Master's thesis

NTNU
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Enhancing Production Logistics in a Ship Recycling Yard through Industry 4.0

Master's thesis in Mechanical Engineering
Supervisor: Marco Semini

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Abstract

This master's thesis explores the transformative potential of Industry 4.0 technologies, to enhance logistical operations within a Norwegian ship recycling yard. The research is specifically focused on the operations of AF Offshore Decom's recycling yard, AF Environmental Base Vats. The study is underpinned by an aspiration to instigate a paradigm shift in the ship recycling industry, fostering a transition towards more innovative, efficient, and sustainable practices. The study is structured around three primary research questions, each contributing to a deeper understanding of the operational logistics, challenges, and potential solutions within the context of industry 4.0, from a production logistics perspective.

The first research question probes into the operational logistics of AF Environmental Base Vats. The inquiry reveals a systematic approach emphasizing efficient space utilization, simultaneous processing of multiple installations and ships, and sustainable recycling practices. However, it also unveils several logistical challenges, including capacity constraints, transportation and handling difficulties, coordination and communication issues, location-specific challenges, and unforeseen issues. These challenges underscore the complexities of ship recycling logistics and highlight the need for innovative solutions to enhance logistical operational efficiency.

The second research question investigates the potential of Industry 4.0 technologies in addressing the logistical challenges identified in the first research question. The study explores a range of technologies, including intelligent robots, automated simulations, Internet of Things, cloud computing, big data analytics, augmented reality, and additive manufacturing, as potential solutions. The technologies, with its unique capabilities, holds the potential to automate tasks, optimize space layout, improve transportation and communication, provide a centralized platform for data management, analyze data for resource optimization, provide visualizations for complex project sites, and produce tools or components on-demand. However, the research also highlights potential barriers to the implementation of these technologies.

The third research question identifies additive manufacturing, augmented reality, and digital twin technologies as promising solutions for potential application in the recycling yard operations. These technologies could offer unique capabilities that has the possibility to enhance operational efficiency and adaptability. Additive manufacturing could streamline operations at AF Offshore Decom's yard by rapidly fabricating essential components, tools, and spare parts on-site, and thereby reducing downtime. Augmented reality could be used to improve communication and training at the yard, providing real-time visual aids and interactive guides for equipment maintenance and operational procedures, thereby enhancing safety and productivity. Digital twin technology could create a virtual replica of the yard, allowing for accurate forecasting, planning, and scenario testing, which could lead to more efficient operations and better decision-making at AF Offshore Decom's yard.

The research findings provide a detailed understanding of the operational logistics and challenges at AF Offshore Decom's recycling yard. It also highlights the potential of Industry 4.0 technologies, specifically additive manufacturing, augmented reality, and digital twin technologies, to address these challenges. These insights lead to strategic recommendations such as on-site fabrication of essential components, improved communication and training through augmented reality, and accurate forecasting and planning through digital twin technology. However, successful implementation requires a strategic approach, considering factors like cost-effectiveness and readiness for industrial application. This thesis contributes to the broader discourse on the application of Industry 4.0 technologies in ship recycling yards, offering concrete recommendations for practitioners. The research underscores the transformative potential of Industry 4.0 technologies in enhancing the logistics of ship recycling operations, paving the way for a more efficient, sustainable, and competitive future.

Sammendrag

Denne masteroppgaven utforsker det transformative potensialet til Industri 4.0-teknologier for å forbedre logistikken i et norsk skipsresirkuleringsverft. Studien er spesielt fokusert på operasjonene til AF Offshore Decom's resirkuleringsverft, AF Environmental Base Vats. Studien er underbygget av et ønske om å fremme en overgang mot mer innovative, effektive og bærekraftige praksiser. Studien er strukturert rundt tre primære forskningsspørsmål, hver bidrar til en dypere forståelse av den operasjonelle logistikken, utfordringene og potensielle løsninger innenfor konteksten av Industri 4.0, fra et produksjonslogistikk perspektiv.

Det første forskningsspørsmålet undersøker logistikken til AF Environmental Base Vats, et norsk resirkuleringsverft. Undersøkelsen avdekker en systematisk tilnærming som vektlegger effektiv utnyttelse av plass, behandling av flere installasjoner og skip samtidig, og bærekraftige resirkuleringspraksiser. Imidlertid avdekker det også flere logistiske utfordringer som hindrer effektiviteten. Disse utfordringene inkluderer kapasitetsbegrensninger, transport- og håndteringsvanskeligheter, koordinerings- og kommunikasjonsproblemer, steds-spesifikke utfordringer og uforutsette problemer. Identifisering og forståelse av disse utfordringene understreker kompleksiteten i skipsresirkuleringslogistikk og fremhever muligheten for mulige løsninger for å forbedre logistisk operasjonell effektivitet.

Forskningsspørsmål to undersøker potensialet til Industri 4.0-teknologier for å håndtere utfordringene identifisert i første forskningsspørsmål. Studien identifiserer teknologiene intelligent robots, automated simulations, Internet of Things, cloud computing, big data analytics, augmented reality, og additive manufacturing, som mulige løsninger. Med sine unike egenskaper, har disse potensialet til å automatisere oppgaver, optimalisere plasslayout, forbedre transport og kommunikasjon, tilby en sentralisert plattform for databehandling, analysere data for ressursoptimalisering, gi visualiseringer for komplekse prosjektområder og produsere verktøy eller komponenter on-demand. Mulige barrierer for vellykket implementering av disse teknologiene fremheves også.

Det tredje forskningspørsmålet identifiserer additive manufacturing, augmented reality, og digital twin teknologier som lovende løsninger for potensiell anvendelse i operasjonene ved resirkuleringsverftet. Disse teknologiene kunne tilby unike evner som har muligheten til å forbedre operasjonell effektivitet og tilpasningsevne. Additive manufacturing kunne effektivisere operasjonene ved AF Offshore Decom's verft ved raskt å produsere viktige komponenter, verktøy og reservedeler på stedet, og dermed redusere nedetid. Augmented reality kunne brukes til å forbedre kommunikasjon og opplæring på verftet, ved å tilby sanntids visuelle hjelpemidler og interaktive guider for utstyrsvedlikehold og operasjonelle prosedyrer, og dermed øke sikkerhet og produktivitet. Digital twin teknologi kunne skape en virtuell kopi av verftet, noe som tillater nøyaktig prognostisering, planlegging og scenariotesting, noe som kunne føre til mer effektive operasjoner og bedre beslutningstaking ved AF Offshore Decom's verft.

Funnene gir en detaljert forståelse av operasjonell logistikk og utfordringer ved AF Offshore Decom's resirkuleringsverft. Den fremhever også potensialet til teknologier innen Industri 4.0, spesielt additive manufacturing, augmented reality, og digital twin teknologier, for å adressere disse utfordringene. Disse innsiktene fører til strategiske anbefalinger, som for eksempel produksjon av essensielle komponenter på stedet, forbedret kommunikasjon og opplæring gjennom augmentert virkelighet, og nøyaktig prognostisering og planlegging gjennom digital twin teknologi. Imidlertid krever vellykket implementering en strategisk tilnærming, med hensyn til faktorer som kostnadseffektivitet og beredskap for industriell anvendelse. Denne oppgaven bidrar til den bredere diskursen om anvendelsen av teknologier innen Industri 4.0 i skipsresirkuleringsverft, og gir konkrete anbefalinger til utøvere. Forskningen understreker det transformative potensialet til teknologier innen Industri 4.0 for å forbedre logistikken for skipsresirkuleringsoperasjoner, og baner vei for en mer effektiv, bærekraftig og konkurransedyktig fremtid.

Preface

This master's thesis, completed in the spring of 2023, represents the culmination of my two-year master's program in Production Management at the Norwegian University of Science and Technology (NTNU). The work was conducted under the Department of Mechanical and Industrial Engineering and signifies the completion of a 19-year academic journey, marking the commencement of a new professional chapter. I would like to extend my deepest gratitude to all those who have supported me throughout this process. In particular, I wish to acknowledge my supervisor, Marco Semini, whose valuable guidance, problem-solving assistance during challenging periods, and constructive feedback have been instrumental in the completion of this thesis.

Additionally, I would like to express my heartfelt appreciation to AF Offshore Decom. Their warm welcome during my visit to their yard and their amiable cooperation throughout the whole process was a critical part of my learning experience. Their dedication and openness in addressing my inquiries related to the thesis is something I am immensely grateful for. A special note of thanks is also due to Ingvild Jenssen, Executive Director and Founder of the NGO Shipbreaking Platform. Her efforts in connecting me with AF Offshore Decom and others in her network have significantly benefited my work. Her role in broadening my professional network and enhancing my understanding of the field is deeply appreciated.

Finally, I would like to express my gratitude to my classmates, especially my office mates at Verkstedteknisk at NTNU in Trondheim, for contributing to a memorable experience during this demanding yet rewarding journey.

Trondheim, June 2023

Håkon Sikveland

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Innhold

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Abbreviations

AI	Artificial Intelligence
AM	Additive Manufacturing
AR	Augmented Reality
DT	Digital Twin
EOL	End-Of-Life
ERP	Enterprise Resource Planning
EU	European Union
EU SRR	European Union Ship Recycling Regulation
EVS	Economic Value Stream
FPSO	Floating Production Storage and Offloading
HKC	Hong Kong Convention
HSE	Health, Safety, Environmental
ILO	International Labour Organization
IoT	Internet of Things
LDT	Light Displacement Tonnage
NEVS	Non-Economic Value Stream
NORM	Naturally Occurring Radioactive Material
NTNU	Norges Teknisk-Naturvitenskapelige Universitet
PCBs	Polychlorinated Biphenyls
PLM	Product Lifecycle Management

1 Introduction

This chapter presents an academic overview of the thesis, including the background and motivation for the research, the purpose and objectives of the study, the research questions to be addressed, the scope of the project, and the structure of the thesis.

1.1 Background and Motivation

Ship recycling is the process of dismantling a ship at the end of its operational life. This practice is carried out when the cost of upgrading and adjusting the vessel to meet current regulations is no longer economically beneficial. Ship recycling yards around the world have varying standards, with many of the ships being recycled in Bangladesh, India, and Pakistan using the beaching method. These yards are notorious for being the least human and environmentally friendly in the industry, despite offering higher prices for end-of-life (EOL) ships due to their lower operation costs(Jenssen 2022). The location of the ship recycling yard and its distance from the ship's last port are also important factors in determining where a ship is broken down(Jain, Pruyn et al. 2016).

As a result of these factors, the three countries have a market share of 88% in terms of ship recycling tonnage (UNCTAD 2022). Shockingly, from 2009 to 2023, 7751 ships were beached, leading to 441 deaths and 384 injuries(Platform 2023). This highlights the need for change in the industry.

Enhancing production logistics can be an effective measure for improving efficiency and decreasing costs in production companies. Nonetheless, ship recycling has witnessed restricted adoption of novel production logistics techniques, primarily owing to the high investment costs and intricacies involved in the disassembly of ships. Nevertheless, heightened focus on ship recycling and the imposition of stricter regulations necessitates shipowners to opt for certified ship recycling yards, irrespective of the cost. This creates an opportunity to incorporate novel production logistics concepts, specifically Industry 4.0 related technologies, which this thesis aims to explore further.

1.2 Purpose and Objective

This study aims to investigate digital transformation, with a focus on Industry 4.0 approaches, in a Norwegian ship recycling yard. The research provides a comprehensive understanding of current practices in the yard and explore the characteristics and challenges found in the recycling yard's logistical operations. It will also investigate how industry 4.0 technologies possibly can solve some of the identified challenges. Furthermore, the study will suggest three of the possible technologies that has the potential to improve the logistical operations and efficiency and investigate them further.

Ship recycling is an essential component of the global maritime sector; however, its traditional practices have raised concerns about their environmental and health consequences. The implementation of Industry 4.0 technologies has been suggested as a potential solution for similar industries, such as shipbuilding. Therefore, examining the applicability of these technologies in the ship recycling industry is of interest.

This research is relevant to various stakeholders, including ship recycling companies and yards, governments, environmental organizations, and academic researchers. The study's findings will contribute to a deeper understanding of Industry 4.0 technologies' potential within the ship recycling industry, offering insights into possible future development and improvement. By analyzing the potential of Industry 4.0 approaches on the ship recycling industry, this research will address the existing knowledge gap in both practical and theoretical aspects of the challenges and opportunities associated with possible digital technologies in ship recycling processes. The insights gained from this study can inform the development of effective strategies for integrating Industry 4.0 technologies into the ship recycling yards, potentially enhancing its effectiveness.

1.2.1 Research Questions

RQ1: How does a Norwegian ship recycling yard operate from a production logistics point of view and what logistical challenges impede its effectiveness?

This research question is focused on understanding how the specific case company, AF Offshore Decom as a ship recycling yard operates from a production logistics perspective. The goal is to gain knowledge and identify the key logistical characteristics and challenges that are impacting the yard's effectiveness. By understanding the challenges, further research can develop recommendations for improving the yard's operations and increasing its efficiency.

RQ2: What Industry 4.0 technologies can contribute to addressing the challenges related to efficient logistics in ship recycling yards and, more generally, contribute to improved performance?

This research question is focused on exploring how Industry 4.0 technologies can be applied to recycling yards with their particular characteristics and how they can address the logistical challenges, as identified in RQ1. The goal is to identify possible technologies that can be used to optimize processes or increase efficiency. By understanding what industry 4.0 technologies can be applied in ship recycling yards, and how, it is easier to develop recommendations.

RQ3: Which promising Industry 4.0 technologies can be further explored for their potential application in AF Offshore Decom's ship recycling yard operations?

This research question aims to identify a set of promising Industry 4.0 technologies based on the findings from the previous chapters, and further examine their potential application in AF Offshore Decom's ship recycling yard operations. The focus will be on providing a more detailed analysis of how specific promising technologies could improve ship recycling processes. Rather than determining a single "most suitable" technology, the research will delve into the advantages and disadvantages of various promising technologies and provide insights on their potential impact on the efficiency and effectiveness of the case company's supply chain. The goal is to offer valuable recommendations for AF Offshore Decom on the implementation of Industry 4.0 technologies in their operations.

1.3 Project Scope

This master's thesis will examine the practice of ship recycling in a certified yard. The research will explore the possible advantages and challenges associated with utilizing Industry 4.0 technologies to enhance logistics within ship recycling practices. Furthermore, the study will propose specific technologies that can be implemented in certified ship recycling yards.

The focus of this research will be on various processes involved in ship recycling, such as dismantling, materials recovery, and waste management. Key stakeholders in the industry, including ship recycling yards, regulatory bodies, non-governmental organizations, and technology providers, will be taken into consideration. The study will concentrate on what happens inside the ship recycling yard to gain a deeper understanding of the practices employed.

Material flow, an essential aspect of ship recycling, will be closely examined as the efficient and sustainable handling of materials is crucial. Additionally, the study will investigate information flow, particularly in relation to data collection, analysis, and decision-making.

