vind AI is already in use, it eliminates the need to stretch BIM beyond its core capabilities, further reducing the practicality of applying BIM in this domain.	Weight: 1,35	Codes:15	1,61
Bureaucratic Complexity / Regulatory Challenges	Score = 4 The cost-effectiveness of using BIM for bureaucratic complexity and regulatory challenges is high, primarily because its application in this area leverages existing functionalities of BIM tools. Features like simulations, visualizations, and data centralization—already part of BIM's core applications—can be repurposed to streamline regulatory processes. This minimizes the need for significant additional investment in software development or personnel training. Given the high potential impact of BIM in areas like permitting and compliance reporting, even small adjustments to workflows can deliver substantial value. For example, replacing lengthy textual reports with dynamic visualizations can save time, reduce misunderstandings, and accelerate approvals, all without incurring major costs. While BIM may not solve all regulatory challenges, its ability to address specific pain points at a low incremental cost makes it a cost-effective option for improving bureaucratic processes.	Score = 2 The plausibility of using BIM to address bureaucratic complexity and regulatory challenges is low, primarily due to the need for widespread acceptance and adoption by governmental agencies and regulatory bodies. These entities are often slow to embrace new technologies, and for BIM to have a meaningful impact, it would require integration into standardized regulatory workflows across multiple organizations and jurisdictions. This level of adoption is challenging to achieve in the short term. BIM may still prove helpful in creating documents or enhancing communication with regulators, such as through visual simulations and concise method statements. However, its broader implementation to replace traditional bureaucratic processes faces significant barriers, including the inertia of existing systems and the need for interoperability with other developers and stakeholders. While BIM has potential in specific applications, the likelihood of achieving widespread adoption and standardization is currently low, reducing its overall plausibility for solving regulatory challenges comprehensively.	Weight: 1,20	Codes:10	2,73

	Technical Feasibility Weight: 25 %	Impact Weight: 12,5 %
Limited Manufacturing and Installation Capacity	Score = 3 While BIM provides robust tools for process optimization, such as precise planning, 3D visualization, and improved data exchange, its effectiveness is constrained when faced with a fundamental lack of physical resources (e.g., vessels, facilities, or personnel). BIM can reduce the demand for these resources by ensuring more efficient planning and execution, but it cannot address the root issue of insufficient capacity. For example, even with perfect process coordination, a shortage of jack-up vessels or manufacturing output still creates a bottleneck beyond BIM's control. Thus, while technically feasible within its scope, BIM's applicability to this challenge is limited, preventing a higher score.	Score = 3 While BIM offers valuable tools to optimize processes and reduce inefficiencies, its impact on limited manufacturing and installation capacity is ultimately limited by the nature of the challenge itself. The core issue—physical constraints like insufficient vessels, production facilities, or skilled workers—cannot be directly resolved through BIM. Even with perfect optimization, these fundamental shortages will persist and continue to bottleneck offshore wind projects. BIM's strength lies in improving process efficiency. For example: Reducing installation time through precise planning and simulation. Avoiding errors that lead to delays or the need for costly rework. Enhancing communication and coordination across stakeholders to minimize downtime. These benefits can reduce the severity of the challenge by maximizing the use of existing resources, but they remain incremental improvements. The reliance on external investments in infrastructure and labor scaling means BIM's impact cannot fully address the scale or scope of the problem.
Material Shortages and Price Volatility	Score = 3 While BIM offers tools that can assist in optimizing material use and procurement planning, its technical feasibility for addressing material shortages and price volatility is fundamentally limited. BIM can: Simulate material needs to allow for better forecasting. Improve communication with suppliers through accurate and detailed models. Reduce waste by ensuring precision in design and installation. These are useful contributions but fall short of directly addressing the core issue: global supply chain constraints and price fluctuations. The challenge lies not in planning or optimizing, but in the physical availability and cost stability of critical raw materials like steel or rare earth elements. No amount of BIM optimization can overcome geopolitical risks, inflation, or energy crises affecting material costs. Furthermore, relying on BIM for these challenges assumes that stakeholders across the supply chain are equipped with the same digital capabilities, which is not always the case. Smaller suppliers or manufacturers may not have the necessary infrastructure to fully integrate BIM workflows, limiting its technical feasibility in real-world applications. Lastly, while BIM can improve planning and procurement processes, this benefit is incremental and heavily dependent on external factors. For example, early material estimation might help secure contracts, but it cannot guarantee supply or mitigate sudden price hikes due to global market dynamics.	Score = 2 BIM's impact on material shortages and price volatility is limited because the root causes—global supply constraints, geopolitical risks, and market price fluctuations—are entirely outside its scope. While BIM can optimize material planning and reduce waste through precise forecasts, these benefits are marginal in the context of a challenge that primarily requires systemic supply chain solutions. From the interviews, it was noted that the error margins are already very low due to the significant planning expenditure required to ensure smooth construction. This suggests that developers and manufacturers are already doing an excellent job in coordinating materials, further reducing the potential impact BIM could have in this area. While BIM might reduce planning costs (which is outside the scope of this factor), its effect on material shortage is indirect and incremental.

	Cost-Effectiveness Weight: 25 %	Plausability Weight: 25 %	Number of Mentions Weight: 12,5%		Weighted Score
Limited Manufacturing and Installation Capacity	Score = 4 BIM is relatively cost-effective when considering its potential to optimize processes in the context of limited manufacturing and installation capacity. While implementing BIM requires investments in software, hardware, and training, these costs are often justified by the significant savings achieved through process improvements. For instance, optimizing the use of expensive installation vessels can save hundreds of thousands of euros for every day of reduced offshore operation time. Given the high costs associated with offshore projects, even small optimizations achieved through BIM can yield substantial returns on investment (ROI). However, the cost barrier of implementing BIM cannot be ignored. Developing interoperable models requires significant computational resources and specialized expertise, which can increase both upfront and operational expenses. Additionally, not all stakeholders may have the same level of technological readiness, potentially leading to inefficiencies or delays in realizing BIM's benefits. Despite these challenges, the high cost of inaction—such as delays caused by inefficient planning or resource mismanagement—makes BIM a worthwhile investment. Its ability to centralize data, minimize errors, and improve production and installation planning ultimately offsets its implementation costs. This balance of investment and tangible benefits, especially in reducing vessel time and streamlining planning processes, makes BIM a strong contender for cost-effectiveness in this context.	Score = 4 BIM's application to address limited manufacturing and installation capacity appears to be plausible, particularly in an industry increasingly open to adopting digital solutions. Larger contractors and manufacturers already utilize BIM and 3D modeling tools, which means the foundational technology and workflows are in place. These existing practices, such as exchanging 3D models and using a single source of truth, make it easier to implement BIM for process optimization without requiring a paradigm shift in industry practices. However, the collaborative effort required across stakeholders, especially when smaller companies are involved, presents challenges. Smaller contractors may lack the resources, technical expertise, or infrastructure to fully adopt BIM. The process of ensuring interoperability and standardization through protocols can also be complex and time-intensive, requiring clear coordination and buy-in from all parties. Despite these hurdles, the critical need for improving installation capacity serves as a strong motivator for stakeholders to experiment with and adopt BIM solutions. The construction industry's willingness to innovate in response to capacity constraints further supports the likelihood of successful implementation. Additionally, simpler applications of BIM, such as construction simulations and process optimization, are realistic and achievable with current tools, even for companies less experienced with BIM.	Weight: 1,26	Codes:12	3,23
Material Shortages and Price Volatility	Score = 2 BIM's cost-effectiveness in addressing material shortages and price volatility is limited. While BIM can optimize planning processes and reduce waste through better material forecasting, these benefits are marginal compared to the core issues driving costs: supply chain constraints and volatile material prices. Developers already spend heavily on planning to ensure smooth construction, as emphasized in the interviews, which has minimized error margins. This reduces the potential for BIM to provide additional cost-saving value in this area. Moreover, implementing BIM requires substantial upfront investments in software, training, and collaboration protocols. These costs can be hard to justify when the primary challenge—material shortages—cannot be directly influenced by BIM. While BIM may indirectly reduce some planning expenditure, its contributions to cost reduction in this context are incremental at best.	Score = 1 The plausibility of using BIM to address Material Shortages and Price Volatility is low. These challenges are fundamentally driven by external factors, such as global supply chain constraints, geopolitical risks, and price fluctuations, which BIM cannot influence. While BIM can optimize material planning and help forecast requirements, these contributions are incremental and add little value compared to existing tools. From the interviews, it was highlighted that Vind AI already plays a significant role in securing capacities and supply chains early. Vind AI's purpose-built capabilities are more effective in addressing these challenges, providing superior results for early procurement and material tracking. Introducing BIM for the same purpose would only lead to redundancy, as the benefits it might bring are minor compared to what Vind AI already achieves. This makes the idea of stretching BIM into this domain neither practical nor necessary.	Weight: 1,00	Codes:3	1,86

	Technical Feasibility Weight: 25 %	Impact Weight: 12,5 %
High Capital Costs	Score = 3 The use of BIM to address high capital costs in offshore wind projects is technically feasible but offers primarily second-degree benefits. BIM can indirectly reduce required capital costs by improving logistics, installation planning, and efficiency in construction. Through better simulations, data management, and the ability to learn from past projects, BIM helps minimize errors, optimize resource usage, and reduce unexpected costs, all of which contribute to a more efficient use of capital. BIM also plays a role in addressing the high risk associated with capital investments in offshore wind by providing tools for advanced risk assessment and mitigation. For example: -Simulations can help identify potential risks during installation or maintenance. -Good data management ensures that decisions are informed by accurate and reliable information, reducing uncertainty for investors. These contributions can make offshore wind projects more attractive to investors by lowering perceived risks, potentially reducing the required risk premium and improving access to financing. However, these are indirect impacts, as BIM does not address the root causes of high capital costs, such as reliance on specialized vessels or expensive components and maerials.	Score = 3 BIM's impact on addressing high capital costs is moderate. While it cannot directly reduce the substantial upfront capital required for offshore wind projects, it can help lower the risk profile, which is a significant contributor to financing costs. Offshore wind projects are characterized by long payback periods and high uncertainty, making risk an expensive factor. BIM can help mitigate these risks by improving planning accuracy, enabling better decision-making through reliable data, and minimizing inefficiencies in logistics and resource allocation. By leveraging BIM's capabilities to simulate scenarios, optimize processes, and learn from past projects, developers can reduce uncertainties that often inflate project budgets. This can make investments more attractive to financiers by lowering the perceived risks and, consequently, the risk premiums demanded by investors. While this does not dramatically decrease the required capital, it can ease access to financing and reduce overall project costs in the long term.
Operational and Maintenance Costs	Score = 5 BIM demonstrates very high technical feasibility for addressing operational and maintenance costs in offshore wind projects by enabling a shift from reactive or pre-scheduled maintenance to predictive, data-driven strategies. As highlighted in interviews, current practices often resemble "playing firefighters," with teams reacting to issues or following rigid schedules set by outdated tools like SAP, leading to inefficiencies, unnecessary maintenance, and prolonged downtimes. By integrating real-time sensor data and digital twins, BIM allows for predictive maintenance that minimizes unplanned repairs, reduces unnecessary tasks, and optimizes scheduling to ensure turbines remain operational for longer periods. Research by Eichner et al. (2022, 2024) further shows how BIM frameworks standardize data and improve decision-making, transforming maintenance into a proactive and cost-effective process. Given BIM's demonstrated effectiveness in other sectors, its readiness to leverage existing digital infrastructure, and its ability to drastically improve maintenance efficiency, it is highly feasible for addressing O&M costs.	Score = 5 BIM's potential impact on reducing operational and maintenance (O&M) costs in offshore wind projects is very high. Current practices rely heavily on outdated tools like SAP and poor document management, which hinder maintenance efficiency and increase costs. Switching to predictive, data-driven, and automated maintenance enabled by BIM can significantly reduce both O&M costs and turbine downtimes. By integrating maintenance processes with project design and lifecycle management, BIM ensures that maintenance becomes an integral part of the development process. This can improve decision-making, reduce unnecessary maintenance activities, and optimize scheduling, leading to substantial cost savings. The shift from reactive maintenance to predictive strategies not only minimizes financial risks but also enhances turbine performance and reliability over the project lifespan.

	Cost-Effectiveness Weight: 25 %	Plausability Weight: 25 %	Number of Mentions Weight: 12,5%		Weighted Score
High Capital Costs	Score = 3 BIM's cost-effectiveness in addressing high capital costs is moderate, as its benefits are largely a byproduct of its application in other areas rather than a direct contribution to reducing upfront costs. Implementing BIM requires a significant initial investment in software, training, and integration, which can be challenging for developers already grappling with high project costs. However, the potential long-term rewards justify these expenditures, particularly in the context of making projects more attractive to investors. By reducing risks and improving planning accuracy, BIM can lower the risk premium associated with offshore wind projects. This, in turn, can increase investor interest and create higher demand for stakes in projects, potentially leading to more competitive financing options. The indirect financial benefits of BIM—such as smoother logistics, better resource allocation, and more accurate risk assessments—can also result in cost savings during project execution, further enhancing its cost-effectiveness. That said, the high upfront costs of implementing BIM might not always be offset by its indirect benefits, particularly for developers with limited budgets or projects with already well-established financial models.	Score: 3 The plausibility of using BIM to address high capital costs depends heavily on its consistent and high-maturity application. While BIM offers tools that can indirectly reduce risks and improve project attractiveness to investors, its success relies on proper implementation and stakeholder alignment. BIM needs to be integrated into project workflows effectively, with a high level of maturity and consistent application across all phases. Without this, its potential benefits—such as improved risk management, cost optimization, and better visualization for investors—are unlikely to be realized. However, when applied correctly, BIM can yield significant monetary benefits that increase its acceptance among stakeholders. For example, investors are more likely to support a project if they are provided with a visually striking, comprehensive simulation that helps them better understand the project's scope and risks. This added clarity and confidence can lead to greater investment interest and a willingness to bear higher initial costs. That said, the need for high maturity and alignment across stakeholders reduces BIM's overall plausibility in addressing high capital costs. Its application is not straightforward and requires significant effort to integrate fully into project workflows.	Weight: 1,32	Codes:14	2,73
Operational and Maintenance Costs	Score: 4 When compared to the extremely high costs of maintenance and operation in offshore wind parks, the expenses associated with implementing BIM are relatively low. While initial investments in software, infrastructure, and personnel training may seem significant, they pale in comparison to the ongoing costs of unplanned maintenance, inefficiencies, and turbine downtimes. BIM's ability to transition O&M strategies to predictive, data-driven systems offers substantial long-term benefits, such as reduced downtime, optimized maintenance schedules, and minimized unnecessary maintenance activities. These benefits can result in significant lifecycle cost savings, especially in a sector where operational costs are a major financial burden. Additionally, the high initial costs of transitioning to BIM are one-time investments, and once integrated, the system's efficiency gains accumulate over time. As such, the upfront costs are far outweighed by the long-term reductions in operational and maintenance expenditures.	Score: 4 The plausibility of implementing BIM to address operational and maintenance costs is relatively high but not without challenges. BIM adoption in O&M requires significant organizational support and a paradigm shift, which can be difficult to achieve given entrenched workflows and resistance to change. However, the attractive benefits of BIM, such as cost savings, reduced downtime, and improved maintenance efficiency, can be demonstrated clearly and with minimal effort, making the case for adoption compelling to stakeholders. Interviews revealed that O&M personnel are actively seeking improvements and have raised concerns about unprofessional standards in current practices. The high costs associated with O&M operations further strengthen the justification for BIM investment, as it directly addresses inefficiencies and provides a strong return on investment. However, successful application requires adoption throughout the entire project lifecycle, from design to decommissioning, which complicates implementation and increases the need for cross-departmental alignment.	Weight: 1,23	Codes:11	3,97

	Technical Feasibility Weight: 25 %	Impact Weight: 12,5 %
Communication With Public	Score = 4 Using BIM for public communication and stakeholder engagement is highly feasible. If a 3D model or digital representation of the offshore wind park is already created for design and planning purposes, it can be easily repurposed for promotional and communication activities. These models allow for visually compelling presentations that simplify complex technical details and foster better understanding among non-technical stakeholders. The process of adapting existing BIM outputs for public communication requires minimal additional effort or resources, making it a byproduct of BIM's core functionalities. The technology and tools required for these visualizations are well-established, widely accessible, and straightforward to deploy for external communication.	Score: 2 While BIM can enhance public communication through visualizations and simulations, the overall impact on project success is relatively low. Public communication is typically not the highest priority in offshore wind projects compared to technical, financial, or logistical challenges. Although BIM's ability to create visually striking and accessible models can improve stakeholder understanding and trust, this benefit does not address the core challenges of project delivery. The contribution of better public communication to project success, while helpful, is more peripheral. Miscommunication with the public is unlikely to be a decisive factor in most offshore wind projects, as regulatory approval and technical execution typically have more significant impacts. Thus, while BIM can provide some value, its overall influence on the success of the project in this context is limited.
Retention of Institutional Knowledge	Score = 3 BIM can moderately support the retention of institutional knowledge. Its centralized platform and ability to store and manage data consistently across project lifecycles make it feasible to reduce reliance on fragmented, project-specific databases. BIM's functionality ensures that documents and lessons learned are stored in an accessible and organized manner, making retrieval more efficient. However, BIM is not explicitly designed for knowledge retention and would require additional customization or integration with specialized knowledge management systems to fully achieve this goal. Challenges include structuring data effectively for future usability and ensuring interoperability with other tools that might be better suited for institutional knowledge retention. While technically possible, it involves additional effort and resources.	Score = 4 Institutional knowledge retention has a significant impact on project success, particularly in complex and long-term offshore wind projects. Organizational learning plays a crucial role in improving efficiency and avoiding repetitive mistakes, and BIM's ability to centralize and streamline data can greatly enhance this process. By providing a structured, easily accessible source of information, BIM can address major challenges, such as interoperability and the availability of data from past projects, which were frequently highlighted in interviews as current pain points. Improving data accessibility and interoperability not only aids in smoother project execution but also facilitates more effective onboarding and training of personnel. A centralized platform reduces the effort and time required to locate historical data and lessons learned, enabling teams to apply insights more readily to new projects. These benefits can compound over time, making BIM a potentially transformative tool for institutional learning, particularly if implemented thoughtfully across the organization.