The scope of this research will not extend to broader maritime industry topics, such as shipbuilding, shipping operations, and ship ownership. Moreover, the study will not directly address the social and environmental impacts of ship recycling on local communities, although these concerns may be indirectly related to the use of Industry 4.0 technologies. The case study will specifically focus on understanding ship recycling yard logistics and investigating how Industry 4.0 can address potential challenges related to effective logistics.

1.4 Thesis Structure

The thesis follows an organized structure as depicted in figure 1. The first chapter provides an introductory overview of the research project by describing the background and motivation, purpose and objective, research questions, and scope of the study. The second chapter outlines the methodology adopted to conduct the research and presents a detailed description of the case company. The third chapter discusses the theoretical framework that underpins the research, with the choice of topics covered in this chapter based on the objectives and research questions of the study.

The subsequent chapters of the thesis address the research questions in a systematic manner. Chapter 4 answers research question 1, while chapter 5 addresses research question 2, and chapter 6 will investigate research question 3. Chapter 7 is the discussions and conclusion chapter and will provide contributions, choices, limitations, experiences and give a summary of findings related to each research question. Further, directions for future research will also be given, drawing on the findings from the preceding chapters. Finally, it presents the conclusion of the thesis.

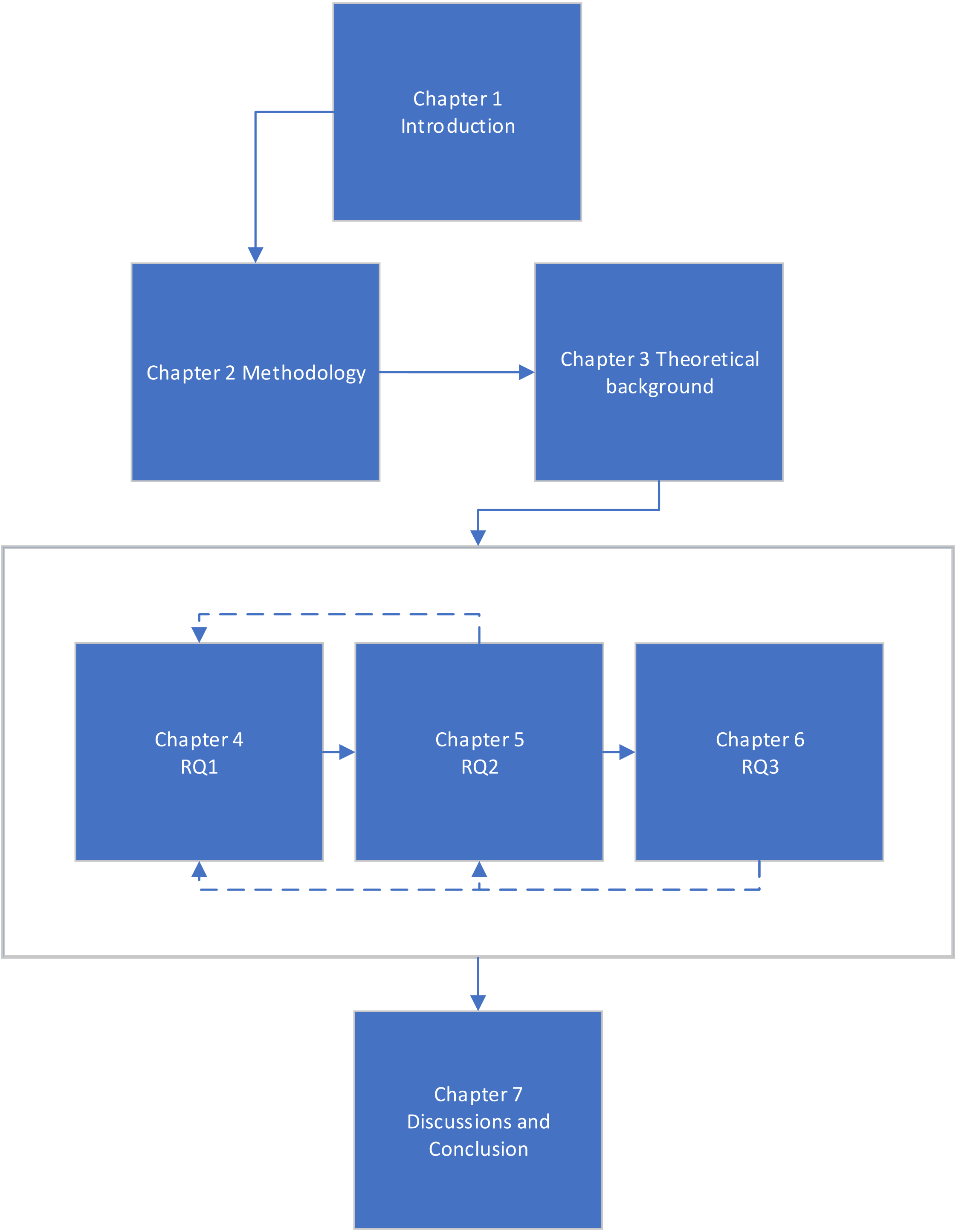

Figure 1: Structure of the thesis.

2 Methodology

The methodology chapter outlines the research methods used to approach the thesis work. It provides an explanation for why these methods were chosen and how they were utilized to carry out the research. This chapter will cover the research design, data collection techniques, and data analysis methods used in the study.

The research methodology for this study will involve a mixed-methods approach, comprising of both qualitative and quantitative research methods. The study will begin with a literature review, using electronic databases and academic journals to explore the ship recycling industry today and the potential for Industry 4.0 technologies in ship recycling yards.

The case study will be conducted at the AF offshore Decom recycling yard in Nedre Vats, Norway, using interviews, observation, and analysis of existing data to gain knowledge about the yard operations, and logistical characteristics and challenges. The findings from the literature review and case study will be synthesized and analyzed to possibly find potential for applying Industry 4.0 technologies to improve logistical processes in the case company's ship recycling yard.

The literature review should cover recent studies, reports, and relevant publications on these topics to provide a solid theoretical foundation for the research questions and methodology. Case study data will be collected through semi-structured interviews with AF Offshore Decom representatives. Secondary data will also be gathered from academic literature, industry reports, and other relevant industry articles.

The literature review also incorporates findings from the Specialization Project conducted in the fall of 2022 as part of the TPK4530 - Production Management course. This project, undertaken with a fellow student, provided initial insights into the ship recycling industry, regulations, operational processes, and relevant production logistics theory.

To ensure the linguistic correctness of the language used in the thesis, tools such as Grammarly and ChatGPT were utilized as translation tools. As a native Norwegian speaker, the ambition was to make the research accessible to a broader audience. These tools served as a bridge in translating words and sentences from Norwegian to English, guaranteeing that the language used in the thesis met the standards of linguistic correctness.

After receiving suggestions from these tools, they were meticulously checked, adjusted and cross-verified, demonstrating my personal oversight and control over the content. The process employed conforms to common good practices for using these tools in academic work, which typically include properly citing and maintaining human oversight and judgment over the tool's outputs. This ensures that the use of these tools aligns with general academic integrity principles and practices.

2.1 Literature Study

The present section outlines the literature review process for this thesis and the methods employed to retrieve relevant literature. In academic research, a crucial aspect is to examine the existing literature pertaining to the field of interest. This practice is necessary to acquire an understanding of the field and contextualize the research within the academic discourse (Fink 2019).

The objective of conducting a literature review for this thesis was to explore pertinent topics and theories related to the study. Initially, a search was conducted to identify the existing literature on the subject and to determine whether any studies had addressed similar research questions. Moreover, a literature review was conducted on the primary areas of focus in this thesis, namely, ship recycling yards and industry 4.0. Developing an understanding of the industry and the technology in question was a critical component in establishing the foundation for the thesis. It should be noted that the literature review was not a comprehensive systematic review of all relevant literature, but rather an effort to gain knowledge with the subject matter. Subsequently, the literature search became more focused on addressing specific research questions concerning industry 4.0 in ship recycling yards.

2.1.1 Data Collection

The study engaged in a literature review process consisting of five major steps. Firstly, relevant keywords were identified and used to retrieve scientific articles from databases such as Google Scholar, Scopus, and Oria. The selected keywords were based on the overall objective and research questions of the project and were refined as the literature study progressed. Boolean operators were used to combine multiple keywords, and a set of selection criteria was established to determine whether a paper was suitable for further analysis.

The criteria included aspects such as the relevance of the paper to the ship recycling industry, ship recycling yards, ship recycling practices and methods, ship recycling yard logistics, production processes, what degree of certification the yard had, and Industry 4.0. Papers that met the selection criteria were subjected to an initial screening phase that involved reviewing the abstract and conclusion to assess their relevance. If the article passed the initial screening, a full-text review was conducted, and the article was used for the literature study.

Additionally, the reference list of the selected articles and the cited-by feature of scientific databases were examined to identify more relevant literature. Endnote was used as a reference management tool for in-text citations and the reference list of the project. This literature review process ensured a review of relevant literature and allowed for the identification of knowledge gaps in the field of ship recycling yard logistics.

Table 1 lists the frequently used keywords and their combinations. However, given the rapid pace of development in the areas of ship recycling and Industry 4.0, the study also included non-traditional academic sources, particularly articles published on NGO shipbreaking platform website. The NGO Shipbreaking Platform is an international coalition of environmental and human rights organizations working to promote safe and sustainable ship recycling practices(Platform 2019).

Research Areas	**Initial Keywords**	**Secondary Keywords**
Ship recycling yards	Ship recycling yards, End-of-life ships, Ship recycling, Ship scrapping, Shipbreaking, Vessel dismantling, Ship decommissioning	Production logistics, Supply chain management, Production processes, Logistics, Methods, Effectiveness, Layout, Material flow, Information Flow, Waste management
Industry 4.0 in ship recycling yards	Digitalization, Industry 4.0 in ship recycling yards, Industry 4.0, Automation, Technologies	Digitalization, Process optimization, Robotics, Unmanned systems, Autonomous vehicles, Augmented reality technologies, Decision-making, Smart technologies, Industrial application

Table 1: Keywords used in the literature study.

2.1.2 Data Analysis

After the literature data collection, the data analysis phase began. The analysis of the literature involved identifying, analyzing the main themes, theories, and findings from the collected sources that were relevant to the research questions. This approach allowed to draw connections between different sources and understand the underlying patterns and relationships.

The first step of the literature analysis was to familiarize with the content by reading and re-reading the selected articles and reports. Then generated initial codes from the literature, focusing on the features and findings that were relevant to the research questions. These initial codes were then combined and organized into themes, which were reviewed and refined to ensure they accurately represented the literature's content. The final stage involved defining and naming the themes, as well as interpreting their relevance to the study's research questions.

The literature study provided a solid foundation for understanding the current state of knowledge in the field, as well as identifying knowledge gaps and areas for further investigation. By synthesizing and analyzing the literature, it has been possible to gain deeper insights into the ship recycling industry, Industry 4.0 technologies, and potential opportunities for improving logistics processes in ship recycling yards. This information was then used to inform the case study and guide the subsequent data collection and analysis processes.

2.2 Case Study

Drawing from the extensive literature on research methods, case study research emerges as a vital tool in understanding the rapidly evolving landscape of technology and managerial practices (Yin 2013). In a domain characterized by constant innovation and shifts, field-based research gains prominence, as it provides valuable insights into real-world challenges and processes. The case study approach is especially beneficial in addressing "how" and "why" inquiries, emphasizing the analysis of contemporary events and phenomena.

(Yin 2013) argues that when there is limited knowledge about the subject under investigation, case studies are a crucial instrument for generating new knowledge. By conducting in-depth investigations of specific cases, researchers can develop grounded theories that contribute to the wider understanding of operations management dynamics. This approach not only facilitates the identification of unique patterns and causal relationships but also allows for the integration of diverse perspectives and experiences in the research process.

In the present study, an exploratory case study approach was primarily used to gain valuable insights into the ship recycling industry, how a ship recycling yard operate, and how they envision their future. The case study served three main purposes:

- To understand how and why ship recycling yards are doing things the way they are.
- To identify challenges by interviewing employees at the ship recycling yard and observing their operations.
- To discuss whether and how principles/methods/approaches from production logistics/industry 4.0 technologies could potentially help solve challenges.

This is what this study has tried to achieve by utilizing the employee’s knowledge, understanding and by discussing relevant opportunities together with AF Offshore Decom representatives.

2.2.1 Data Collection

The case study was particularly used in the work with RQ1, which is about understanding how the specific case company, AF Offshore Decom as a ship recycling yard operates from a production logistics perspective.

The work with the case study started in January 2023 when there was a meeting with the Executive Director and Founder of NGO shipbreaking platform. She recommended to contact AF Offshore Decom in Norway for a collaboration. AF Offshore Decom was happy to collaborate so the 13. March 2023, a visit to AF Environmental Base Vats in Nedre Vats, Norway was carried out.

The visits to the case company consisted of a two-day residence with a presentation of the company, discussions on the topic, tour of the yard and semi-structured interviews with multiple employees in the company.

The visits to the recycling yard have provided valuable input. Observing the production environment present in the yard was of a great value for the research conducted in this thesis. In addition to the visit additional meetings were held both before and after the visit to make sure the gathered information was correct and making sure the thesis became as relevant as possible for the yard.

Most personnel on the case company visit held management positions, so they had a comprehensive understanding of the organization. Especially the discussions with the yard Engineering Manager, which had experience from the yard operations and been part of the ship recycling project from the start gave valuable input to the work with this thesis.

The personnel that the discussions were held with had the following positions:

- Engineering Manager, AF Offshore Decom
- Director Sustainability, Communication & Tendering, AF Offshore Decom
- Project Director, AF Offshore Decom
- Site Manager, AF Offshore Decom
- Logistics Manager, AF Offshore Decom

A workshop was also conducted with representatives from AF Offshore Decom where preliminary results of the work were presented during the final stages of the thesis. This interactive session facilitated an exchange of insights and allowed for a comprehensive review of the findings. Subsequently, a draft of the thesis was shared with them for feedback, further strengthening our academic-industrial relationship and ensuring the practical relevance of the research.

3 Theory on Ship Recycling and Industry 4.0

This chapter aims to lay a solid foundation of knowledge and provide the theoretical background necessary for the subsequent chapters of this thesis. It offers an overview of the ship recycling industry, including the definition of "ship recycling," its importance, challenges, brief history, methods, production processes, ship recycling yards, and existing regulations and guidelines. Parts of this chapter incorporates findings from the Specialization Project conducted in the fall of 2022 as part of the TPK4530 - Production Management course, particularly in subchapter 3.1. The material from this project has been carefully revised and integrated to enhance the understanding of the ship recycling industry. Relevant production logistics theory is also introduced, and the chapter further introduces the concept of Industry 4.0 and the technologies involved. The theoretical knowledge presented in this chapter is instrumental in understanding the main concepts, challenges, and opportunities investigated in this thesis.