	Cost-Effectiveness Weight: 25 %	Plausability Weight: 25 %	Number of Mentions Weight: 12,5%		Weighted Score
Communication With Public	Score = 3 The cost-effectiveness of using BIM for public communication is moderate. While the initial investment in BIM tools and creating 3D models may seem high, leveraging these models for public communication purposes comes at a relatively low additional cost. Since the 3D park or digital twin is often already developed for technical and planning purposes, repurposing it for external communication involves minimal extra resources, making it a byproduct of existing BIM functionalities. However, the return on investment in this context is not substantial. Public communication and stakeholder engagement, while important, are not primary drivers of project cost savings or efficiency. The benefits of improved public understanding and acceptance may indirectly reduce delays or conflicts, but these impacts are less tangible and harder to quantify compared to BIM's effects on operational or technical challenges.	Score: 2 When considered in isolation, the plausibility of implementing BIM solely for public communication is low. The costs and effort required to establish BIM workflows are unlikely to be justified if the only objective is improving public engagement. Creating detailed 3D models or digital twins for communication purposes requires substantial investment in tools, training, and implementation, which would be impractical without broader project applications. While BIM's visual assets are highly effective for public communication, the benefits in this isolated context do not outweigh the resources needed to implement and maintain the system. Public communication, while important, is not typically a core challenge in offshore wind projects, and alternative, simpler tools could likely achieve similar results at a lower cost and effort.	Weight: 1,00	Codes:3	2,61
Retention of Institutional Knowledge	Score = 4 Retention of institutional knowledge through BIM is inherently cost-effective because it leverages tools and systems already being implemented as part of broader BIM adoption. While there are initial costs involved in shifting from Excel sheets and decentralized methods to a BIM-based approach, these are not unique expenses but rather an optimization of existing workflows. The financial benefits arise from reducing inefficiencies, such as the time employees spend searching for past data or lessons learned, and improving the accessibility and usability of historical project insights. Since lessons learned already play a critical role in the lifecycle of offshore wind projects, transitioning to a centralized BIM-based approach requires more of a reallocation of effort rather than a substantial increase in workload or investment.	Score: 3 Adopting BIM for institutional knowledge retention requires a paradigm shift toward consistent and high-maturity usage of the tool, which can make this application less feasible. BIM is not a purpose-built tool for lessons learned but functions more as an add-on to enhance the process, making its adoption less straightforward. This adds complexity, as it would demand organizational commitment to ensure interoperability, standardization, and proper training for users to integrate BIM effectively into knowledge retention workflows. However, EnBW's existing focus on lessons learned provides a strong foundation for gaining organizational support. If the current processes are suboptimal, demonstrating how BIM can address inefficiencies and improve data accessibility might lead to easier adoption. The potential organizational buy-in, combined with the clear benefits of reducing inefficiencies in knowledge sharing, creates an opportunity for feasibility. Still, the reliance on consistent BIM usage and maturity keeps the overall plausibility at a moderate level.	Weight: 1,49	Codes:20	3,1

	Technical Feasibility Weight: 25 %	Impact Weight: 12,5 %
Process and Coordination Challenges	Score = 5 From a technical standpoint, BIM is highly feasible for addressing process and coordination challenges in offshore wind projects. Existing literature demonstrates BIM's robust capabilities in improving coordination across project phases, ensuring seamless communication among stakeholders. For instance, Yang and Hu (2020), Bezkorovayniy et al. (2018), and Jia (2019) highlight BIM's effectiveness in handling complex data exchanges and integrating information throughout the project lifecycle, which are critical for overcoming coordination barriers. BIM's technical compatibility with tools such as Geographic Information Systems (GIS) and project lifecycle management systems further enhances its applicability. Cloud-based BIM platforms enable multiple stakeholders to access and modify project data simultaneously, reducing errors and ensuring data consistency. The ability to automate updates and maintain a single source of truth minimizes version conflicts, as shown in studies like Lou and Shin (2020). This makes BIM a technically strong tool for addressing the intricate demands of process coordination. While organizational and stakeholder-related hurdles may pose implementation challenges, these are managerial rather than technical issues. Technically, the tools and workflows required for effective coordination already exist and have been proven in multiple contexts.	Score: 5 The potential impact of BIM on addressing process and coordination challenges is extremely high, as corroborated by both literature and interview data. BIM's ability to centralize project information, provide real-time updates, and enable interoperability makes it a powerful tool for improving coordination in offshore wind projects. Bezkorovayniy et al. (2018) and Yang and Hu (2020) emphasize BIM's effectiveness in managing transitions between project phases and improving supplier coordination, which are critical for complex and large-scale projects like those in offshore wind. Interviews consistently highlighted process and coordination as a significant area needing improvement. BIM's integration can bridge gaps between stakeholders, align processes, and prevent misalignments, especially given EnBW's current shift from a project-by-project approach to managing multiple projects simultaneously under tight market conditions. This shift demands stronger coordination frameworks, and BIM provides the tools necessary to establish these processes while reducing risks and delays. Moreover, BIM's connection to other factors such as logistics and high capital costs further amplifies its impact. Effective coordination not only streamlines workflows but also enhances cost management and logistical planning, creating a ripple effect across multiple aspects of project execution. Given the lack of standardized processes at EnBW and the high relevance of establishing workflows that adapt to evolving market dynamics, BIM's integration during process creation is especially impactful.

	Cost-Effectiveness Weight: 25 %	Plausability Weight: 25 %	Number of Mentions Weight: 12,5%		Weighted Score
Process and Coordination Challenges	Score = 4 Implementing BIM to address process and coordination challenges will undeniably incur significant initial costs. These include tailored software solutions to meet EnBW's specific needs, extensive training for employees, and potentially hiring new personnel or subcontracting experts for implementation. However, the potential benefits substantially outweigh these expenses. As highlighted in interviews, EnBW's current lack of standardized processes and reliance on project-by-project coordination lead to inefficiencies and additional costs. BIM's ability to integrate workflows, enhance collaboration, and reduce misalignments directly addresses these issues, delivering significant savings over time. For example, improved coordination and planning reduce rework, delays, and miscommunication, which are costly in both financial and operational terms. Moreover, the literature (Bezkorovayniy et al., 2018; Yang and Hu, 2020) supports BIM's effectiveness in optimizing lifecycle cost management and streamlining processes across complex projects. Considering EnBW's position in managing multiple projects under tight market conditions, the long-term benefits of adopting BIM—such as improved efficiency, reduced delays, and cost savings in coordination—make the investment highly justifiable. The balance between the initial expenditure and the extensive lifecycle benefits solidifies BIM's cost-effectiveness in this context.	Score = 4 The plausibility of implementing BIM to address process and coordination challenges is relatively high, despite requiring a significant paradigm shift. This is a pressing issue for EnBW, and BIM's core strengths align well with the organization's needs, offering strong motivation for adoption. Higher-level management is already concerned with improving coordination and processes, which increases the likelihood of securing the organizational support necessary to implement BIM effectively. Furthermore, EnBW has shown a high willingness to adopt new technologies, which could facilitate the cultural and procedural shift required for successful BIM integration. While challenges such as interoperability and inconsistent data formats remain, these are not unique to EnBW but common across the construction and engineering sectors. Established solutions and best practices for these issues already exist, further supporting the feasibility of BIM adoption. Given the organizational focus on this challenge, the availability of solutions, and the strong alignment of BIM's capabilities with EnBW's needs, the plausibility of adoption is high, supporting a score of 4.	Weight: 5,00	Codes:142	4,45

	Technical Feasibility Weight: 25 %	Impact Weight: 12,5 %
Data Management	Score = 5 The technical feasibility of applying BIM for data management in offshore wind projects is extremely high, as centralized data management and real-time collaboration are core capabilities of BIM. The centralization of all project-related data into a single, accessible platform aligns directly with the requirements for efficient document management and smart data systems. This approach minimizes fragmentation, reduces errors, and enhances decision-making, as supported by Azhar et al. (2012) and Lou et al. (2021). Moreover, BIM's support for open-standard formats, such as Industry Foundation Classes (IFC), ensures seamless interoperability across various software systems. This capability is particularly relevant in offshore wind projects, where multiple stakeholders and software platforms need to collaborate effectively (Lou et al., 2021; Singh et al., 2011). By enabling real-time updates and access to the most current data, BIM reduces versioning conflicts and fosters better communication among stakeholders, as highlighted by Shin (2017) and Ivson et al. (2020). Real-world implementations, such as those discussed by Yang and Hu (2020), have demonstrated BIM's ability to integrate smart data systems and optimize decision-making in complex engineering contexts. The proven track record of BIM in construction and engineering projects, combined with its ability to address specific offshore wind challenges like data safety and standardization, confirms its technical capability for this application. Therefore, BIM is not only technically feasible but also highly effective in tackling data management issues in offshore wind projects.	Score = 5 Data management is a critical area for improvement in offshore wind projects, as consistently highlighted in interviews. The current reliance on tools like Think Project, while functional, still revolves around outdated document-based systems rather than leveraging actionable, integrated data. BIM offers a transformative approach by moving away from static documents to centralized, smart data systems that enable real-time collaboration and data-driven decision-making. Switching to BIM can help resolve many ongoing struggles by introducing structured and standardized processes that reduce fragmentation and inconsistency. This aligns with the feedback that existing tools and processes are not fully optimized, leaving room for significant efficiency gains. The ability to work with live, interconnected data rather than static files represents a paradigm shift that would directly address these pain points. Moreover, the adoption of BIM has the potential to go beyond incremental improvements by fundamentally changing how data is managed and shared across teams. This is especially relevant in EnBW's context, where managing multiple projects simultaneously under tight market conditions requires robust, reliable, and accessible data systems. The shift toward data-centric workflows would not only improve project execution but also enhance strategic decision-making and operational efficiency. The interviews have consistently stressed that moving away from document-based workflows to actual, usable data is essential. BIM's capabilities perfectly align with this goal, positioning it as a high-impact solution for improving data management in offshore wind projects.

	Cost-Effectiveness Weight: 25 %	Plausability Weight: 25 %	Number of Mentions Weight: 12,5%		Weighted Score
Data Management	Score = 4 Implementing BIM for data management involves upfront costs, including software acquisition, potential customization to meet EnBW's specific needs, and significant investment in training personnel. Additionally, integrating BIM with existing systems, such as Think Project, and ensuring interoperability across platforms might require additional resources and time. However, these costs must be weighed against the potential long-term benefits. BIM's centralized data management, real-time updates, and seamless collaboration capabilities can substantially reduce inefficiencies caused by fragmented data and outdated document-based workflows. This would lead to significant time savings, fewer errors, and better project coordination, which ultimately result in cost reductions over the project lifecycle. Moreover, transitioning to data-driven workflows with BIM can support process improvements that are not limited to individual projects but extend across the organization. While the initial investment is not negligible, the ongoing costs are expected to be relatively low compared to the substantial benefits, particularly when applied at scale across multiple projects. The recurring issue of inefficiency in current data management systems, as highlighted in interviews, makes this investment even more justifiable. By addressing these inefficiencies, BIM can unlock significant financial value through reduced delays, streamlined operations, and improved decision-making. While the upfront costs are substantial, the long-term gains in operational efficiency, reduced rework, and better project outcomes make the implementation of BIM for data management highly cost-effective.	Score = 4 The implementation of BIM for data management is plausible but requires overcoming several barriers. While the technical feasibility is high, as BIM is inherently designed for centralized data management, the challenges lie in the organizational and procedural shifts needed to ensure successful adoption. Interviews highlighted the ongoing inefficiencies in existing systems like Think Project, which rely on outdated, document-based workflows rather than data-driven approaches. This indicates a strong need and motivation for improvement, increasing the plausibility of BIM adoption. Furthermore, transitioning to data-centric workflows aligns well with EnBW's organizational goals, particularly as it scales up operations and undertakes multiple offshore wind projects simultaneously. However, achieving this transition requires a paradigm shift in how data is managed across the organization. Stakeholders must commit to adopting BIM consistently across project lifecycles, and significant training and change management efforts will be necessary. Despite these challenges, there appears to be a willingness to adopt new technologies and improve current processes, as expressed in interviews. This creates a conducive environment for the adoption of BIM for data management. The interoperability challenges between existing systems and BIM, while notable, are not unique to EnBW. Solutions, such as open standards like IFC and customized integration tools, are widely available and proven effective in similar industries. Combined with the high demand for improved data management, these factors make BIM adoption for data management a plausible step forward, particularly given the pressing need for efficiency and standardization in current operations.	Weight: 3,76	Codes:99	4,21

MCDA 2 – Factor Evaluation

This section includes the outcome matrix, weighting matrix, and ratings matrix for the second MCDA iteration.

Ranking	Weighted Score	Factor
1	4,80	Data Management
2	4,80	Operational and Maintenance Costs
3	4,30	Process and Coordination Challenges
4	3,70	Technological Advancements and Innovation
5	3,60	Logistical and Installation Challenges

Criteria	Weight (%)	Explenation for Change
Technical Feasibility	30	Offshore wind projects involve complex logistics, harsh environments, and long operational lifespans, making the technical viability of any digital solution critical. BIM's technical capabilities, as evidenced in the application scenarios and cross-sector implementation examples, are robust. However, ensuring that these solutions can withstand offshore-specific conditions and integrate with marine operations is paramount. Feasibility is foundational—if BIM is not technically capable, the other benefits cannot be realized—justifying an increase to 30%.
Impact	30	Offshore wind projects are highly capital-intensive, with delays, miscommunication, and poor coordination resulting in substantial financial and operational risks. The application scenarios highlighted BIM's potential to streamline processes, reduce errors, and optimize maintenance, which aligns strongly with offshore wind's need for precision and risk reduction. Since a well-targeted BIM application could address some of the most pressing challenges, the impact potential is prioritized at 30%.
Cost-Effectiveness	20	While cost considerations are always relevant, offshore wind projects inherently involve large investments. In this context, cost-effectiveness is more about ensuring long-term efficiency gains than minimizing upfront expenses. Since BIM's financial returns often materialize gradually and require initial investment, cost—though important—is not as decisive as feasibility or impact, warranting a reduction to 20%.
Plausability	20	Plausibility is vital, but early evaluations suggest BIM's core functionalities align well with EnBW's operational challenges. While organizational barriers and the need for change management exist, there is already an expressed demand for better digital solutions. Therefore, plausibility is still relevant but less of a differentiator, meriting a reduction to 20%.

	Technical Feasibility Weight: 30 %	Impact Weight: 30 %
Logistical and Installation Challenges	Revised Justification (Score = 5): BIM demonstrates high technical feasibility for addressing logistical and installation challenges in offshore wind projects. Its successful implementation by contractors such as Heerema and other offshore heavy-lift specialists, combined with extensive applications in the broader construction sector, affirms its suitability for this context. BIM's capabilities in dock layouts, logistical planning, vessel coordination, and lifting simulations are not only well-established in conventional construction but have also proven adaptable to offshore environments. Tools such as Navisworks, Synchro, and Bentley LiftSim are already widely applied to simulate complex lifting operations, plan barge movements, and visualize sequencing processes—features that align directly with the requirements of offshore wind logistics and installation phases. The integration of BIM with complementary technologies, such as Radio Frequency Identification (RFID) to enhance crane positioning accuracy, further underscores its feasibility. Research by \citet{Liu2024} demonstrated that this combination reduces positioning errors to within 0.4 meters during offshore construction, significantly improving hoisting precision compared to traditional methods like laser ranging. This example highlights BIM's capacity to enhance offshore construction processes and exemplifies its potential when integrated with emerging technologies. Practical validation from the development of application scenarios further reinforced BIM's suitability in this area. The scenario work illustrated how BIM-supported sequencing, lifting simulations, and visual path optimization effectively reduce operational risk and enhance site coordination during offshore installations. While certain offshore-specific variables, such as weather conditions, currents, and vessel dynamics, remain beyond the scope of BIM's core capabilities, these limitations are well understood in practice and do not diminish BIM's feasibility. Moreover, integration with marine simulation software, such as OrcaFlex or Kongsberg tools, is common in the industry, representing a complementary step rather than a technical barrier. Considering the extensive industry adoption, the maturity of available tools, and the results from the scenario work, BIM's technical feasibility for supporting logistical and installation challenges is confirmed. Therefore, a score of 5 remains appropriate.	Revised Justification (Score = 3): BIM has a notable impact on addressing logistical and installation challenges in offshore wind projects, primarily through its capacity to optimize processes such as dock layouts, vessel coordination, lifting simulations, and assembly planning. These tools are particularly valuable for offshore construction, where large components, narrow weather windows, and costly vessel operations make precise planning essential. BIM's ability to improve accuracy and identify potential issues in advance reduces the need for physical adjustments, lowering risks and minimizing costly delays during installation. However, while the application scenarios confirmed these benefits, they also highlighted that the most direct and substantial impact is realized by contractors responsible for offshore transport and installation. Developers like EnBW primarily benefit indirectly, as improved planning reduces overall project risks, enhances schedule reliability, and supports efficient resource utilization. Yet, these advantages are less pronounced compared to the direct operational gains experienced by contractors. Given that EnBW's role is more focused on overseeing project delivery rather than conducting installation activities, the impact, while still significant, is better reflected by a score of 3.

	Cost-Effectiveness Weight: 20 %	Plausability Weight: 20 %	Weighted Score
Logistical and Installation Challenges	Revised Justification (Score = 3): BIM presents notable cost-effectiveness for addressing logistical and installation challenges in offshore wind projects. While initial investments in software licenses, personnel training, and process adaptation are necessary, these costs are generally manageable, especially as established BIM solutions for lifting simulations, vessel planning, and assembly coordination are readily available and already applied in offshore construction. The cost-saving potential is substantial, as BIM reduces errors, optimizes resource utilization, and enhances scheduling efficiency. However, the application scenarios highlighted that the most significant financial benefits are again concentrated on contractors responsible for offshore operations, who bear the highest costs related to vessel time, heavy lifting, and weather-dependent delays. For developers like EnBW, the financial returns are more indirect—stemming from reduced project risk and improved coordination—rather than direct operational cost reductions. This indirect nature of the primary cost benefits for EnBW, coupled with the fact that certain advanced BIM functionalities may require ongoing customization or integration with existing project management systems, suggests that the cost-effectiveness, while still favorable, is better reflected with a rating of 3.	Revised Justification (Score = 3): While BIM's application to logistical and installation challenges is technically feasible and has been demonstrated by contractors, its plausibility within EnBW's organizational context is more limited. As a project developer, EnBW is typically not directly involved in the detailed planning and execution of offshore installations. These responsibilities primarily fall to contractors, who already employ specialized BIM tools for lifting simulations, dock layouts, and offshore assembly planning. Although EnBW could potentially benefit from greater oversight and improved coordination with contractors, the company's current focus and expertise lie more in project development and overall project management rather than the hands-on execution of logistical processes. Introducing BIM for installation planning within EnBW would likely require overcoming cultural and structural barriers, such as rethinking existing interfaces with contractors and ensuring that EnBW's internal teams possess the necessary skills to interpret and act on BIM-generated plans. Furthermore, the integration of EnBW's internal systems with contractor systems would require a collaborative data-sharing environment, which can be challenging given the varying digital maturity levels across suppliers. While these hurdles are not insurmountable, they reduce the overall plausibility compared to other areas where EnBW holds more direct control over processes.	3,6

	Technical Feasibility Weight: 30 %	Impact Weight: 30 %
Technological Advancements and Innovation	Revised Justification (Score = 4): BIM demonstrates high technical feasibility for supporting technological advancements and innovation within offshore wind projects. The development of detailed simulations, integration of new turbine models, and optimization of processes involving larger and more advanced components align well with existing BIM capabilities. Tools facilitating these tasks are already established in the AECO industry and have been adapted successfully in other offshore sectors. However, while the fundamental technical capabilities are present, certain limitations specific to offshore environments introduce complexity. For example, interviewees highlighted the challenge of accounting for unpredictable weather conditions and dynamically changing marine environments, which can reduce the reliability of simulations if not properly integrated into BIM workflows. Nonetheless, this constraint relates more to data input quality and process integration than to inherent limitations of BIM itself. Given that BIM tools can accommodate the complexity of cutting-edge offshore installations, the technical feasibility rating remains high. A slight reduction could be justified if emphasizing the complexity of marine-specific uncertainties, but the overall consensus from both the literature and focus group discussions supports retaining the score of 4.	Revised Justification (Score = 5): BIM has a substantial impact on managing technological advancements and innovation within offshore wind projects. As turbine manufacturers push the boundaries with increasingly larger and more efficient models, developers and contractors face rising complexity in both design and construction processes. These advancements introduce tighter tolerances and reduce margins for error, placing greater emphasis on precision and coordination throughout project execution. BIM's capacity to support digitalized planning and advanced simulation is critical under these conditions. It allows for the early detection of design conflicts and facilitates the visualization of complex component assemblies. In the context of offshore wind, where transporting, installing, and maintaining large, cutting-edge turbines is logistically challenging, BIM mitigates risks and improves efficiency. The focus group underscored that as turbines grow in size and complexity, the need to preemptively simulate transport and installation becomes increasingly vital to avoid costly setbacks during offshore operations. While contractors benefit most directly from these capabilities, developers like EnBW also experience indirect gains. Enhanced planning minimizes delays, improves resource utilization, and safeguards project timelines—factors crucial in an environment where financial margins are tightening. The application scenarios further emphasized BIM's potential to streamline interfaces between manufacturers, developers, and contractors, ensuring that evolving technologies can be integrated smoothly into project workflows. Given the growing complexity of turbine technology, the consensus among industry experts suggests that BIM's role is evolving from a beneficial tool to an essential enabler of technological innovation in offshore wind development.