3.1 Overview of the Ship Recycling Industry

Ship recycling, also known as ship dismantling, shipbreaking, or ship disposal, involves the disassembly of a ship in a designated area or yard, with the aim of collecting and reusing components, waste, and materials. This activity is considered to be environmentally friendly, as most parts of the ship can be reused or recycled, including materials, machinery, electrical components, and household equipment. However, ships that are recycled often contain hazardous waste such as polychlorinated biphenyls (PCBs), asbestos, and other heavy metals, which must be handled responsibly to prevent negative impacts on the environment(Sunaryo and Indianto 2020).

Once the ship has been stripped of hazardous waste and other necessary or desired components, the dismantling process can begin. This typically involves cutting the ship into smaller pieces, which can then be transported to another designated area for further processing. The ship is cut into small enough parts to facilitate handling and recycling(Sunaryo and Indianto 2020).

There are different types of yards involved in ship recycling activities. Some yards are involved in both ship construction and ship recycling. In addition, there are designated ship recycling yards that specialize solely in the dismantling of ships. These specialized yards bring forth focused expertise and utilize specialized equipment to carry out the recycling process.(Sunaryo and Indianto 2020).

3.1.1 The Definition of Ship Recycling

The definition of ship recycling refers to the process of dismantling old, decommissioned, or obsolete ships and recovering valuable materials and components for reuse. This process aims to minimize waste and reduce the environmental impact of discarding such large structures. Shipbreaking, on the other hand, is a term often used interchangeably with ship recycling. However, some might argue that shipbreaking primarily focuses on the breaking down and dismantling of a ship's structure, with less emphasis on the recovery and recycling of materials and correct handling of hazardous waste. In this context, shipbreaking could be considered a more destructive and environmentally harmful process compared to ship recycling, which emphasizes sustainability and resource recovery. Nonetheless, in practice, the terms are frequently used synonymously.

In this thesis, the term "ship recycling" will be exclusively used to emphasize the focus on sustainable practices and responsible resource recovery. By using this term, the intention is to highlight the importance of reusing and recycling valuable materials from decommissioned ships, minimizing waste, and reducing the environmental impact. This choice of terminology reflects the thesis's commitment to promoting environmentally friendly and sustainable approaches in the field of ship dismantling and disposal.

3.1.2 Importance and Challenges of Ship Recycling

According to estimates, around 1800 ships that are over 500 gross tons reach the end of their operational lives annually. Recycling these ships provides an environmentally friendly and economically viable solution for their disposal, while also creating employment opportunities and producing raw materials. However, the current practices for managing obsolete ships pose significant challenges. The majority of end-of-life ships, accounting for 80% of the world's end-of-life tonnage in 2017, are dismantled manually by migrant workers on the beaches of India, Bangladesh, and Pakistan, which has led to high rates of fatalities, injuries, and work-related diseases. To work as a shipbreaker is considered the most dangerous job globally by the International Labor Organization(Čulin 2019).

The risks to workers' health are compounded by the toxic fumes from ship recycling and hazardous materials, leading to an increased risk of cancer. In Bangladesh, for example, from 1993 to 2013, 400 worker fatalities and over 6000 injuries were reported, with toxic gas explosions and inadequate safety equipment contributing to 47.5% of accidents. Life expectancy for ship recycling workers is considerably lower, ranging between 40 and 50 years old, as opposed to the global average of 72 years(CYBUL 2021).

Moreover, ship recycling activities can have detrimental environmental impacts. In numerous unregulated operations, beaching the ship on a shallow shore is the first step in the dismantling process. Hazardous materials, such as asbestos and polychlorinated biphenyl, are frequently disposed of in the ocean as the ship is dismantled. Ship recycling sites have been found to contain high levels of ammonia, which is toxic to fish. The heavy metals found in various ship components have been discovered in shipyards, causing harm to human health and the environment. Oil remnants left in tankers and fuel lines have also been identified in seawater and along the shore. The cumulative impact of these issues on the environment during the ship dismantling process is significant(CYBUL 2021).

Therefore, ship recycling should be carried out using techniques that prioritize the safety of workers and the environment. Despite the existence of strict safety standards and regulations in some locations, accidents resulting in severe injury or death are still prevalent, as evidenced by the reports of the United States Department of Labor (CYBUL 2021). Developing safer and more sustainable approaches for the disposal of obsolete ships is an urgent task that requires the concerted efforts of all stakeholders involved.

3.1.3 History of Ship Recycling

The history in this chapter is gathered from articles written by (DYK 2019) and (CONSULTING GREEN SHIP LTD 2022). The practice of recycling ships has a diverse and extensive history, as various societies and cultures employed distinct methods and techniques. In earlier periods, ships were disassembled, with the timber repurposed. The wood from primitive dugout canoes, for example, was utilized to construct walls and shelters. Viking ships similarly provided villages with valuable timber and copper components, which were subsequently integrated into future construction projects. This tradition persisted over time, with contemporary examples including the luxurious London department store "Liberty," constructed in 1875 using timbers from the HMS Impregnable and HMS Hindustan.

In cases where repurposing wooden-hulled ships was difficult or impossible, the vessels were often set on fire or deliberately sunk. This approach became outdated with the emergence of metal-hulled ships, which could not be easily destroyed. As the shipbuilding industry advanced, wood was replaced by iron and steel, emphasizing the significance of ship scrapping during the industrial revolution. For instance, after World War II, approximately 500 000 tons of steel were reclaimed from decommissioned British ships and scrapped in locations such as Inverkeithing in Britain. In the late 19th century, other countries, including the Netherlands, Germany, Italy, and Japan, purchased British ships for scrapping.

A novel ship recycling method arose in the 1930s when beaching ships was found to be more cost-effective than using dry docks or alternative techniques. Ships were lightened for beaching, which necessitated a three-meter tide and full speed upon shoreline impact. Hydraulic shears, wrecking balls, and oxy-acetylene torches were employed to dismantle the vessels into smaller fragments. During the 1930s, some of the largest breakers in the UK also refurbished and sold furniture and machinery from ships later sent to the beaches.

The techniques employed in the past closely resemble those in developing countries today. Beginning in the 1980s, Alang, a coastal town in India, and Kaohsiung port in Taiwan, experienced significant growth in ship scrapping, followed by Pakistan and Bangladesh. The broader shipping industry was slow to recognize this development, as original ship owners were often unaware of their vessels' final destinations. However, increasing attention has been drawn to the hazardous working conditions at these shipyards and the associated environmental pollution.

In response to evolving environmental regulations throughout the 1980s and 1990s, the ship recycling industry began to prioritize minimizing the environmental impact of the process while safeguarding the workers involved. Consequently, ship recycling yards started adopting cleaner and safer practices.

3.1.4 Ship Recycling Methods

The process of dismantling ships involves a variety of methods that differ based on factors such as ship size, type, and condition. While the tools and techniques used in ship recycling have undergone significant changes over time, there has been relatively little innovation in the last five decades (Perivier, Puckett et al. 2022). Nonetheless, ship recycling methods can be broadly categorized into four approaches: alongside, beaching, dry-dock, and landing.

Alongside: The alongside method is predominantly used in China, Europe, and the United States. The ship is positioned next to a dock or pier within a protected port or waterway, where it is disassembled by cranes from the top down. The slicing activities continue until the bottom section of the hull can be hoisted out as a single unit and then dragged onto a ramp for ultimate dissection within a completely enclosed space.(platform 2020).

Beaching: Beaching refers to the practice of intentionally grounding a ship on a tidal mudflat. Typically, the vessel is positioned during high tide, and dismantling operations occur at low tide when the ship is not submerged. This method, utilized by 70% of ship recycling operations, is prevalent in South Asia. Due to cutting activities occurring in the intertidal zone, pollutants are unavoidably released into the environment and dispersed by tidal movements. Complete containment or remediation is not possible. The beaching technique faces significant criticism for its dangerous work conditions and the environmental damage it inflicts on delicate coastal ecosystems and nearby populations.(platform 2020).

Dry-dock: This technique involves placing the ship in a flooded dock, which is then drained to enable the dismantling process. This method ensures that the ship is taken apart in a fully contained area, minimizing environmental pollution risks. It also permits the use of cranes to lift larger parts of the ship for further handling. Dry-docks are mainly used in Europe (platform 2020).

Landing: The landing method is employed in areas with minimal tidal changes, where the ship is driven onto, or pulled up a concrete slipway extending into the sea. The cutting process commences at the front and moves towards the back, ensuring that the cutting area remains above the drainage system on the ramp. Cranes and winches are also utilized to pull the ship further onto the shore and remove cut sections (platform 2020).

The processes for ship dismantling are relatively uniform across methods; however, the sequence in which the ship is disassembled varies. The dry-dock and alongside methods involve the dismantling of the ship from the top to the bottom, whereas the landing and beaching methods involve the disassembly from front to back. During landing, the ship is positioned in water and dragged up onto a concrete platform with winches. To prevent water pollution, a drainage system is often installed slightly above the transition from water to concrete. The ship is then towed a distance beyond this line, and the front is disassembled into sections. Prior to cutting the ship, it is always towed above the drainage system. Beaching shares the same principles, but the ship is pulled directly onto regular sandy or muddy beaches without the presence of a concrete platform. The ship enters the beach during high tide and utilizes an anchor to remain stationary. The process for disassembly is almost the same as with landing, but the transportation of parts differs from the use of cranes and winches. Workers carry heavy chains and cables to the ship, fasten them, and then move the ship further up the beach using machines. Dry-dock and alongside methods are regarded as safer and more environmentally friendly due to their controlled environments. In a dry-dock, the ship is docked before the water is pumped out, after which the disassembly process is conducted from the top to bottom. The alongside method is similar, but the ship docks on a quay rather than a dry-dock, and a crane is employed to transport the pieces to the secondary cutting area.

3.1.5 Ship Recycling Processes

The processes involved in ship recycling exhibit great similarity across the various methods employed. Ship recycling can be broadly categorized into three distinct phases: pre-cutting, cutting, and post-cutting.

During the pre-cutting phase, the ship is prepared for disassembly by removing various components such as loose items, liquids, hazardous materials, insulation, flooring, tiling, cables, and electrical equipment. In a study conducted by (Jain, Pruyn et al. 2017),it was revealed that approximately 7% of the light displacement tonnage (LDT) of the case ship was eliminated during this initial phase prior to cutting.

The cutting phase consists of primary and secondary cutting procedures. In primary cutting, the ship's hull is divided into ferrous and non-ferrous blocks. While some minor differences may exist in the handling of blocks and equipment, the overall process remains consistent across methods. For instance, some yards employing beaching techniques utilize gravity to displace cut materials, while more advanced South Asian yards rely on cranes. Additionally, during this phase, machinery is either extracted for reuse or designated as scrap for secondary cutting. Secondary cutting further reduces large blocks obtained from primary cutting into smaller pieces, commonly utilizing gas cutting torches.

In the post-cutting phase, the first step involves sorting the resulting pieces for potential reuse or recycling, and those that cannot be utilized further. The subsequent sub-process includes segregating and transporting reusable or recyclable pieces. Non-valuable pieces are examined for possible separation of valuable components, provided that the value of the separated part exceeds the cost of separation. The final sub-process entails transporting the valueless pieces to landfill sites or downstream disposal facilities. It is important to note that this thesis is focused on ship recycling yards, and as such, downstream processes will not be explored further. (Jain, Pruyn et al. 2017) research estimated that approximately 3.4% of their case ship was deemed valueless and designated for disposal, while the remaining 96.6% was suitable for reuse or recycling. Although these percentages pertain to a specific case ship, they provide insight into the proportion of a ship that can be reused or recycled, emphasizing the significance of ship recycling processes. The processes within the three phases are illustrated in figure 2.

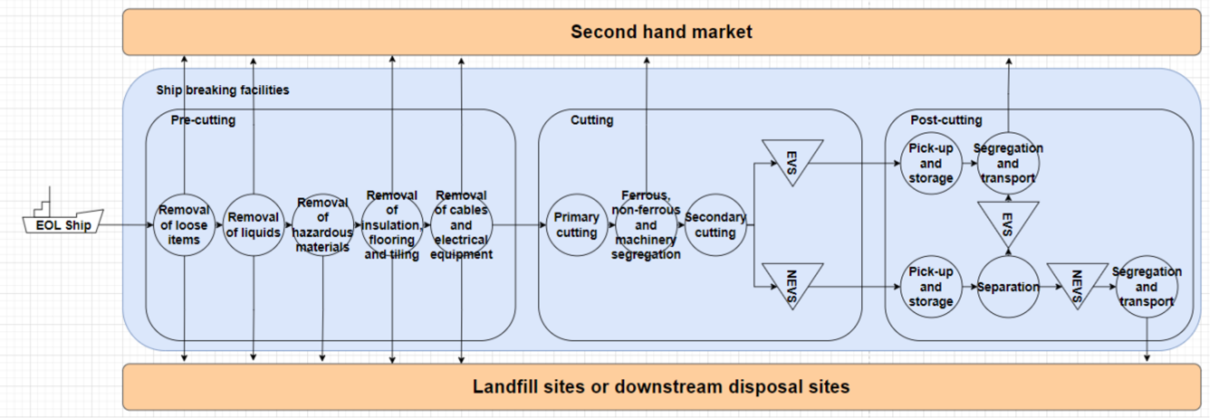

Figure 2: The processes a ship goes through in a ship recycling yard. Source: Specialization project (2022).

In figure 2, the words EOL, EVS and NEVS are used.

- EOL means end-of-life ships.
- EVS means economic value stream.
- NEVS means non-economic value stream.

3.1.6 Ship Recycling Yards

Ship recycling yards are unique facilities dedicated to recycling decommissioned ships, which means ships that are no longer in operation. The primary goal is to recycle as much material as possible, including salvaging any parts that are still in good condition, which can often be sold for reuse. This not only helps to reduce waste, but also provides a source of valuable materials. Before a yard can start this recycling work, it must receive official permission from relevant regulatory authorities. These authorities ensure that the yards maintain proper standards and procedures to protect both people and the environment. Everyone involved in the yard - from the owners to the workers - plays a key role in ensuring the recycling process is carried out effectively and efficiently. Teamwork is essential in managing the complex task of dismantling large vessels. It's also critical that these shipyards adhere to all international rules and regulations concerning ship recycling. This ensures safety, prevents environmental harm, and promotes ethical work practices. Finally, it's important to highlight that these authorized recycling yards can only accept ships that meet specific regulatory requirements. Just as the yards themselves need authorization, so too do the ships that are to be recycled(Sunaryo and Indianto 2020).

3.1.7 Existing Regulations and Guidelines for the Ship Recycling Industry

Several rules and regulations have been put in place to address concerns and ensure that ship recycling is conducted in a safe and responsible manner. A list of requirements to comply with to be part of the European Union (EU) list of certified yards is shown in table 2 and the relationship between the different regulations and guidelines will be shown in figure 3. While an in-depth description of these rules and regulations is not a part of this thesis, a brief overview of the most relevant ones will be provided.

The Basel Convention, a significant international regulation aimed at controlling the movement of hazardous waste, was later augmented by the Ban Amendment. The EU introduced a new regulation, the European Union Waste Shipment Regulation, as an early enforcement of The Basel Convention with the Ban Amendment. The Ban Amendment's international entry into force coincided with the establishment of the Hong Kong Convention (HKC), which is a global regulation developed exclusively for the ship recycling industry. Although it has not yet entered into force internationally, many countries have implemented it into national law. To expedite the process of countries being able to certify the HKC, and as an improvement to the European Union Waste Shipment Regulation, the EU implemented the European Union Ship Recycling Regulation (EU SRR) into its laws. The EU SRR is a direct continuation of the HKC, with some more stringent requirements and the earlier proposed guidelines converted to requirements. Compliance with the table 2 requirements implies adherence to the strictest standards, thereby meeting all international regulations concerning ship recycling yards.

13.1	**In order to be included in the European List, a ship recycling yard shall comply with the following requirements, in accordance with the relevant Hong Kong Convention provisions and taking into account the relevant guidelines of the IMO, the ILO, the Basel Convention and of the Stockholm Convention on Persistent Organic Pollutants and of other international guidelines:**
(a)	It is authorized by its competent authorities to conduct ship recycling operations.
(b)	It is designed, constructed and operated in a safe and environmentally sound manner.
(c)	It operates from built structures.
(d)	It establishes management and monitoring systems, procedures and techniques which have the purpose of preventing, reducing, minimising and to the extent practicable eliminating: (i) health risks to the workers concerned and to the population in the vicinity of the ship recycling yard, and (ii) adverse effects on the environment caused by ship recycling.
(e)	It prepares a ship recycling yard plan.
(f)	It prevents adverse effects on human health and the environment, including the demonstration of the control of any leakage, in particular in intertidal zones.

(g)	It ensures safe and environmentally sound management and storage of hazardous materials and waste, including: (i) the containment of all hazardous materials present onboard during the entire ship recycling process so as to prevent any release of those materials into the environment; and in addition, the handling of hazardous materials, and of waste generated during the ship recycling process, only on impermeable floors with effective drainage systems: (ii) that all waste generated from the ship recycling activity and their quantities are documented and are only transferred to waste management yards, including waste recycling yards, authorised to deal with their treatment without endangering human health and in an environmentally sound manner;
(h)	It establishes and maintain an emergency preparedness and response plan; ensures rapid access for emergency response equipment, such as fire-fighting equipment and vehicles, ambulances and cranes, to the ship and all areas of the ship recycling yard.
(i)	It provides for worker safety and training, including ensuring the use of personal protective equipment for operations requiring such use.
(j)	It establishes records on incidents, accidents, occupational diseases and chronic effects and, if requested by its competent authorities, reports any incidents, accidents, occupational diseases or chronic effects causing, or with the potential for causing, risks to workers' safety, human health and the environment.
(k)	It agrees to comply with the requirements of paragraph 2.

Table 2: EU SSR Article 13.1. Source: (UNION 2013).

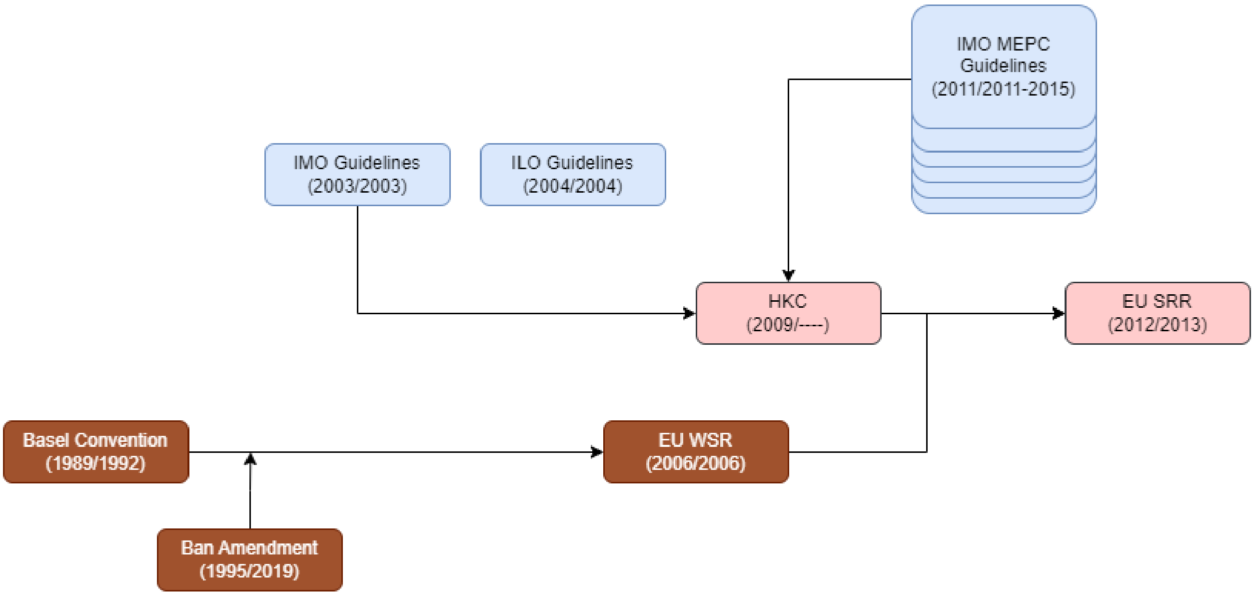

Figure 3: Connection of regulations/guidelines. Source: Specialization project (2022).

The diagram presented in figure 3 depicts the interrelationships between the primary legal provisions governing ship recycling. The arrows signify the hierarchical dependencies among the regulations and guidelines, in a chronological timeline sequence from left to right. It is important to note that there are other laws as well, but this is just meant as an overview of the regulations.

The brown boxes in the diagram pertain to waste management, while the blue boxes outline general guidelines for ship recycling, and the pink boxes represent regulations specifically tailored for the ship recycling industry. The figures in parentheses represent the year of publication followed by the year of enforcement.

It is noteworthy that the box representing the International Labour Organization (ILO) Guidelines appears unconnected to other boxes in the diagram. This is because these guidelines do not have a direct regulatory role and rather function as independent guidelines.

3.2 Production Logistics Theory

In the next subchapters, the focus will be on providing an understanding of production logistics and its various aspects, particularly layout, material flow and information flow, planning and control, and Industry 4.0. The purpose is to offer a detailed overview of production logistics theory, enabling readers to gain a deeper comprehension of the subject matter.

Production logistics refers to the efficient organization and management of production and logistics, which is crucial for the profitability and sustainability of production companies. This concept encompasses a multitude of elements, such as control and delivery methods, management principles, planning processes, information handling, supply chain management, layout and material flow, inventory management, forecasting, and digital systems for management and processes. In certain contexts, technical equipment for internal material flow, like robots, can be considered part of production logistics. However, they may also be viewed as components of the technical production system(Strandhagen, Romsdal et al. 2021).

This subchapter will now delve into the specific aspects of production logistics, with a particular focus on layout, material flow and information flow, planning and control, and the emerging concept of Industry 4.0. These elements have been chosen because of their potential to uncover opportunities for improvement in contemporary production environments, particularly within the context of ship recycling yards.

Ship recycling yards are typically characterized as labor-intensive, high-risk environments with limited technological advancements. Investigating these specific elements is a strategic choice. By examining these aspects of production logistics within the context of ship recycling yards, this thesis aims to identify opportunities for enhancing logistical operations, with the hope of contributing the ship recycling yard and making it a safer, more efficient, and more sustainable yard.

3.2.1 Layout

(Stevenson, Hojati et al. 2015)delineates facility layout as the systematic organization of departments, work centers, and equipment, with an emphasis on the circulation of work, materials, and information within a given system. The primary goal of layout design is to facilitate an unimpeded flow of work, materials, and information throughout the system. (Stevenson, Hojati et al. 2015) identifies three fundamental types of layout designs: product layout, process layout, and fixed-position layout.

Product layouts are fitting for systems that produce standardized goods or services through a repetitive process and exhibit a high-volume flow. Such layouts generally take the form of a straight or U-shaped production line, determined by the sequence of tasks executed. Instances of product layouts encompass automatic car washes, automobile assembly lines, and cafeteria queues.

Conversely, process layouts, also referred to as functional layouts, are appropriate for goods or services necessitating diverse processing with a medium volume flow. The processing sequence fluctuates based on the specific jobs, resulting in an intermittent workflow. Process layouts comprise a functional organization of systems wherein analogous types of processes are performed. A machine shop with distinct departments for drilling, milling, and grinding exemplifies a process layout.

Fixed-position layouts are those where the product or project under development remains stationary, and the requisite materials, equipment, personnel, and ancillary activities are brought to the product's location as needed. This layout is characteristic of industries such as construction, shipbuilding, and other capital goods sectors due to the product's inherent nature. Although shipbuilding is generally categorized as a fixed-position layout, it does not fully conform to this classification since ships under construction possess a certain degree of mobility, unlike construction projects, which are entirely stationary.

In summary, facility layout is pivotal in enhancing productivity, efficiency, and quality. The selection of a suitable layout design hinges on the product or service's nature, production volume, and process requirements. Familiarity with the fundamental types of layouts and their respective characteristics can facilitate the choice of the most fitting layout design for a particular situation(Stevenson, Hojati et al. 2015).

3.2.2 Material Flow and Information Flow

Material flow and information flow are two essential components in production logistics and is a central part to consider when talking about layout.

Material flow refers to the physical movement of raw materials, components, and finished products throughout the various stages of a supply chain. This includes the procurement, transportation, storage, and distribution of goods. Effective management of material flow ensures that resources are utilized efficiently, and production schedules are maintained to minimize costs and meet customer demands. The goal is to achieve a smooth, continuous flow of materials with minimal disruptions or bottlenecks(Chopra and Meindl 2016).

Information flow, on the other hand, pertains to the exchange of data and communication between different entities involved in a supply chain. This may include information about product specifications, order statuses, inventory levels, transportation schedules, and other pertinent details. Efficient information flow enables better coordination, planning, and decision-making within the supply chain. Through effective information sharing, companies can better predict demand, manage inventory levels, and respond to changes in the marketplace(Chopra and Meindl 2016).

3.2.3 Planning and Control

Production logistics involve the planning, implementing, and controlling the effective and efficient flow of goods and services. It's crucial for effective resource allocation, cost management, and maintaining the timeliness of the production process. In the context of planning and control, it incorporates activities from material procurement to the final delivery of products(de Man, Strandhagen et al. 2020).

Emerging technologies have significantly transformed planning and control within production logistics. Innovations such as Advanced Planning Systems, Internet of Things (IoT), big data analytics, artificial intelligence (AI), and machine learning are reshaping the planning frameworks, making them more responsive and efficient. The use of sophisticated sensors and IoT allows for real-time tracking and management of resources, contributing to a more event-driven, reactive way of planning. In particular, AI and machine learning have introduced more automated and autonomous decision-making, reducing the necessity for human intervention. However, human planners still play a vital role, especially in handling ill-defined problems, exceptions in planning, and where the context of business realities are complex. With big data analytics, managers can make planning decisions based on evidence rather than intuition, leading to more informed and effective decisions(de Man, Strandhagen et al. 2020). This is particularly crucial in industries like ship recycling yards, where efficient management of resources, waste, and environmental impacts is vital.

Industry 4.0 has accelerated this transformation, promoting both vertical and horizontal integration. Vertical integration refers to the integration of systems across different hierarchical planning levels, while horizontal integration refers to the integration across different stages of the value creation process. Such integration allows for more real-time planning and scheduling, leading to more robust and cost-effective supply chains(de Man, Strandhagen et al. 2020).

In the context of ship recycling yards, these technologies could possibly help improve logistical operations by providing real-time information about the location and status of ships, installations, and components, supporting better decision-making, and allowing for quick responses to changes and uncertainties. However, there are challenges. For instance, (de Man, Strandhagen et al. 2020) points out that the integration of such technologies could lead to changes that are not fully captured by the current planning and control frameworks.

3.3 Industry 4.0

Industry 4.0 signifies a new stage in the organization and control of the industrial supply chain(I-scoop.eu 2021). It involves a confluence of several technological advancements, including both innovation to existing technologies and the development of entirely new ones(Strandhagen, Buer et al. 2020). At its core, Industry 4.0 is built upon principles such as cyber-physical systems, innovative IT technologies, and smart systems, and seeks to facilitate efficient human-to-machine interaction that can enhance supply chain processes(Sanders, Elangeswaran et al. 2016).

Central to Industry 4.0 is digitalization, which encompasses several interrelated aspects, including device identification and connectivity, the establishment of seamless digital information flows, increased levels of automation and robotization, as well as more intelligent decision-making(Strandhagen, Romsdal et al. 2021). Importantly, digitalization has the potential to transform all aspects of a business model, opening up new possibilities for innovation and growth. It is expected that Industry 4.0 will cause significant disruptions to industrial production, with implications for business models, organizational structures, and the creation of smart production environments(Sanders, Elangeswaran et al. 2016).

Industry 4.0 was initially introduced as a component of a high-technology strategic initiative by the German government in 2011. It has subsequently been characterized as the fourth industrial revolution, with the objective of amalgamating physical and virtual domains through the employment of cyber-physical systems to attain optimal efficiency and autonomy. The adoption of Industry 4.0 signifies a transition from the conventional "centralized" method of production to a more "decentralized" approach. Considering these diverse interpretations, (Ang, Goh et al. 2017) suggest a cooperative network methodology that incorporates seven principal enabling technologies: intelligent robotics, automated simulations, the Internet of Things, cloud computing, Additive Manufacturing (AM), Augmented Reality (AR), and big data analytics. Through the integration of these technologies, Industry 4.0 can actualize its complete potential and accomplish its intended results. It is crucial to acknowledge that this list of seven technologies is not all-inclusive and may undergo further modification as the field progresses(Ang, Goh et al. 2017).

(Ang, Goh et al. 2017) made an illustration (figure 4) that presents an overview of the seven Industry 4.0 technologies, and the evolution of the four Industrial Revolutions. The figure serves as a visual aid for understanding the historical progression of industrial revolutions and its convergence with digital technologies, providing a framework for analyzing the key components and innovations of Industry 4.0.