	Cost-Effectiveness Weight: 20 %	Plausability Weight: 20 %	Weighted Score
Technological Advancements and Innovation	Revised Justification (Score = 5): BIM demonstrates high cost-effectiveness in managing technological advancements and innovation in offshore wind projects. Many of the necessary software solutions, such as tools for 3D modeling, clash detection, and advanced simulation, are readily available and well-established in both the AEC industry and offshore sectors. These off-the-shelf solutions reduce development costs and can be integrated into existing workflows with relative ease. While the initial implementation requires investment in software licenses, staff training, and adjustments to project processes, these costs are minor compared to the overall capital expenditure associated with offshore wind projects—particularly given the increasing size and complexity of turbine components and installation operations. The focus group discussions emphasized that reducing errors during planning and installation is critical, as mistakes involving large, specialized components offshore can lead to extensive delays and significant financial losses. BIM's ability to detect design clashes early, optimize logistics for turbine installation, and support more precise planning directly translates into cost savings. These savings arise from avoiding rework, minimizing offshore vessel time, and ensuring smoother construction processes. Over the project lifecycle, the financial benefits generated through reduced risk and improved efficiency are likely to outweigh the initial investment, making BIM a highly cost-effective solution for supporting technological advancements in offshore wind development.	Revised Justification (Score =): While BIM applications supporting technological advancements and innovation exhibit strong technical feasibility, their practical implementation at EnBW faces several challenges, warranting a moderate plausibility rating. Although incremental adoption of BIM-supported processes—such as simulations for new turbine models or VR-based safety training—has proven successful in certain offshore wind contexts (e.g., drone applications and AR safety walkthroughs discussed in the focus group), the broader integration of BIM across innovation-related processes remains uncertain. This is primarily due to EnBW's limited experience with BIM and the absence of a standardized digital ecosystem that seamlessly links planning, construction, and operations. The potential of BIM for enabling innovative workflows, particularly in floating wind and advanced installation processes needs to be acknowledged, but successful application depends heavily on robust data maintenance and organizational acceptance also needs to be adressed. Furthermore, the willingness to adopt digital solutions varies within EnBW, as highlighted in the discussion on resistance to data input procedures and user-friendliness. While innovation-driven teams (e.g., those experimenting with drones and AR) may be more receptive, departments with more traditional practices could pose barriers. The need for coordination with external stakeholders, such as turbine suppliers and contractors, further complicates the seamless integration of BIM into innovation processes. Given these organizational and cultural hurdles, the plausibility of fully leveraging BIM for technological advancements should be considered moderate, reflecting both the promising potential and the notable implementation challenges.	3,7

	Technical Feasibility Weight: 30 %	Impact Weight: 30 %
Operational and Maintenance Costs	Revised Justification (Score = 5): BIM demonstrates very high technical feasibility for addressing operational and maintenance (O&M) costs in offshore wind projects. The technology's capacity to integrate sensor data, create digital twins, and facilitate real-time condition monitoring aligns closely with the needs of offshore wind O&M processes. Current industry practices often rely on rigid schedules driven by traditional tools like SAP, leading to reactive "firefighting" approaches when issues arise. BIM's functionality supports a transition to predictive maintenance, enabling early detection of potential failures, optimized maintenance scheduling, and improved resource planning. Application scenarios illustrate how digital twin models can aggregate sensor data from turbines, visualize component health, and automate maintenance planning. This allows operators to proactively manage maintenance activities, reducing both downtime and unnecessary site visits. Furthermore, existing BIM-enabled solutions for asset management and condition monitoring are already employed in other sectors, indicating that the underlying technology is mature and adaptable to offshore wind operations. Combined with EnBW's existing digital infrastructure and the increasing industry focus on data-driven maintenance, BIM is highly feasible for optimizing O&M processes in offshore wind projects.	Revised Justification (Score = 5): BIM's potential impact on reducing operational and maintenance (O&M) costs in offshore wind projects remains very high. Current practices frequently rely on outdated tools like SAP and fragmented document management systems, which contribute to inefficiencies, delayed responses, and increased maintenance costs. BIM supports a shift toward predictive, data-driven, and automated maintenance, enabling early identification of potential failures and facilitating better resource allocation. By integrating maintenance processes with the design and lifecycle management of turbines, BIM creates a continuous flow of accurate data throughout the project lifecycle. This approach ensures that maintenance is not treated as a separate, reactive activity but becomes embedded in the overall project development and operational strategy. As a result, BIM can optimize maintenance schedules, reduce unnecessary site visits, and minimize unplanned downtime—leading to substantial cost reductions over the long term. The growing complexity of offshore wind assets and the increasing focus on maximizing uptime further amplify BIM's value. Its capacity to enhance decision-making and enable condition-based maintenance strategies makes it a crucial tool for operators like EnBW aiming to reduce O&M costs and improve asset performance across the project lifespan.

	Cost-Effectiveness Weight: 20 %	Plausability Weight: 20 %	Weighted Score
Operational and Maintenance Costs	Revised Justification (Score = 5): BIM demonstrates very high cost-effectiveness for addressing operational and maintenance (O&M) costs in offshore wind projects. The focus group discussions emphasized the significant inefficiencies in current O&M practices, with participants highlighting reliance on rigid, schedule-driven approaches and limited integration of real-time data. These practices often lead to unnecessary maintenance interventions and costly downtime. BIM, particularly when integrated with sensor data and digital twin technologies, enables a transition to predictive maintenance strategies. This allows for early identification of potential failures and more efficient scheduling of maintenance activities. The scenarios developed during the second iteration illustrated how BIM-based systems could centralize condition monitoring data, automate work order generation, and facilitate offshore maintenance planning, ensuring that vessel trips and technician deployments are optimized. While initial costs for software implementation, sensor integration, and staff training may be substantial, the long-term financial benefits are likely to outweigh these investments. Reduced downtime, fewer unnecessary inspections, and improved planning efficiency lead to lower overall O&M expenditures. The focus group further stressed that predictive maintenance is already gaining traction in parts of the industry, and BIM could act as a catalyst to streamline its broader adoption. Therefore, BIM is assessed as highly cost-effective for improving O&M processes in offshore wind operations.	Revised Justification (Score = 4): The plausibility of implementing BIM to address operational and maintenance (O&M) costs is relatively high, though it remains dependent on overcoming several organizational and procedural barriers. Successful integration requires alignment across the entire project lifecycle—from design to decommissioning—which can be challenging given the traditionally siloed nature of departments within offshore wind projects. The transition from document-centric tools, such as SAP, to a BIM-based, data-driven approach demands significant organizational support, investments in training, and a shift in established workflows. However, the potential benefits of BIM—such as reducing turbine downtime, optimizing maintenance scheduling, and enhancing decision-making—can be clearly demonstrated, providing a compelling incentive for stakeholders. The high operational costs and increasing complexity of offshore wind farms further amplify the need for efficiency improvements, strengthening the case for BIM adoption. Additionally, the growing dissatisfaction with current O&M practices and the demand for professionalization within maintenance teams increase the likelihood of acceptance. While initial resistance is expected, the demonstrated return on investment and the increasing digitalization of the industry suggest that BIM adoption for O&M is plausible, provided that change management is adequately addressed and cross-departmental cooperation is ensured.	4,8

	Technical Feasibility Weight: 30 %	Impact Weight: 30 %
Process and Coordination Challenges	Revised Justification (Score = 5): BIM demonstrates very high technical feasibility for addressing process and coordination challenges in offshore wind projects. BIM platforms are specifically designed to facilitate data integration, real-time collaboration, and streamlined information exchange across all project phases. Existing BIM solutions already support complex multi-stakeholder coordination processes in the AECOO industry, and their core functionalities—such as clash detection, model-based workflows, and cloud-based data sharing—are directly applicable to offshore wind projects. BIM's compatibility with other digital tools, including Geographic Information Systems (GIS) and project lifecycle management platforms, further strengthens its technical suitability for improving coordination in offshore wind. The ability to establish a central data environment ensures that all parties work with up-to-date information, minimizing version conflicts and improving decision-making. Automation capabilities, such as automated design updates and rule-based workflows, also reduce manual errors and enhance process efficiency. While implementation complexity may arise from organizational and stakeholder issues, these are not technical limitations. The BIM systems required to address coordination and process challenges are well-established, widely available, and have already demonstrated their effectiveness in complex infrastructure and energy projects.	Revised Justification (Score = 4): BIM's potential impact on addressing process and coordination challenges is significant but may not fully warrant the highest possible rating. While BIM undoubtedly improves information flow, centralizes data, and facilitates better collaboration across project phases, the extent to which it can transform offshore wind project coordination—particularly within EnBW—may be somewhat constrained by external dependencies and existing work practices. Literature supports BIM's effectiveness in enhancing phase transitions and supplier alignment, with Bezkorovayniy et al. (2018) and Yang and Hu (2020) demonstrating its value in complex infrastructure settings. Interviews also consistently highlighted coordination issues as a major concern at EnBW, particularly given the company's evolving approach toward managing multiple projects simultaneously. In this context, BIM's capabilities could indeed strengthen alignment between departments and reduce process disruptions. However, BIM's ultimate impact may be moderated by the fact that coordination challenges often stem from human, contractual, and organizational factors that technology alone cannot fully resolve. Successful coordination still relies heavily on clear roles, responsibilities, and mutual understanding across stakeholders—areas where BIM can support but not substitute fundamental project management practices. Additionally, the adoption of BIM may introduce new complexities if not accompanied by standardized processes and appropriate training, limiting its immediate transformative effect. Therefore, while BIM has substantial potential to improve process and coordination challenges, the practical limitations of human factors and organizational alignment suggest a slightly more conservative impact rating is appropriate.