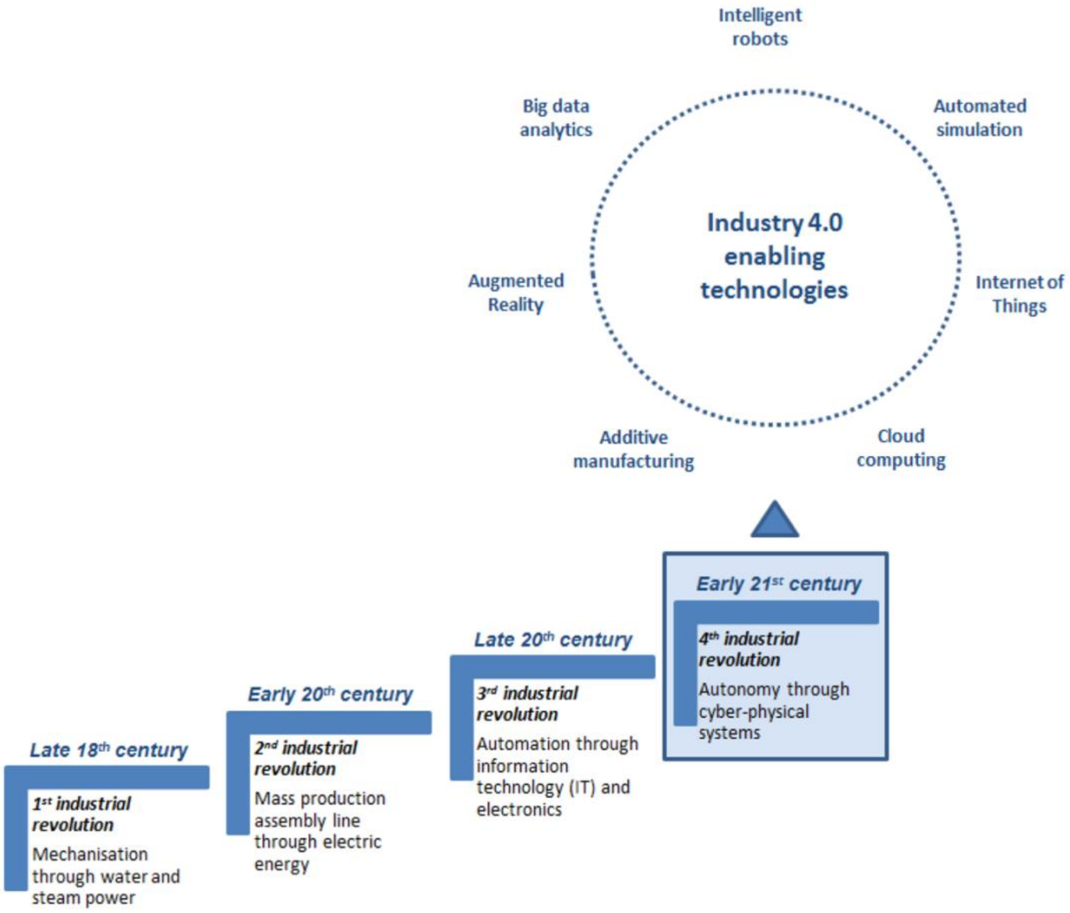

Figure 4: Timeline showcasing the progression of industrial revolutions and the technologies. Source: (Ang, Goh et al. 2017).

Industry 4.0 is a major technological development that has the potential to transform industrial procedures and value creation. One area where it can have an impact is production logistics. However, the extent to which Industry 4.0 technologies can be applied in production logistics depends on the company's specific production environment. To make the most of Industry 4.0 in production logistics, it is important to understand which aspects of the technology are most relevant to a particular company's needs and how they should be implemented in that company's unique production environment(Strandhagen, Alfnes et al. 2017).

3.3.1 Technologies

This part will continue to explore industry 4.0 technologies based on research by (Ang, Goh et al. 2017). The fundamentals of each of these technologies will be explained.

The principal aim of Industry 4.0 is to attain mass customization while maintaining minimal production costs, comparable to those in mass production. This is achieved by harnessing innovation, reducing costs, improving responsiveness to customer needs, developing optimal solutions, employing intelligent systems, and utilizing alternatives to on-demand manufacturing. Contemporary advancements in industrial digitalization and the Internet have enabled the effortless integration of the physical manufacturing value chain with its virtual counterpart in cyberspace, referred to as the Digital Twin (DT). This integration has fundamentally revolutionized decision-making processes and business practices in conventional manufacturing settings(Lee, Kao et al. 2014). The enabling technologies of Industry 4.0 include:

Intelligent Robots: The latest generation of robots is becoming increasingly self-sufficient, adaptable, and collaborative when combined with other Industry 4.0 technologies. These robots can communicate with each other and work more closely with humans, making them highly functional(Ang, Goh et al. 2017).

Automated Simulations: Simulations recreate the physical world in a digital model, which is already employed in most design processes. In Industry 4.0, simulations will evolve towards smarter design, automating the "test-and-optimize" procedure and finding more extensive use in shipyard and ship operations(Ang, Goh et al. 2017).

Internet of Things: IoT connects physical objects with their virtual representations on the internet. This technology allows devices in the field to communicate and interact with each other within an Industry 4.0 setting, decentralizing analysis and decision-making, and enabling real-time responses(Ang, Goh et al. 2017).

Cloud Computing: Cloud computing offers a range of IT services over a network that can be scaled according to user needs. It allows machine data and functionalities to be deployed on the cloud, promoting more data-driven technologies and monitoring systems within the Industry 4.0 context(Ang, Goh et al. 2017).

Additive Manufacturing: AM encompasses a group of processes that create objects by adding material instead of removing it from a solid block. In Industry 4.0, AM techniques can be widely employed to produce customized product batches, offering construction benefits such as intricate and lightweight designs using for example 3D-printing(Ang, Goh et al. 2017).

Augmented Reality: AR transforms the real environment into a digital interface by overlaying virtual objects onto the real world. Through Industry 4.0, companies can use AR to give employees real-time information, improving decision-making and work procedures with AR devices. AR can also help develop digitized visual workflows for training workers(Ang, Goh et al. 2017).

Big Data Analytics: Big data analytics refers to the analysis of massive or complex datasets and can be applied within Industry 4.0 to support real-time decision-making. This is achieved by collecting and evaluating data from various sources both inside and outside the organization(Ang, Goh et al. 2017).

It is crucial to recognize that while each of the above-mentioned Industry 4.0 technologies holds individual value, the central idea of Industry 4.0 is to merge these technologies, enabling them to work together and achieve a smooth integration of all activities. Although Industry 4.0 has been rapidly adopted in general manufacturing, such as consumer products, its implementation in engineering structures like ships is not yet widespread. Recent research on Industry 4.0 applications in the ship industry mainly focuses on enhancing ship operations, such as fleet performance monitoring, route optimization, and unmanned ships, using big data and the IoT(Ang, Goh et al. 2017). There are limited examples of Industry 4.0 applications in ship recycling yards operations, which this paper aims to address.

3.3.2 Industry 4.0 Applications to Ship Recycling

In recent years, the maritime industry has been following global trends by focusing on the environmental impacts associated with its activities. This has included exploring the advantages of adopting new technological methods(Lee and Nam 2017). (Lee, Noh et al. 2018) suggest that the ship recycling industry has a greater environmental impact than shipbuilding industry. This implies that there should be greater emphasis on implementing industry 4.0 technology in the ship recycling yards to help transform it into a more sustainable industry.

A promising application of Industry 4.0 technologies in the ship recycling yards is the digitalization of traditional practices. Companies are now developing technologies to upgrade these practices. Some of them are still concepts but it is still interesting to investigate them. The collective goal of the different developers is to make solutions that leverage the power of Industry 4.0 and other innovative technologies, leading to safer and more efficient ship recycling yards.

One such technology is water jet cutting, which is transforming the conventional method of dismantling ships through torch cutting. This eco-friendly and cost-efficient technology has been supplied to the maritime sector by companies such as Wika and Hammelmann, Microstep, Muotorer, and Thibault. Other notable innovations include Leviathan's heavy robotics and water cutting technologies and LUT University's ship recycling machinery based on robotics and mechatronics(Perivier, Puckett et al. 2022).

Aseco Europe, a Dutch company, has developed a groundbreaking ship recycling yard, the Circular Maritime Technologies (CMT). This yard can dismantle the largest ships within six days without requiring any workforce onboard. The objective of CMT is to produce clean steel through a low carbon, contained, and circular process. There will be no open fire or hot work, ensuring maximum safety for people and the environment(Perivier, Puckett et al. 2022).

Material and waste recovery is another area where new technologies are making a difference. NautilusLog offer digital solutions for mapping hazardous materials on ships, while Nomura Kohsan and Econ Industries specialize in removal of these(Perivier, Puckett et al. 2022).

While obvious challenges remain, the adoption of these innovative technologies is an exciting step towards a more sustainable future in the industry. (Pournara and Konstantinidis) envision a future "Shipyard 4.0" as an ecosystem where technology and data integrate seamlessly with management systems and operational processes. This interconnected system leverages key Industry 4.0 technologies to optimize shipbuilding and recycling procedures. They underscore the importance of real-time traceability of raw materials, facilitated by AI and cloud-based systems, linking the ship recycling process to ship reproduction. These innovations, as per (Pournara and Konstantinidis), are set to transform yards into more efficient, sustainable and environmentally responsible entities. The adoption of Industry 4.0 technologies in current ship recycling yard’s is a topic that has not been studied much, even though it seems like these technologies have the potential to greatly improve the operations at the yards. This gap in research not only leaves us lacking in knowledge but also hampers the growth and improvement of this important industry.

4 Norwegian Ship Recycling Yard Logistics

The purpose of this chapter is to provide an in-depth analysis of the logistical operations at AF Offshore Decoms recycling yard. AF Offshore Decom is a prominent player in the Norwegian offshore recycling industry, specializing in the recycling of offshore installations and vessels. The case study and information presented in this chapter is based on interviews with managers and employees at their yard. The findings offer insights into the yard's operations and commitment to sustainability while highlighting the challenges and opportunities for improvement. This chapter aims to provide a comprehensive analysis of the yards logistics operations and offers a deeper understanding of the Norwegian ship recycling industry.

4.1 Case Company – AF Offshore Decom AS

The case company is a subsidiary company of AF Gruppen. AF Offshore Decom is a specialized company that focuses on decommissioning and recycling of offshore oil and gas installations and ships, while its parent company, AF Gruppen, is a leading contractor and industrial group with a focus on creating value and opportunities through project activities. They have an uncompromising attitude towards safety and ethics, and their vision is to clean up the past and build for the future.

AF Offshore Decom remains a subsidiary of AF Gruppen and benefits from the resources and support of the larger parent company. The ownership of AF Offshore Decom by AF Gruppen allows for synergies between the two companies, as AF Offshore Decom can leverage AF Gruppen's expertise, while AF Gruppen can benefit from AF Offshore Decom's specialized knowledge and experience in offshore decommissioning and recycling.

4.1.1 AF Gruppen

AF Gruppen is a Norwegian construction and engineering company that operates within various industries, including infrastructure, buildings, energy, and offshore. The company has a strong focus on sustainability and safety, with a goal of reducing its environmental impact and promoting a safe work environment for its employees.

AF Gruppen has a decentralized organizational structure, which allows for flexibility and adaptability to different market conditions and customer needs. The company's business model is based on collaboration and long-term relationships with customers, suppliers, and partners, which has contributed to its success and growth over the years.

In terms of financial performance, AF Gruppen has shown consistent revenue growth and profitability, with a strong focus on cost control and efficient operations. The company's strategic priorities include expanding its market presence and capabilities within its core industries, investing in digitalization and innovation, and continuing to prioritize sustainability and safety.

4.1.2 AF Environmental Base Vats

AF Environmental Base Vats, henceforth also referred to as "ship recycling yard", "recycling yard" or simply "yard" in this thesis, is a part of AF Gruppen's offshore decommissioning subsidiary, AF Offshore Decom. Located in Vats, Norway, this facility specializes in the recycling and disposal of offshore oil and gas installations and ships. The facility is designed to handle large and complex offshore structures, such as platforms, drilling rigs, jackets, and ships. While the facility handles a variety of offshore decommissioning tasks, the focus of this thesis will primarily be on the ship recycling aspect of its operations.

AF Environmental Base Vats offers a range of services, including cleaning, cutting, recycling, and disposal of offshore structures. The facility has equipment and technologies that enable it to handle materials in an environmentally sustainable manner. For example, the whole production area has a water drainage system underground that collects and cleans every drop of contaminated fluid that is being released during the dismantling processes. The expansive production area also allows AF Environmental Base Vats to handle multiple projects simultaneously while ensuring safe and environmentally friendly operations.

AF Environmental Base Vats is an integral component of AF Offshore Decom's capabilities in offshore decommissioning and recycling. The yard's operational experience and expertise in dismantling and disposal enable it to provide safe and sustainable solutions for the recycling of offshore oil and gas installations and ships. Figure 5 provides an overview of the yard when it is devoid of projects.

Figure 5: AF Environmental Base Vats. Source: AF Gruppen (2023).

4.1.3 AF Offshore Decom AS

AF Offshore Decom is a Norwegian company that specializes in decommissioning and recycling of offshore oil and gas installations and ships and is currently dismantling and recycling the 235meter long Floating Production Storage and Offloading (FPSO) ship, as seen in figure 6. AF Offshore Decom offerings include engineering, project management, and offshore execution. With several successfully completed decommissioning projects in the North Sea, the company has established a solid track record in the industry. Its approach is based on a comprehensive understanding of the environmental, technical, and regulatory challenges associated with decommissioning and recycling, as well as a dedication to safety and sustainability.

AF Offshore Decom's ability to provide integrated solutions that cover all aspects of decommissioning is one of its primary strengths. It has developed innovative technologies and methodologies that allow for the safe, effective, and environmentally responsible execution of decommissioning and recycling projects. Collaboration and stakeholder engagement are also key to the company's operations. By working closely with clients, regulators, and other stakeholders, AF Offshore Decom ensures that all phases of the recycling process are meticulously planned and executed to reduce environmental impact while promoting transparency and accountability.

AF Offshore Decom have a track record of 97% recycling rate for materials received for decommissioning with 350 000 tons dismantled and recycled. In the 46 installations they have recycled, 20 000 tons of hazardous waste have been removed from the waste cycle. AF Offshore Decom is a top player in the green offshore decommissioning and recycling sector. The company's commitment to safety and sustainability has positioned it well to meet the demands of decommissioning in the 21st century.

Figure 6: Picture of the FPSO vessel. Source: AF Gruppen (2023).

4.2 Products, Markets, and Customers

AF Offshore Decom, as a leading company in the Norwegian offshore decommissioning and recycling industry, offers a variety of services and products catering to the needs of the oil and gas decommissioning and recycling sector. This subchapter delves into the products, markets, and customers of the company, drawing upon insights gleaned from interviews conducted with managers at AF Offshore Decom.

Products

AF Offshore Decom specializes in providing comprehensive decommissioning and recycling services for oil and gas installations and ships. These services encompass platform removal, subsea infrastructure decommissioning, and onshore recycling. Key products and services include:

Topside Removal: They specializes in topside removal, a crucial aspect of the recycling process of a platform. The company's expertise in topside removal ensures minimal disruption to the environment and surrounding facilities, while meeting regulatory requirements and client expectations.

Subsea Infrastructure Decommissioning: In addition to topside removal, AF Offshore Decom is proficient in dismantling and removing subsea structures, including pipelines, jackets, and umbilical’s. The company leverages its experience to perform complex subsea decommissioning tasks, ensuring that these operations are carried out safely. AF Offshore Decom helps its clients mitigate potential environmental risks and adhere to their decommissioning obligations.

Onshore Recycling: AF Offshore Decom's commitment to sustainable practices extends to onshore recycling, where the company processes and recycles materials from decommissioned offshore installations and ships. Equipped with state-of-the-art facilities, AF Offshore Decom is capable of minimizing waste and reducing the environmental impact of its operations. The company's onshore recycling efforts contribute to a circular economy and help its clients meet their sustainability goals.

Markets

AF Offshore Decom operates primarily in the North Sea, targeting the oil and gas markets in Norway and the United Kingdom. The need varies in line with the oil market, but the company's services are in high demand, as both countries have stringent regulations governing the decommissioning and recycling of offshore installations. The North Sea market is characterized by aging infrastructure, which necessitates decommissioning as platforms reach the end of their operational lives. There are 250 installations that need to be removed by 2030, which AF Offshore Decom can compete to obtain. AF Offshore Decom's extensive experience and capabilities in this region give it a competitive advantage in addressing the unique challenges associated with decommissioning projects in the harsh North Sea environment.

Customers

AF Offshore Decom's primary customers are oil and gas operators, both national and international, that have offshore installations in the North Sea. These companies include major players such as Equinor, BP, Shell, and Total Energies. The company has successfully built a reputation for delivering high-quality services and maintaining strong relationships with its customers. By aligning its offerings with the regulatory requirements and environmental standards of its customers, AF Offshore Decom has positioned itself as a preferred partner for decommissioning projects in the North Sea. AF Offshore Decom has established itself in the offshore decommissioning and recycling industry by offering innovative and environmentally sustainable solutions. Their commitment to quality, safety, and customer satisfaction has allowed it to forge good relationships with its clients, ensuring continued success in the competitive decommissioning market.

4.3 Recycling Yard Layout and Infrastructure

AF Offshore decom´s onshore recycling yard is AF Environmental Base Vats. This is as mentioned a specialized yard that focuses on the recycling of offshore installations and ships. The base is strategically located in Vats, Norway, offering a unique combination of a deep-water quay, extensive yard space, and direct access to the North Sea. This enables AF Offshore Decom to efficiently handle large-scale recycling projects. The yard is a former platform construction facility, which since 2005, has focused on recycling of decommissioned offshore installations and in newer times, ships. AF offshore decom has recently taken on a project to recycle a 235-meter, 25,000-ton FPSO ship. The yard is designed to handle various types of vessels and installations, adapting its methods and processes for each unique project. As a result, the infrastructure at the yard is versatile and equipped to meet the varying requirements of dismantling projects.

The yard consists of three quays: Barge Quay and Raunes Quay, with a 182-meter-wide main quay situated between them, capable of storing approximately 7000 tons of material on the quay side. The yard also features additional facilities such as operations offices, and a workshop with a waste station located nearby. Trucks that enter and exit the yard are required to traverse a designated transit area. In this area, they undergo a process of weighing and scanning by a specialized portal designed to detect Naturally Occurring Radioactive Material (NORM) values. This procedure serves dual purposes: it quantifies the amount of material being transported and screens for any indications of NORM values. It is important to note that the case company does handle NORM, which inherently contains very low levels of radioactivity. This underscores the presence of radioactive elements, albeit at minimal and naturally occurring levels, within the materials managed by the company.

Furthermore, a warehouse is available for storing parts and equipment, while a larger storage area is positioned outside the yard for optimal space utilization. Accommodations and canteens, along with the main administration building housing offices, are also situated outside the yard. Additionally, a state-of-the-art water filtration system is installed beneath the entire project area, collecting every drop of water that falls onto it. Lastly a stationary shear is positioned in the project area for easy access when needed. Look at figure 7 for an illustration of the layout at AF Environmental Base Vats.

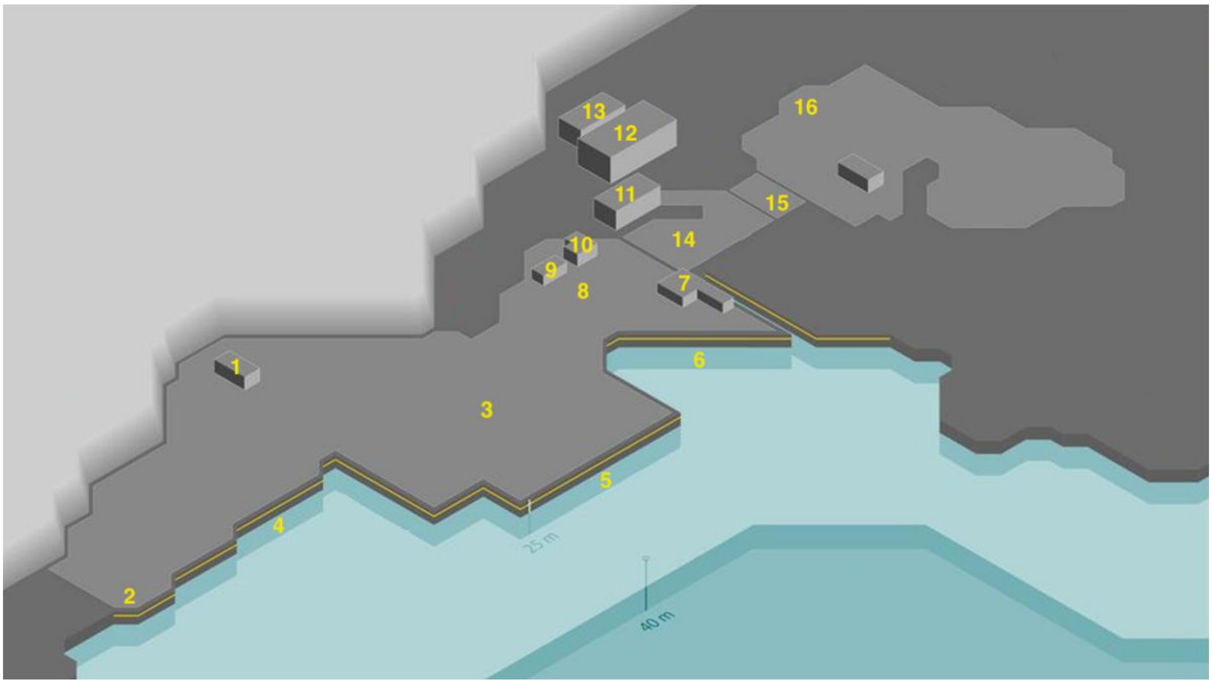

Figure 7: Layout of AF Environmental Base Vats. Source: This is a modified illustration based on an original illustration provided by AF Gruppen (2023).

In table 3 a list of facilities connected to the numbers in figure 7 is given.

Numbers	Facilities
1	Stationary shear
2	Underground membrane covering the yard marked as a yellow line
3	Project area
4	Barge quay
5	Main quay (182-meters)
6	Raunes quay
7	Water treatment plant and hazardous waste storage
8	Weight station
9	Operations office
10	Workshop
11	Warehouse
12	Main administrative office
13	Accommodation and canteen
14	Transit area
15	Main gate and yard entrance
16	Storage area

Table 3: Numbers and descriptions for AF Environmental Base Vats Layout illustration.

The main quay, Barge quay, and Raunes quay provide extensive docking space, ensuring efficient loading and unloading of materials, installations, or vessels. The strategic positioning of the operations office and workshop near the quays and project area facilitates smooth coordination between project management and operations. This proximity allows for quick response in addressing any issues that arise during the production process. The waste station plays a crucial role within the facility. It serves as a central hub for cleaning, sorting, and storing materials and waste, ensuring that the materials are processed and managed safely and efficiently. The water treatment plant and hazardous waste storage located within the waste station further contribute to the yard´s responsible practices.

The transit area, equipped with a NORM gate/sensor, is a vital checkpoint for materials leaving the facility. It ensures that all outgoing materials are safe and obtain acceptable NORM values, preventing any potential hazards during transportation and disposal. This area is also closely situated to the warehouse, which houses equipment, tools, and supplies for ongoing projects, facilitating easy access to essential resources when needed. The larger storage area, located away from the project zone, helps optimize the use of valuable space within the facility. It ensures that materials and equipment not currently in use do not impede ongoing projects or other operations. Moreover, the accommodations and canteen are situated just outside the base nearby, providing a living environment for employees and minimizing disruption to the production processes.

The project area also features a distinctive underground membrane system that stretches across the entire site. The membrane is 3-4mm thick and positioned between 3 layers of asphalt and 40cm of sand, this membrane collects wastewater from the production zone, directing it towards the mountain side and not towards the ocean. The water is then pumped true drainage pipes, into a 9000 cubic meter wastewater pool situated inside the mountain, close to the production area. The system then filters this wastewater, ensuring that the yard operations do not harm the surrounding environment. As a result, only clean water is released into the fjord and the hazardous waste is stored on barrels and transported away for further disposal and recycling. This represents the world's largest and most advanced water filtration system in a recycling yard and even if it is 20 years old it is still considered a state-of-the-art system. It is also easy to clean up and remove if the base were to be shut down, so everything would be as it was before.

Regarding machinery, the yard possesses a mix of owned and rented equipment, adhering to AF's policy of minimal equipment ownership. This strategy allows the yard to flexibly adapt to each project's specific needs. The machinery at the yard includes cranes, excavators with shears, excavators with grapples, wheel loaders, forklifts, trucks, and cars. In total, there are 3 owned machines which are a single crane, a 200-ton excavator with Europe’s biggest hydraulic shear hanging from its arm and a recently purchased 40-ton excavator with grapples used behind the 200-ton machine for clearing steel. All other machines at the yard are rented on an as-needed basis. All the equipment’s are transported around the yard self-propelled using its belts or wheeled systems. The cranes are also mobile and can be extended up to a height of 140 meters. They also have a stationary shear. The stationary shear helps optimize the flow of materials by cutting large pieces of metal into manageable sizes faster than using torches. This process enables efficient dismantling of larger pieces of metal.

The transportation routes within the yard are meticulously planned to facilitate smooth movement of materials and machinery. The main transportation routes are designed to connect the storage areas to the processing facilities. The secondary routes are strategically placed to provide access to different parts of the yard, with a goal of reducing congestion and enhancing overall productivity. The transportation routes are equipped with appropriate signage and safety features to maintain a secure working environment.

The yard utilizes a workforce composed of both in-house staff and outsourced personnel, all of whom are considered multi-skilled operators. The duration for completing projects varies greatly, with larger offshore jackets taking around six months to complete. The yard places a strong emphasis on planning and logistics to ensure efficient execution and maintain safety as their top priority. This focus on planning ensures that the yard's layout and infrastructure are well-prepared to accommodate the diverse range of projects that come its way.

4.4 Logistical Processes and Material Flow

The recycling of installations and ships involves a series of processes and operations that aim to maximize resource recovery. In this subchapter, the various stages of the ship recycling process for the FPSO vessel, are detailed. The discussion begins with the arrival of the ship, proceeds to examine the plans for its complete dismantlement, and explores the material flow throughout the process.

The ship recycling processes can be divided into several stages:

Pre-loading preparation: Before loading the ship onto the project area, certain preparations must be carried out. For instance, in the case of the FPSO vessel, up to 5000 tons of materials had to be removed before the ship could be brought onshore. This was necessary to optimize the utilization of the self-propelled modular transporters used for moving the vessel onto the quay, as the ship was slightly too heavy. This involved disassembling the helipad while the ship was docked alongside, as well as controlled flushing of ballast water. Cleaning the underside of the ship was also conducted while the ship was laying alongside.

Front-running: The front-running stage is an essential initial step in the ship recycling process, focusing on the preparation of the vessel for dismantling. This phase entails the removal of interior elements, cleaning, and addressing potential hazardous materials. Key components of the front-running stage include:

- Clearing out living quarters, control rooms, and dining areas: These spaces within the ship are emptied of furnishings, equipment, and other items to facilitate subsequent dismantling and recycling.
- Flushing and cleaning tanks: All tanks in the ship are thoroughly cleaned and flushed to ensure they are free from contaminants and deemed suitable for further processing.
- Hazardous materials removal: During this phase, potentially hazardous materials such as asbestos, batteries and mercury switches are identified and safely removed from the vessel.

- Pipe marking and labeling: Pipes within the ship are marked and labeled to streamline the dismantling process and ensure that appropriate handling and disposal methods are employed.
- Cutting and removing sections of the vessel: Certain parts of the ship are cut and removed according to a predetermined plan.

Specialists in handling NORM may also be engaged during the front-running stage to perform cleaning tasks and measure radiation levels. By effectively carrying out the front-running stage, the yard can establish a solid foundation for the subsequent phases of the recycling process.

Cutting and Dismantling: The ship undergoes a systematic dismantling process, adhering to a pre-established recycling plan that in Curlews case prioritizes the removal of the front section to create space for other projects at the yard, before cutting and tearing the ship down from top to bottom. The cutting process employs various tools and techniques, including cutting torches, hydraulic shears affixed to excavators, cranes for lifting, and machinery for pulling components downward. Diamond cutters and wire saws have been tried to cut steel but were found to be less efficient. Shears with assistance of cutting torches are the most effective methods. In specific circumstances, explosives may be utilized to bring structures to the ground safely with reduced human interaction. Bigger cutting equipment, such as the stationary shear, plays a crucial role in this process. Capable of cutting steel up to 22 cm thick and 6 meters wide, this shear reduce the ship's components into manageable sizes suitable for subsequent transportation and recycling.

Material Sorting and Processing: After cutting, the materials are sorted, cleaned, and processed for recycling. Steel is sent to a smelting plant in Mo i Rana, and other alloys to Stena in Skien, Norway. Other precious metals are also being sold to the highest bidder to companies like Stena, Metallco, and Norscrap West. Engines and turbines in good condition may also be sold on public sales websites or to others that are interested.

Material Transportation and Disposal: Approximately 40 000 to 50 000 tons of steel are transported to Mo i Rana annually via bulk ship carriers. The smelting plant determines the size of the steel pieces, and requests pieces with a maximum size of 4 by 4 meters and under 300kg. The schedule for filling and dispatching the ship is determined by AF Offshore Decom, and thus, the frequency varies. On average, between 50 and 100 tons of materials are transported daily.

Waste management is a vital part of the ship recycling process and hazardous materials are managed securely and in accordance with environmental regulations. Any hazardous waste that cannot be recycled or processed is transported to a designated disposal site situated 25 minutes away. At this location, layers of protective material are employed to prevent contamination, with a total of five layers being utilized. A barrier sheet is placed between each layer to enhance protection. Moreover, the entire disposal site is meticulously mapped out, ensuring accurate knowledge of the materials' locations at all times.