	Cost-Effectiveness Weight: 20 %	Plausability Weight: 20 %	Weighted Score
Process and Coordination Challenges	Revised Justification (Score = 4): Implementing BIM to address process and coordination challenges in offshore wind projects involves notable upfront costs, including investments in software solutions tailored to EnBW's needs, training for employees, and potentially hiring external experts to manage the transition. These initial expenses are considerable; however, the long-term cost savings derived from improved coordination and process efficiency justify this investment. Interview data highlights that EnBW's current approach—characterized by fragmented, project-by-project coordination—frequently results in delays, rework, and miscommunication, all of which increase project costs. BIM's capacity to centralize project data, automate updates, and align workflows across departments can directly reduce these inefficiencies, leading to better resource allocation and fewer costly errors. While the initial financial burden is non-negligible, literature, including Bezkorovayniy et al. (2018) and Yang and Hu (2020), supports BIM's potential for long-term cost optimization by streamlining project processes and enhancing lifecycle cost control. Considering EnBW's ambition to handle multiple projects concurrently under tight timelines, the cost-effectiveness of BIM lies not merely in cutting coordination costs but also in its potential to stabilize project delivery and minimize risk across its growing portfolio. Consequently, the financial benefits over the project lifecycle outweigh the initial expenses, warranting a strong, though not perfect, rating for cost-effectiveness.	Revised Justification (Score = 4): The plausibility of implementing BIM to address process and coordination challenges in offshore wind projects is relatively high, though not without obstacles. EnBW's growing awareness of process inefficiencies and the organization's ongoing efforts to standardize workflows provide a favorable context for BIM adoption. The alignment between BIM's core capabilities—such as enhancing collaboration, automating updates, and establishing a central data platform—and EnBW's process improvement goals creates a strong rationale for organizational support. Furthermore, EnBW has demonstrated openness to digital transformation, as evidenced by previous investments in project management software and digital tools. This willingness to innovate suggests that the organizational culture is generally receptive to BIM integration. However, the transition would require overcoming entrenched habits and fostering cross-departmental alignment, which could slow initial adoption. While interoperability issues and the need for data standardization remain challenges, these concerns are common across the industry, and established solutions exist. With the proper training and phased implementation approach, BIM adoption is achievable, particularly given the increasing internal pressure to enhance coordination across EnBW's expanding offshore wind portfolio. This combination of internal demand, technological readiness, and a supportive organizational trajectory supports a score of 4 for plausibility.	4,3

	Technical Feasibility Weight: 30 %	Impact Weight: 30 %
Data Management	Revised Justification (Score = 5): BIM demonstrates very high technical feasibility for addressing data management challenges in offshore wind projects. BIM systems are specifically designed to centralize, structure, and automate data handling processes, aligning closely with the core needs of offshore wind projects. Existing BIM solutions, such as Autodesk BIM 360 and Navisworks, offer proven capabilities to integrate, link, and manage large volumes of data across project phases. These platforms allow for the attachment of certificates, compliance documents, and inspection reports directly to model components, streamlining document control and ensuring real-time access to up-to-date information throughout the asset lifecycle. The data management scenario (Appendix \ref{appendix:2ndIteration}) further illustrates how BIM can facilitate the automatic verification of compliance documents, enable the tracking of component statuses, and improve auditability through automated logging of updates and approvals. This approach reduces the reliance on static documents like PDFs and Excel files, which often lead to version conflicts and fragmented data, as seen in current practices using platforms like Think Project. BIM's technical feasibility is further supported by its compatibility with open data standards (e.g., Industry Foundation Classes – IFC), enabling interoperability between different systems. Automated synchronization features ensure that changes in one part of the model propagate across the entire dataset, reducing errors and enhancing data consistency. Given the maturity of BIM solutions in data-centric industries and their capacity to replace document-centric workflows with structured, relational data models, BIM is highly feasible for transforming data management practices in offshore wind projects.	Revised Justification (Score = 5): BIM's potential impact on improving data management in offshore wind projects is exceptionally high. Offshore wind development relies heavily on accurate, up-to-date information spanning multiple stakeholders and project phases. BIM's ability to transition from document-centric workflows to integrated, data-driven systems aligns directly with the sector's need to reduce errors, improve collaboration, and ensure traceability across the lifecycle. The application scenarios developed in the second iteration (Appendix \ref{appendix:2ndIteration}) illustrate BIM's capacity to automate document verification, link certificates directly to components, and facilitate real-time status tracking. This shift towards centralized data environments enables immediate access to verified information, addressing one of the most persistent challenges identified in interviews—the reliance on static documents and fragmented tools like Think Project. Furthermore, BIM's capacity to integrate with other systems, such as Geographic Information Systems (GIS) and digital twin platforms, amplifies its impact. It allows data consistency across the lifecycle, from design to decommissioning, supporting more informed decision-making and minimizing costly delays caused by missing or outdated information. Given EnBW's complex multi-project environment, BIM's role in ensuring data quality and accessibility is particularly critical. This makes BIM not merely a tool for incremental improvement but a fundamental enabler of more strategic, data-driven project execution, solidifying its position as a high-impact solution for offshore wind data management.

	Cost-Effectiveness Weight: 20 %	Plausability Weight: 20 %	Weighted Score
Data Management	Revised Justification (Score = 4): Implementing BIM for data management involves substantial initial costs, including software acquisition, system customization to meet EnBW's project-specific requirements, and training of personnel to adapt to data-centric workflows. Integrating BIM with legacy systems like Think Project, ensuring interoperability across platforms, and transitioning from document-based processes further add to these upfront expenses. However, the long-term financial benefits of BIM significantly outweigh these initial investments. BIM's centralized data environment reduces costly errors stemming from outdated, inconsistent information and fragmented data silos. The application scenarios developed in the second iteration (Appendix \ref{appendix:2ndIteration}) demonstrate how automated data validation, digital component tracking, and certification management can prevent delays and streamline documentation processes, leading to notable cost savings across the project lifecycle. Additionally, BIM's potential to facilitate organization-wide data consistency supports cost reductions beyond individual projects, particularly as EnBW scales its offshore wind portfolio. While initial investments remain considerable, the enduring improvements in efficiency, reduced rework, and enhanced decision-making position BIM as a highly cost-effective solution for data management in offshore wind projects.	Revised Justification (Score = 5): The implementation of BIM for data management in offshore wind projects is not only plausible but increasingly inevitable given the pressing need for efficiency, standardization, and improved coordination. While BIM adoption requires organizational adjustments, EnBW is already relatively advanced in recognizing the need for better data handling, making this transition more feasible. Interviews indicate widespread dissatisfaction with current document-based workflows, such as those in Think Project, reinforcing the urgency for a shift toward data-driven processes. Unlike other applications of BIM that may face significant resistance, data management is an area where the benefits are immediate and clearly visible. The transition to structured, centralized data repositories ensures a single source of truth, minimizes miscommunication, and enhances traceability across project lifecycles. The application scenarios developed in the second iteration (Appendix \ref{appendix:2ndIteration}) illustrate how BIM can streamline certification management, digital component tracking, and compliance reporting—areas where inefficiencies currently result in delays and increased costs. Moreover, EnBW is already progressing towards more structured data management approaches, further supporting the plausibility of BIM adoption. The willingness to integrate new technologies, combined with the tangible operational benefits, significantly lowers the barriers to implementation. While interoperability between BIM and existing systems requires attention, solutions such as open standards (e.g., IFC) and API-driven integrations are well-established in similar industries. Given the strong alignment between BIM's capabilities and EnBW's strategic goals, the transition to BIM-based data management is not only plausible but a highly logical next step.	4,8

MCDA 3 – Factor Evaluation

This section includes the outcome matrix, weighting matrix, and ratings matrix for the third MCDA iteration.

Ranking	Weighted Score	Factor
1	5,00	Operational and Maintenance Costs
2	4,50	Data Management
3	4,00	Technological Advancements and Innovation
4	3,90	Process and Coordination Challenges
5	2,80	Logistical and Installation Challenges

Criteria	Weight (%)	Explenation for Change
Technical Feasibility	20	The focus group consistently highlighted that the technical capabilities of BIM are rarely the limiting factor. BIM tools are well-established in other industries and many functionalities (e.g., data integration, 3D modeling, clash detection, lifting simulations) are already available and technically feasible for offshore wind. The primary challenges lie elsewhere—particularly in organizational readiness, user adoption, and ensuring BIM is actually used as intended across teams. Since feasibility is rarely the deciding factor, it should hold less weight when prioritizing BIM applications.
Impact	30	The focus group emphasized that BIM's greatest value lies in addressing high-impact pain points, particularly in data management and O&M. These are areas where existing practices are seen as especially inefficient, and improvements could yield substantial gains in reducing downtime, improving information flow, and supporting operations across project phases. This makes impact a decisive factor when selecting BIM applications.
Cost-Effectiveness	20	While cost considerations remain important, the focus group suggested that the potential savings from process optimization and reduced errors often justify the investment in BIM. Initial costs (software, training) are significant but not prohibitive, particularly given the large budgets typical for offshore wind projects. Moreover, the focus group stressed that cost is not the primary barrier—organizational and procedural issues are more decisive. Therefore, cost-effectiveness remains relevant but should not outweigh impact or plausibility.
Plausability	30	Plausibility emerged as a key concern during the focus group. Participants repeatedly stressed that cultural resistance, user acceptance, and the challenge of integrating BIM into existing processes are the most significant hurdles. Even highly promising applications could fail if employees resist adoption or if BIM is perceived as burdensome. Successful implementation depends heavily on ease of use, training, and demonstrating quick, tangible benefits to end users. Therefore, plausibility should be weighted more heavily, reflecting its role as a practical gatekeeper for BIM adoption at EnBW.