4.4.1 Process Management and Information Flow

The efficient management of material flow during the recycling process is achieved through a combination of pre-planning and real-time decision-making. At the yard, much of the material flow management is conducted through morning meetings for planning purposes, while further decisions are made throughout the day via radio communication. Operators are readily available to collect and transport materials around the yard, communicating through different radio channels between operators, the stationary shear, cranes, and other equipment.

To maintain an overview of progress and upcoming tasks, regular meetings are held with project management, which includes the operations managers, planners, foremen, and operators. Morning meetings are utilized for task assignment and discussing challenges. The operations managers review the day's tasks in front of a board displaying the yard layout, utilizing movable pieces for clarity and visualization. Challenging cases are addressed using digital illustrations. Daily work progress is monitored during afternoon meetings attended by the operations managers, foremen, and health and safety representatives. Documentation is maintained and submitted to track progress, with project progress reported through monthly and daily reports. All materials entering or leaving the yard are weighed on wheel loaders and trucks before being transported to the quay edge for ship transport or driven out of the yard via road.

Work tasks are planned using paper or oral communication, involving operators in the process. Systems such as Product Lifecycle Management (PLM) and Enterprise Resource Planning (ERP) are utilized to some extent. Although these systems are effective for their current purposes, there is potential for improvement and increased use, as manual records in paper form are more susceptible to errors.

AF Offshore Decom representatives points out that continuous improvements are made to the yard's processes and systems in response to the dynamic nature of recycling operations, focusing on developing better material flow strategies and optimizing available space. Emphasis is placed on worker competence, training, and adherence to safety procedures to minimize accident risks and ensure the successful execution of the recycling plan.

4.4.2 Material Flow

Figure 8 depicts the typical material flow inherent in a recycling project. The illustration employs the layout figure as a schematic representation, with an explanation of the various symbols and lines provided in figure 9:

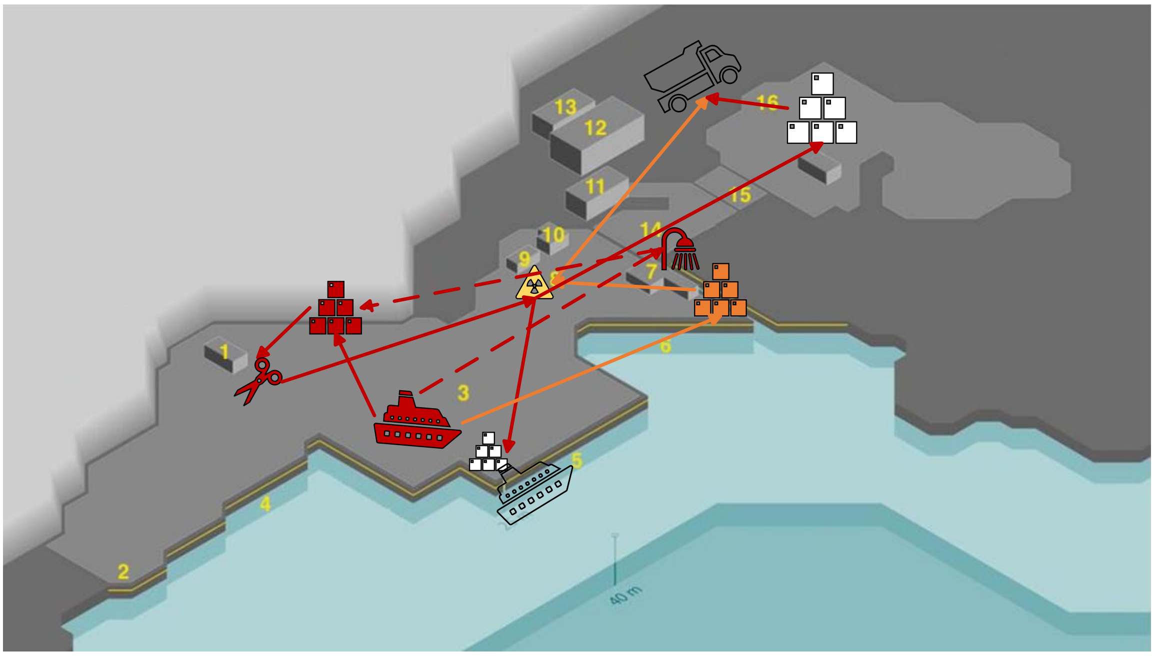

Figure 8: Illustration of the material flow in AF Environmental Base Vats. Source: This is a modified illustration based on an original illustration provided by AF Gruppen (2023).

In figure 9 is a description of the symbols and lines used to illustrate the different stations and material flow in the yard.

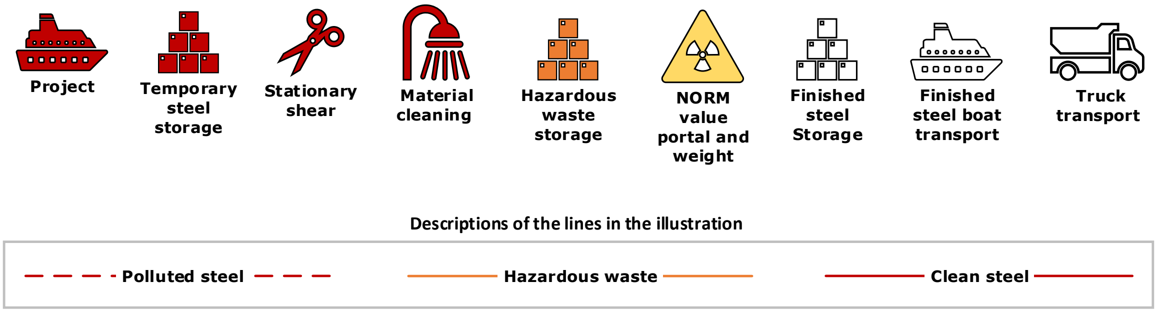

Figure 9: Description of symbols and lines in the material flow illustration.

At the yard, the process of dismantling steel structures involves the use of a hydraulic shear connected to an excavator, which can cut up to 5 cm thick steel in a single bite. Alternatively, manual cutting is performed using oxy-propane torches. In certain cases, explosives are employed to weaken structures, making them easier to handle by machines or manual labor.

Upon cutting the steel into manageable sizes, it is temporarily stored near the stationary shear. The storage location depends on the steel's condition; approximately 95% of the steel is clean steel and stored directly, whereas 5% of the steel is polluted steel which requires cleaning at the hazardous waste storage facility. After cleaning, the polluted steel is transported back and stored near the stationary shear with the rest of the clean steel. This shear then cuts all the steel into pre-determined lengths, approximately 4 by 4 meters, and with a weight limit of 300 kilograms per piece, to be shipped to the smelting plant in Mo I Rana.

Prior to the departure of any material from the yard, it is mandatory for it to undergo screening through the NORM portal. This measure is implemented to ensure that materials with acceptable levels of NORM are not inadvertently transported. Furthermore, each piece of material is weighed to track project progress. After these checks, the steel is either stored in a designated area or directly transported to the quayside, where an excavator, also equipped with a radioactivity sensor to measure the NORM values, loads the bulk carrier for shipment to the smelting plant in Mo I Rana as seen in figure 10.

Figure 10: Loading a bulk carrier with steel for transportation to the smelting plant.

Hazardous waste is sent directly to the hazardous waste storage facility, where various measurements and tests are conducted to ensure the safe handling of different material types. Subsequently, this waste is directly transported from the yard's hazardous waste storage facility to either an underground repository or another facility equipped to handle the material, using trucks. Non-hazardous waste, on the other hand, is simply collected in containers and transported for recycling.

If any material is found to have to high NORM values, it is handled further by certified professionals with the necessary expertise to handle the material safely and appropriately.

The mapped and illustrated material flow in the yard can provide a deeper understanding of the logistics and processes involved in the dismantling projects. It is important to note that the material flow presented in this illustration serves as a typical example and may not encompass all possible variations that could be encountered in different projects. The complexities of recycling operations, as well as the unique characteristics of each project, can lead to variations in the actual material flow. The information used to create this representation was obtained from representatives at AF Environmental Base Vats and pertains mainly to the material flow surrounding the FPSO vessel.

4.5 Recycling Yard Capacity and Throughput

The capacity and throughput of the recycling yard for dismantling ships and offshore installations emphasize efficient space utilization, processing speeds, and the flexibility to accommodate various project demands.

Spanning across 80 000 square meters with a 182-meter-long main quay and two smaller quays, the facility provides ample space for various recycling activities. The yard's layout has been designed to optimize the use of space, to try and ensure efficient processing and storage. The facility is equipped with state-of-the-art machinery and infrastructure, including the mentioned water management system that directs all the contaminated water into a 9 000 cubic meter storage tank. Given Vats' rainy climate, the system is specifically designed to accommodate any volume of rainfall on the base, ensuring sufficient capacity regardless of precipitation levels.

A crucial element of the yard capacity is the ability to handle multiple ships and installations concurrently. The yard can accommodate up to five ships at once, depending on their size and recycling needs, as well as an even greater number of other offshore installation types. This capacity allows the company to sustain a consistent project processing flow. Figure 11 show the yard filled with projects; however, yard representatives emphasize that even at full capacity, they maintain order and meticulously plan the placement of items.

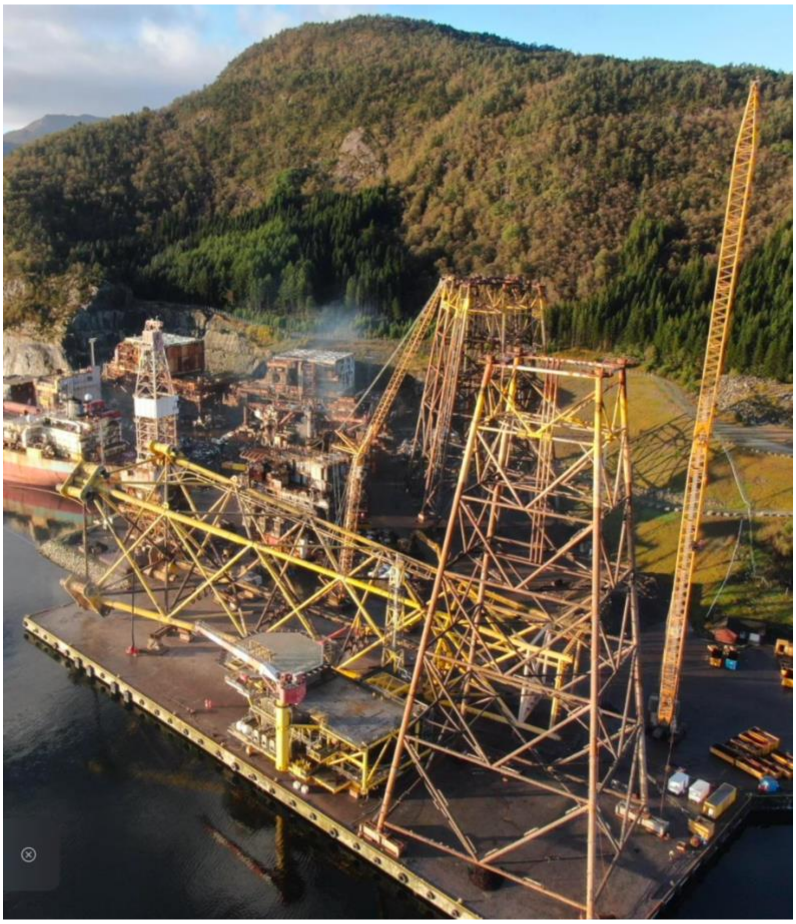

Figure 11: AF Environmental Base Vats with Projects. Source: AF Gruppen (2023).

The throughput of the yard is measured by the rate at which ships and installations are processed. The average time taken to recycle a ship or dismantle an offshore installation is approximately three to six months. However, this timeframe can vary depending on factors such as the size and complexity of the project, the availability of resources, and specific recycling requirements.

Moreover, throughput is influenced by factors such as regulations, environmental considerations, and health and safety standards. The company strictly adheres to international and local regulations, including guidelines set forth by the Norwegian Environment Agency, ensuring that the recycling process is carried out in an environmentally responsible and safe manner. This commitment to sustainability and safety may impact the throughput, as the yard prioritizes these aspects over accelerating the recycling process.

AF Offshore Decom has a policy of owning minimal equipment, instead opting to rent based on the needs of individual projects. This approach allows them to adapt their processes and methods for different projects, while still utilizing the same core principles: weaken, tear down, dismantle. The company has in total dismantled and recycled 350 000 tons of material.

The yard capacity and throughput are characterized by efficient space utilization, the ability to process multiple ships and installations simultaneously, and a commitment to sustainable and safe recycling practices. AF Offshore Decom is responsive to market demands and has adapted to handle increasingly complex installations, even those built with thicker steel and larger dimensions. This adaptability has allowed them to remain competitive in an industry that has 250 installations slated for removal by the year 2030.

4.6 Health, Safety, and Environmental Considerations

AF Offshore Decom demonstrates a strong commitment to maintaining high standards in Health, Safety, Environmental (HSE) management. The organization adheres to strict HSE regulations and guidelines set by them self, national, and international authorities, such as the Norwegian Environment Agency and the Norwegian Radiation and Nuclear Safety Authority. Managers emphasize that their primary focus is on ensuring the safety of employees and minimizing the environmental impact of their operations.

One key aspect of AF Offshore Decom's HSE efforts is the implementation of robust safety management systems, which include regular audits, inspections, and employee training. These systems enable the company to monitor and evaluate its HSE performance, identify potential risks, and implement appropriate preventive measures. Employees are encouraged to report any safety concerns or near misses, fostering a proactive safety culture within the organization.

AF Offshore Decom develops waste management plans for each project, collaborates with various local stakeholders for cleaning projects, and sends hazardous waste to designated disposal facilities. This approach to waste management ensures that the company adheres to HSE regulations.

The complex nature of recycling projects often results in unique HSE risks that may not be fully anticipated or addressed by existing guidelines. Managers recognize that the yard must continuously adapt its HSE practices to accommodate the evolving nature of its work. Additionally, some managers expressed concern over the potential for complacency in the workforce, as employees may become accustomed to working in hazardous environments. To address this issue, AF Offshore Decom encourages regular communication between employees and management, as well as ongoing training and awareness programs. Transparency is a defining feature of the Norwegian ship recycling industry and helps uphold HSE standards across the sector. AF Offshore Decom maintains open communication with its competitors, sharing information and experiences to promote best practices in the industry.

The company's earnings from projects like the FPSO depend on the chosen methodology, execution, and contractual obligations. This encourages engineers to balance profit maximization with safety and environmental standards throughout the project. Despite this challenge, the company remains highly dedicated to maintaining HSE standards. The organization follows strict HSE regulations and guidelines and consistently looks for ways to improve. The goals is to uphold excellent HSE performance with no injuries and minimized impact on the environment.