	Technical Feasibility Weight: 20 %	Impact Weight: 30 %	Cost-Effectiveness Weight: 20 %	Plausability Weight: 30 %	Weighted Score
Logistical and Installation Challenges	Reduced to 2 Discussions in the focus group confirmed that installation planning is predominantly handled by contractors (e.g., Heerema, Vestas), with EnBW having limited influence over these processes. The need for EnBW to implement BIM specifically for this area appears less compelling. This reduces the likelihood that EnBW itself would adopt BIM for installation purposes, warranting a downgrade from 3 to 2.	3	3	3	2,8
Technological Advancements and Innovation	4	5	reduced to 4 While BIM can facilitate innovation, the focus group cautioned that it could also introduce complexity and additional costs if not managed properly. They noted that benefits often materialize later, meaning early-stage costs may outweigh initial gains.	3	4
Operational and Maintenance Costs	5	5	5	Increased to 5 Focus group participants from operations (e.g., Expert 4) highlighted that the need for better maintenance processes is urgent. The potential for predictive maintenance, integrating sensor data, and using digital twins was well-received. The group recognized the transition from reactive to data-driven maintenance as an immediate priority, making implementation plausible despite organizational hurdles.	5
Process and Coordination Challenges	5	4	4	Reduced to 3 Participants stressed that fragmented workflows and project-by-project approaches remain deeply entrenched. Transitioning to BIM would require a significant cultural shift, and skepticism among employees could hinder adoption. This reality suggests greater difficulty in achieving cross-departmental alignment, lowering plausibility.	3,9
Data Management	Remains 5 but Reinforced The focus group emphasized that EnBW is already progressing toward data-centric workflows, with Think Project and Vind AI laying the groundwork. The challenge is more cultural than technical. Therefore, the maximum rating remains appropriate, now with stronger support.	Remains 5 but Strengthened Participants unanimously identified data issues as a critical pain point. They stressed that current tools like Think Project are helpful but insufficient. A central BIM platform would address these inefficiencies and improve decision-making, confirming the high impact rating.	4	Reduced to 4 While the focus group confirmed that EnBW is already relatively far along in recognizing data management issues and taking steps towards improvement, the group emphasized that maintaining data systems remains a persistent challenge. Concerns were raised about human factors, such as inconsistent data classification and reluctance to adopt digital workflows. This complexity reduces the certainty that BIM-based data management will be seamlessly implemented, warranting a slight downgrade from 5 to 4.	4,5

I. Creation Scenarios 2.Iteration

A multi-step approach was employed to develop the scenarios for the five prioritized factors, integrating insights from various sources to ensure a comprehensive and well-founded analysis. Online research was combined with findings from the literature review, allowing for the identification of relevant BIM applications and best practices across different domains. Throughout this process, notes were systematically compiled and organized using Miro, serving as a visual workspace to structure key insights, explore interconnections between concepts, and refine potential implementation pathways.

Different conceptual directions were iteratively examined to establish a holistic understanding of how BIM can be leveraged to address each factor effectively. This process involved exploring alternative applications, technical feasibility considerations, and industry precedents to assess BIM-driven solutions' practicality and potential impact. The structured organization of insights within Miro facilitated a dynamic and flexible analysis, enabling a comparative evaluation of different approaches and identifying key enablers and barriers to implementation. The resulting scenarios reflect an integrated perspective, synthesizing theoretical knowledge with practical insights to provide a well-rounded foundation for the subsequent framework development.

Data Management

BIM-Anwendungsszenario

Herausforderung

Ausgangssituation:
Datenmanagement ist eine zentrale Herausforderung in Offshore-Windprojekten. Aktuell sind Daten oft fragmentiert, verteilt auf mehrere Plattformen (z. B. Think Project, Excel-Tabellen, PDFs) und durch isolierte Workflows gekennzeichnet. Dies führt zu:

- **Fragmentierte und unstrukturierte Daten:**
  - Daten liegen oft in separaten Systemen vor (z. B. Think Project, Excel, PDFs), die schwer weiterzuverarbeiten sind.
  - Diese Formate sind nicht für die Analyse oder Verknüpfung geeignet, was Effizienz und Entscheidungsfindung behindert.
- **Veraltete, dokumentbasierte Prozesse:**
  - Arbeitsabläufe basieren häufig auf statischen, isolierten Dokumenten, was Versionierungskonflikte und Informationsverluste verursacht.
  - Dokumente (z. B. PDFs oder Excel-Dateien) werden häufig per E-Mail verschickt und müssen manuell in die Projektabläufe integriert werden.
- **Inkonsistentes Datenformat:**
  - Unterschiedliche Formate und Standards verhindern den reibungslosen Austausch und die Integration von Informationen zwischen Stakeholdern.

BIM-Lösung:

- **Zentralisierte Datenplattform:**
  - Alle projektbezogenen Daten (Pläne, Zertifikate, Zeitpläne, Compliance-Dokumente) werden in einem einzigen BIM-Modell zusammengeführt.
  - **Vorteil:** Konsistenz und Aktualität der Daten, die für alle Projektbeteiligten in Echtzeit verfügbar sind.
- **Standardisierung und Interoperabilität:**
  - Nutzung offener Standards (z. B. IFC) zur Integration verschiedener Softwarelösungen.
  - **Beispiel:** CAD-Daten und Compliance-Dokumente werden direkt im BIM-Modell integriert und allen Teams zugänglich gemacht.
- **Automatisierte Datenaktualisierungen:**
  - Änderungen in einem Modell (z. B. Bauplan) werden automatisch in allen verknüpften Bereichen (z. B. Zeitplänen, Stücklisten) aktualisiert.
  - **Nutzen:** Reduktion von Fehlern und Nacharbeiten durch konsistente und synchronisierte Daten.
- **Analyse und Visualisierung:**
  - BIM-Modelle erlauben dynamische Visualisierungen und Risikoanalysen, die statische Dokumente nicht bieten.
  - **Beispiel:** Simulationen für Materiallieferungen oder Optimierung von Installationsplänen.

Vorherige Situation:

- **Dokumente:**
  - Zertifikate, Compliance-Berichte, Baupläne, Installationsanweisungen, Logbücher, Wartungspläne.
  - **Format:** Meist statische PDFs oder Excel-Dateien, die per E-Mail verschickt oder in unterschiedlichen Systemen abgelegt werden.
  - **Probleme:**
    - Versionierungskonflikte durch manuelle Ablage.
    - Schwierige Nachvollziehbarkeit von Änderungen.
    - Unübersichtliche und redundante Datenstrukturen.
- **Manueller Aufwand:**
  - Mitarbeiter verbringen Stunden mit dem Abgleich und der Aktualisierung von Dokumenten in separaten Tools wie Think Project.
  - Vertragspartner senden ihre Dokumente oft per E-Mail, was zu Verzögerungen führt.

Szenario in der Praxis:
Ein Offshore-Windprojekt nutzt BIM, um Datenmanagementprobleme zu lösen:

1. **Vorher:** Zertifikate und Pläne wurden manuell in separaten Systemen aktualisiert, was zu Verzögerungen und Datenverlusten führte.
2. **Mit BIM:** Zertifikate und Baupläne werden direkt ins BIM-Modell integriert und automatisch mit Zeitplänen und Compliance-Dokumenten synchronisiert.
3. **Ergebnis:** Zeitersparnis bei Prüfungen und Freigaben, bessere Abstimmung zwischen Planern und Bauleitern.

Zusätzlich ermöglicht BIM die effiziente Planung zukünftiger Wartungsarbeiten:

1. Installationsdaten werden während der Bauphase gesammelt und später für Betrieb und Wartung direkt im Modell genutzt.

Erwartete Ergebnisse:

1. **Effizienzsteigerung:** Schnelle, automatisierte Workflows reduzieren Verzögerungen.
2. **Kostenersparnis:** Weniger Nacharbeiten und besser koordinierte Prozesse.
3. **Konsistenz und Transparenz:** Einheitliches Datenformat minimiert Fehler und Missverständnisse.
4. **Langfristiger Nutzen:** Daten aus der Bauphase stehen für Betrieb und Wartung zur Verfügung.

Zertifikate verknüpfen:

1. In der BIM-Software (z. B. Autodesk Revit oder Navisworks) ist jedes Bauteil, wie z. B. ein Fundament, als Objekt im 3D-Modell hinterlegt.
2. Jedes Objekt hat eine Eigenschafts- oder Attributstabelle, die Metadaten wie Materialtyp, Hersteller, und Geometriedaten enthält.
3. Das Zertifikat (z. B. ein PDF) wird über die Attributstabelle mit dem Bauteil verknüpft. Dies erfolgt durch einen **Hyperlink** oder den Upload der Datei in eine verknüpfte Datenbank (z. B. BIM 360).

Mit BIM:

- **Dokumenten- und Datenstruktur:**
  - **Ablage:**
    - Zertifikate (z. B. Materialnachweise) werden direkt im BIM-Modell mit den betroffenen Bauteilen (z. B. Fundamenten) verknüpft.
    - Compliance-Daten und Baupläne werden als verknüpfte Dokumente abgelegt, sodass sie im Modell leicht zugänglich bleiben.
  - **Datenformat:**
    - Unterstützung offener Standards wie IFC (Industry Foundation Classes) für Geometriedaten.
    - Ergänzung durch PDFs und Excel-Dateien, die automatisch mit Metadaten versehen werden, um sie durchsuchbar zu machen.
- **Automatisierung:**
  - **Upload-Prozess:**
    - Vertragspartner laden Dokumente über ein BIM-Portal hoch, das automatische Format- und Plausibilitätsprüfungen durchführt.
  - **Automatische Synchronisation:**
    - Änderungen an einem Zertifikat oder einem Bauplan werden sofort mit verknüpften Elementen (z. B. Zeitplänen, Materiallisten) synchronisiert.
- **Verantwortlichkeiten und Nachverfolgbarkeit:**
  - **Verantwortlichkeiten:**
    - Jedes Dokument wird im Modell mit einem verantwortlichen Akteur verknüpft (z. B. Vertragspartner, Bauleiter).
  - **Änderungsverfolgung:**
    - Änderungen werden automatisch protokolliert (wer, was, wann geändert hat) und im Modell sichtbar gemacht.
- **Einbindung von Vertragspartnern:**
  - **Große Firmen:**
    - Vertragspartner mit eigenen BIM-Systemen können über offene Standards (z. B. IFC) Daten austauschen.
  - **Kleine Firmen:**
    - Einfaches Web-Interface für den Dokumentenupload und die Verknüpfung mit dem Modell, ohne komplexe Softwareanforderungen.
- **Übersichtlichkeit und Nutzerfreundlichkeit:**
  - **Benutzeroberfläche:**
    - Klare, intuitive Dashboards für unterschiedliche Nutzerrollen (z. B. Planer, Bauleiter, Betreiber).
    - Farbmarkierungen oder Statusanzeigen für Dokumente (z. B. „freigegeben", „in Prüfung").
  - **Zugriffsrechte:**
    - Rollenbasiertes Zugriffssystem stellt sicher, dass nur relevante Daten sichtbar sind.

Compliance-Daten ablegen:

1. Compliance-Dokumente (z. B. Genehmigungen oder Inspektionsberichte) werden nicht direkt an einzelne Bauteile gekoppelt, sondern einem **Modellbereich** oder einer Projektphase zugeordnet.
2. Diese Dokumente werden in einer zentralen Bibliothek der BIM-Plattform (z. B. BIM 360 Docs) gespeichert und mit **Metadaten** (z. B. Projektname, Phase, Verantwortlicher) versehen.
3. Über die Projektübersicht können diese Dokumente nach Kategorie, Status oder Phase gefiltert werden.

Baupläne als verknüpfte Dokumente:

1. Baupläne werden entweder direkt im Modell hinterlegt oder mit spezifischen Modellansichten verknüpft.
2. In BIM-Software wie Revit können PDF-Baupläne oder DWG-Dateien als **Anhänge** oder **Hyperlinks** an Modellansichten gekoppelt werden.
3. Über Software wie BIM 360 können Planversionen verwaltet werden. Bei einer neuen Planversion wird die alte automatisch archiviert und die neue Version ersetzt.

Beispielhafter Workflow:

- **Ein Vertragspartner liefert ein Zertifikat für ein Fundament:**
  - Zertifikat wird über das Portal hochgeladen und automatisch geprüft.
  - BIM verknüpft das Zertifikat mit dem betroffenen Fundament im Modell.
  - Status: „In Prüfung."
- **Freigabe durch Bauleiter:**
  - Bauleiter prüft das Zertifikat und markiert es im Modell als „freigegeben."
  - Änderungen werden protokolliert und an alle relevanten Beteiligten kommuniziert.
- **Nachnutzung der Daten:**
  - Installationsdaten und Zertifikate stehen später für Wartungsteams zur Verfügung.
  - Wartungspläne basieren auf den im Modell gespeicherten Informationen.

Verzeichnis für Zertifikate einrichten:

1. **Zentrale Zertifikatsübersicht:**
    a. In BIM-Software wie BIM 360 oder Navisworks wird ein Dashboard eingerichtet, das den Status aller benötigten Zertifikate anzeigt.
    b. Jedes Bauteil, jeder Projektabschnitt oder jede Phase wird mit einer Checkliste von Zertifikaten verknüpft (z. B. Materialzertifikate, Sicherheitsnachweise).
2. **Darstellung:**
    a. Ampelsystem: „Grün“ für vollständig und geprüft, „Gelb“ für hochgeladen, aber noch nicht geprüft, „Rot“ für fehlend.

Automatisierte Prüfungen und Workflows:

1. **Standardisierte Vorlagen:**
    a. Anforderungen an Zertifikate werden vorab definiert (z. B. Dokumenttyp, Format, erforderliche Inhalte).
    b. Die BIM-Plattform prüft automatisch grundlegende Kriterien wie Dateiformat, Dokumenttyp und Metadaten (z. B. Projektzuordnung).
2. **Benachrichtigungen:**
    a. Automatische Erinnerungen an Verantwortliche, wenn ein Zertifikat fehlt oder geprüft werden muss.

Nachvollziehbarkeit und Audit-Tools nutzen:

1. **Protokollierung:**
    a. Jede Aktion im BIM-Modell wird protokolliert (z. B. Hochladen, Freigabe, Änderungen).
    b. Das erleichtert die Nachvollziehbarkeit im Falle von Problemen oder Audits.
2. **Versionierung:**
    a. Alle Versionen eines Zertifikats werden automatisch archiviert, um Fehler durch veraltete Dokumente zu vermeiden.

Erwartete Ergebnisse:

- **Effizienzsteigerung:** Weniger Zeitverlust durch automatisierte Prozesse und zentrale Datenablage.
- **Bessere Nachvollziehbarkeit:** Klare Verantwortlichkeiten und vollständige Änderungsprotokolle.
- **Einfachere Zusammenarbeit:** Große und kleine Vertragspartner können problemlos eingebunden werden.
- **Langfristige Vorteile:** Daten aus der Bauphase direkt für Betrieb und Wartung nutzbar.

BIM-Lösung für die Schweißnahtprüfung:

- **Zentralisierte Ablage und Verknüpfung:**
    - Jedes Segment des Monopiles wird im BIM-Modell als eigenes Objekt hinterlegt (z. B. Rohrsegmente, Flansche).
- **Prüfberichte (z. B. Ultraschall- oder Röntgenprüfung):**
    - Die Prüfberichte werden als PDF oder digitales Dokument direkt mit der jeweiligen Schweißnaht im Modell verknüpft.
    - Verknüpfung über Attribute wie Segment-ID, Schweißposition und Prüfdatum.
- **Zugriff:**
    - Nutzer können im Modell die Schweißnaht auswählen und direkt auf den zugehörigen Prüfbericht zugreifen.
- **Automatisierte Workflows und Prüfungen:**
    - Beim Hochladen eines Prüfberichts prüft die BIM-Software:
    - Vollständigkeit (alle erforderlichen Felder ausgefüllt).
    - Format (korrektes Dateiformat, wie PDF oder DICOM für Röntgendaten).
    - Plausibilität (z. B. Übereinstimmung von Schweißnaht-ID und Segment-ID).
- **Status-Tracking:**
    - Jede Schweißnaht hat im Modell einen Status: „In Prüfung“, „Freigegeben“, „Korrektur erforderlich“.
    - Automatische Benachrichtigungen an den Bauleiter oder Prüfer, falls Dokumente fehlen oder unvollständig sind.
- **Nachverfolgbarkeit und Verantwortlichkeiten:**
    - Jeder Bericht wird im Modell mit einem Verantwortlichen (z. B. Schweißfachingenieur) verknüpft.
    - Änderungen (z. B. Korrekturen am Bericht) werden automatisch protokolliert und sind nachvollziehbar.
- **Audit-Protokolle:**
    - Alle Freigabeprozesse werden dokumentiert, einschließlich Zeitstempel und Prüfer.
- **Integration externer Vertragspartner:**
    - **Große Prüffirmen:**
        - Prüfdaten (z. B. Ultraschall- oder Röntgenbilder) werden direkt über offene Standards (IFC, BCF) ins BIM-System integriert.
    - **Kleine Firmen:**
        - Upload über ein webbasiertes Portal mit klar definierten Vorlagen und Metadatenfeldern (z. B. Segment-ID, Prüfername).
- **Visualisierung und Berichterstattung:**
    - Im BIM-Modell werden alle Schweißnähte farblich markiert:
    - Grün: „Freigegeben“
    - Gelb: „In Prüfung“
    - Rot: „Nacharbeit erforderlich“
    - Eine zentrale Übersicht zeigt den Status aller Schweißnähte und Prüfungen, filterbar nach Segmenten, Prüfern oder Terminen.

Beispielprozess:

1. **Prüfbericht hochladen:**
    a. Die Prüffirma führt eine Ultraschallprüfung durch und lädt den Bericht über das BIM-Portal hoch.
    b. Das System prüft automatisch die Segment-ID und Metadaten auf Konsistenz.
    c. Status wird im Modell auf „In Prüfung“ gesetzt.
2. **Manuelle Prüfung durch den Qualitätsmanager:**
    a. Der Qualitätsmanager überprüft die Ergebnisse (z. B. Ultraschallbilder und Messwerte) direkt im BIM-System.
    b. Bei Freigabe wird der Status auf „Freigegeben“ gesetzt, und das System informiert die Bauleitung automatisch.
3. **Übersicht für die Bauleitung:**
    a. Bauleiter sehen im BIM-Dashboard, welche Schweißnähte freigegeben, in Prüfung oder nachzuarbeiten sind.
    b. Planungen für den nächsten Bauabschnitt basieren auf den freigegebenen Segmenten.
4. **Nachträgliche Wartung:**
    a. Während der Betriebsphase sind alle Prüfberichte direkt im Modell verfügbar, falls Reparaturen oder Inspektionen notwendig werden.

Erwartete Ergebnisse:

1. **Übersichtlichkeit:**
    a. Echtzeit-Status aller Schweißnähte im Modell.
    b. Schnelle Identifikation fehlender oder fehlerhafter Dokumente.
2. **Effizienz:**
    a. Reduktion der Prüfzeit durch automatisierte Workflows.
    b. Vermeidung von Nachfragen und Fehlern durch klare Zuordnung und Dokumentation.
3. **Langfristige Nachnutzung:**
    a. Prüfberichte bleiben für Wartung und Audits verfügbar.