4.7 Main Characteristics

This subchapter presents a summary of the main characteristics of AF Offshore Decom in table 4. The aim is to provide an overview of the key features that define the organization and its position within the offshore decommissioning and recycling industry.

Characteristics	Description
Expertise in Recycling	AF Offshore Decom possesses extensive knowledge and experience in the field of offshore decommissioning. The company's proficiency in platform removal, subsea infrastructure decommissioning, and onshore recycling enables it to provide comprehensive and efficient solutions to its clients.
Commitment to Sustainability	AF Offshore Decom places a strong emphasis on environmental sustainability in its operations. The company's processes and technologies are designed to minimize waste, reduce environmental impact, and promote the recycling of materials from decommissioned platforms.
Focus on the North Sea Market	AF Offshore Decom primarily targets the oil and gas markets in Norway and the United Kingdom. The company's deep understanding of the unique challenges associated with recycling projects in the harsh North Sea environment gives it a competitive edge in this region.
Strong Customer Relationships	AF Offshore Decom has cultivated good relationships with its clients, which include major oil and gas operators. The company's commitment to quality, safety, and customer satisfaction has positioned it as a preferred partner for recycling projects in the North Sea.
Regulatory Requirements	AF Offshore Decom operates in a highly regulated environment, with stringent decommissioning and recycling standards. The company's ability to align its offerings with these regulatory requirements is critical to its success.
Innovation and Technological Advancement	AF Offshore Decom is curious to adopting new technology and innovative processes to enhance the efficiency and effectiveness of its recycling services. They are trying to develop their own technologies while also exploring other technologies, such as drones and ROVs, for inspections instead of sending workers to inspect at heights using lifts or to examine structures or hulls underwater.
Skilled Workforce	The company's success is underpinned by a highly skilled and experienced workforce. AF Offshore Decom's employees possess the necessary expertise to manage complex recycling projects, ensuring the delivery of high-quality services that meet customer expectations.

Table 4: Main identified characteristics.

These characteristics attribute collectively to contribute to the company's position within the offshore decommissioning and recycling industry and its ability to serve its clients in a competitive market.

4.8 Logistical Challenges

Table 5 aims to identify the main logistical challenges faced by the yard. The different challenges are categorized into capacity constraints, transportation and handling, regulations, coordination and communication, location-specific challenges, and unforeseen issues.

Category	Challenges
Capacity Constraints	• Yard capacity constraints arising from undergoing recycling projects, leading to challenging scheduling for new projects. • Efficient allocation of resources and prioritization of projects to maximize productivity and minimize delays. • Loss of skilled workers due to aging, emphasizing the need to recruit and train new skilled personnel to maintain productivity in the coming years.
Transportation and Handling	• Long distances for transporting steel if it cannot be stored at the quay. • Handling of large, heavy components requiring specialized equipment and skilled personnel. • Storage space limitations, including the need for a closer storage area. • Optimizing distances and processes at different stations.
Regulations	• Time-consuming navigation of complex regulations, potentially leading to project execution delays.
Coordination and Communication	• Sometimes there are challenges in coordinating with various stakeholders, such as suppliers, contractors, and authorities. • Efficient communication and collaboration to ensure smooth project execution. • Delays, increased costs, and potential safety risks due to miscommunication or lack of coordination.
Location-specific Challenges	• Some recycling projects are situated in difficult-to-reach locations, posing logistical challenges in terms of transportation and accessibility. The dynamic nature of the project site and the complexity of maneuvering around them contribute to these challenges. • The project area layout is often difficult to plan due to changes in various projects that can occupy substantial space. Consequently, extra planning and resources are required for these projects, along with the utilization of specialized transport methods and equipment.

	• Gravel used to level out the project area, which over the years has accommodated increasingly difference in elevation gets polluted by the projects on top of it.
Unforeseen Issues	• Unpredictable nature of recycling projects leading to unforeseen logistical issues • Unexpected complications during the dismantling process requiring additional resources or changes to the project timeline. Examples include: - Hydraulic shear on an excavator breaking and taking two months to repair. - workers scheduled for work being canceled due to unforeseen issues. - Booking other companies and workers for cleaning and marine growth removal in the summertime.

Table 5: Identified challenges at the yard.

The table provides an overview of the key challenges encountered by the yard during its operations. Drawing on insights from interviews with representatives at AF Environmental Base Vats and observations done at the yard visit, the table effectively highlights the various factors, that impact the recycling processes.

4.9 Practices and Innovations

AF Offshore Decom employs several practices and innovative solutions to enhance the efficiency and effectiveness of their logistics operations. This subchapter summarizes the practices and innovative solutions observed at the AF Environmental base Vats that contribute to improved logistics operations.

Digitalization: The yard has and will embrace more digitalization to streamline its operations and improve communication between various stakeholders. By utilizing digital tools and software, AF Offshore Decom aim to manage schedules, resources, and project timelines, ensuring smooth execution and minimizing delays.

Modular approach: AF Offshore Decom has adopted a modular approach to its recycling process. This approach involves breaking down the overall projects into smaller, more manageable modules. This technique allows for better planning, resource allocation, and execution of tasks, leading to improved efficiency and reduced project timelines.

Innovative technologies: The yard has invested in innovative technologies to improve the dismantling process and address logistical challenges. Examples include advanced cutting tools, remote-controlled equipment, and robotics like drones, ROVs, small plastic 3D-printers for model creation and VR-technology.

Continuous improvement: AF Offshore Decom fosters a culture of continuous improvement, encouraging employees to identify areas for improvement and propose innovative solutions. This approach helps the yard to stay adaptive and responsive to changing industry demands and evolving project requirements.

Collaboration with stakeholders: The yard actively collaborates with various stakeholders, such as suppliers, contractors, and authorities, to share knowledge and best practices. This collaboration allows AF Offshore Decom to stay informed of the latest industry trends and improve its operations.

Training and development: AF Offshore Decom place a strong emphasis on employee training and development. The company provides ongoing training programs to equip its workforce with the skills and knowledge necessary to handle complex recycling projects effectively. This focus on training helps improve the overall efficiency of the yard's operations.

AF Offshore Decom has adopted various practices and innovative solutions to enhance its logistics operations. By embracing digitalization, investing in innovative technologies, fostering continuous improvement, collaborating with stakeholders, focusing on employee training, the yard has the potential to even further improve its efficiency and adaptability in the face of complex recycling projects.

5 Opportunities for Efficient Recycling Yard Logistics with Industry 4.0

This chapter offers a comprehensive exploration of Industry 4.0 technologies and their potential to mitigate logistical challenges in AF Offshore Decom's Recycling Yard. Initially, it establishes the general potential of these technologies in the ship recycling industry. It then transitions to the specific context of AF Offshore Decom's yard, detailing its logistical characteristics and challenges. Further, the chapter provides a tabulated connection between these challenges and potential Industry 4.0 solutions. Finally, it delves into the opportunities and barriers related to adopting these technologies within the case study context, offering insights to guide future implementation strategies.

5.1 Assessing the Potential of Industry 4.0 Technologies for Recycling Yards

In general, the use of Industry 4.0 approaches to the ship recycling procedures in the ship recycling yards would support sustainability(Pournara and Konstantinidis). Assessing the potential of Industry 4.0 technologies for AF Offshore Decom's recycling yard involves understanding how these technologies can be applied to address the specific logistical challenges faced by the yard. Here is an overview of the potential impact of these technologies on AF Offshore Decom's recycling yard:

Intelligent Robots: Intelligent robots can possibly increase efficiency, precision, and safety by automating tasks that are repetitive, hazardous, or require heavy lifting. In the recycling yard, they can potentially reduce dependency on skilled personnel, minimize safety risks, and improve handling of large components.

Automated Simulations: Automated simulations could be used to optimize storage space layout and improve the overall yard organization. By using digital twin technology, simulating different scenarios and configurations, make it possible to identify the most efficient setup, leading to better space utilization and streamlined workflows.

Internet of Things: IoT could play a significant role in optimizing transportation, communication, and real-time monitoring at the recycling yard. With IoT-enabled devices, it is possible to track the movement of materials and equipment, optimize routes, and ensure efficient communication and coordination among stakeholders.

Cloud Computing: Cloud computing can be used as a tool to provide a centralized platform for data storage, management, and collaboration. By adopting cloud-based solutions, the recycling yard can improve regulations, simplify communication among stakeholders, and streamline project management processes.

Additive Manufacturing: AM can help the recycling yard quickly produce tools, spare parts, or other required components on-demand. This can reduce delays caused by unforeseen complications during the dismantling process and minimize the need for a large inventory of spare parts.

Augmented Reality: Augmented reality can possibly enhance communication and collaboration among team members by providing real-time information and visualizations. AR can improve project execution by helping workers visualize complex processes, reducing errors, and minimizing delays caused by miscommunication or lack of coordination.

Big Data Analytics: Big Data analytics could help the recycling yard make data-driven decisions by analyzing historical data, patterns, and trends. It can aid in optimizing resource allocation, project prioritization, and anticipating potential issues in the recycling process.

Industry 4.0 technologies clearly have the potential to impact AF Offshore Decom's recycling yard. By leveraging these technologies, it seems like the yard can improve efficiency, safety, communication, and overall project execution. However, it is crucial to carefully evaluate the feasibility of implementing these technologies in the specific context of the recycling yard, considering opportunities and barriers to adoption.

5.2 Identified Logistical Characteristics and Challenges.

The case study detailed in Chapter 4 provides an understanding of the existing main characteristics and the general challenges encountered in the ship recycling yard. This subchapter aims to summarize the more specific logistical characteristics and challenges identified. However, it's important to clarify that the highlighted challenges are not all-encompassing. Instead, they have been chosen specifically for their potential to be addressed using Industry 4.0 technologies.

5.2.1 Logistical Characteristics

While the main characteristics provided a general understanding of the yard and its operations, the logistical characteristics provide more specific insights into the operational challenges and opportunities for improvement. This distinction becomes especially relevant when considering the potential applications of Industry 4.0 technologies, which often target specific logistical challenges. The logistical characteristics of the AF Offshore Decom ship recycling yard can be summarized as follows:

Inbound and outbound logistics: The yard receives decommissioned offshore installations for recycling. Additionally, it sends out materials for recycling and waste products for further processing or disposal.

Capacity and space constraints: The yard operates within a reasonable large space but still must manage its operations effectively to optimize capacity utilization since the structures often are large and heavy.

Highly regulated industry: The ship recycling industry is governed by a complex set of national and international regulations, which mandate strict environmental and safety standards. This creates a unique logistical challenge, as compliance with these standards requires much monitoring.

Multi-stakeholder environment: The recycling operations involves various stakeholders, including ship owners, regulatory authorities, and other companies both local and international. Coordination among these stakeholders can be critical to ensuring a smooth and efficient recycling process.

Material flow complexity: The ship recycling process generates a wide variety of materials, which must be sorted, stored, and transported to appropriate facilities for further processing or disposal. This complexity adds to the logistical challenges of managing the recycling yard.

Fluctuations in demand: The ship recycling yard experiences fluctuations in demand, which can create periods of intense activity followed by periods with less activity. This necessitates careful planning and resource allocation to accommodate these fluctuations.

5.2.2 Challenges

In chapter 4, the case study highlights several logistical challenges observed in the ship recycling yard. From these, a set of challenges with the potential to be addressed using Industry 4.0 technologies has been selected. Below, you will find an outline of the selected categories and the corresponding challenges.

Capacity Constraints:
- Efficient allocation of resources and prioritization of projects to maximize productivity and minimize delays.

Transportation and Handling:
- Long distances for transporting steel if it cannot be stored at the quay.
- Handling of large, heavy components requiring specialized equipment and skilled personnel.
- Storage space limitations, including the need for a closer storage area.
- Optimizing distances and processes at different stations.

Regulation Navigation:
- Time-consuming navigation of regulations, potentially leading to project execution delays.

Coordination and Communication:
- Challenges in coordinating with various stakeholders, such as suppliers and contractors.
- Efficient communication and collaboration to ensure smooth project execution.
- Delays, increased costs, and potential safety risks due to miscommunication or lack of coordination.

Location-specific Challenges:
- Some recycling projects are situated in difficult-to-reach locations, posing logistical challenges in terms of transportation and accessibility. The dynamic

nature of the project site and the complexity of maneuvering around them contribute to these challenges.

Unforeseen Issues:

- Unpredictable nature of recycling projects leading to unforeseen logistical issues.
- Unexpected complications during the dismantling process requiring additional resources or changes to the project timeline.

5.3 Opportunities for Industry 4.0

Industry 4.0 presents significant opportunities for organizations to enhance their performance by leveraging experiential data, advanced technology, and the growth of telecommunications. This paradigm shift fosters the evolution of organizations, promoting increased productivity and reduced risk(Donepudi 2014). Industry 4.0 can lead to improved safety and job satisfaction, ultimately resulting in better outcomes and enhanced overall performance(Donepudi 2014). This transformative era, characterized by the integration of advanced technologies, has the potential to address the historical environmental consequences associated with the ship recycling sector. By harnessing the key pillars of the Fourth Industrial Revolution, the industry can revolutionize its practices, adopting sustainable and eco-friendly methods, while simultaneously enabling more efficient and responsible resource utilization. With this in mind, Industry 4.0 has the potential to transform the ship recycling yard ecosystem(Pournara and Konstantinidis).

Building upon the challenges selected in the previous subchapter, table 6 has been created to provide a clear overview of the logistical challenges identified in the ship recycling yard and their potential solutions using Industry 4.0 technologies:

Categories	Challenges	Potential Industry 4.0 Technologies	How the Technology Could Address the Challenge
Capacity Constraints	Efficient allocation of resources and prioritization of projects	Big Data Analytics	Analyzing historical data, patterns, and trends to optimize resource allocation and project prioritization
	Minimizing delays	Automated Simulations	Identifying efficient setups and processes through simulations to reduce delays
Transportation & Handling	Long distances for transporting steel	Internet of Things	Real-time tracking and optimization of transportation routes and materials movement
	Handling of large, heavy components	Intelligent Robots	Automating heavy lifting and hazardous tasks, reducing dependency on skilled personnel

	Storage space limitations	Automated Simulations	Simulating storage space layouts to optimize space utilization and workflow
	Optimizing distances and processes at different stations	Internet of Things	Tracking equipment and materials for efficient process management and coordination
Regulations	Time-consuming navigation of complex regulations, potentially leading to project execution delays.	Cloud Computing	Centralized platform for data storage, management, and collaboration, simplifying regulatory navigation
Coordination & Communication	Challenges in coordinating with various stakeholders	Augmented Reality	Enhancing communication by providing real-time information and visualizations to improve collaboration
	Efficient communication and collaboration	Cloud Computing	Streamlining communication among stakeholders and project management processes
	Delays, increased costs, and potential safety risks due to miscommunication or lack of coordination	Augmented Reality	Providing real-time visual guidance to reduce errors and minimize delays
Location-specific Challenges	Difficult-to-reach locations	Intelligent Robots	Automated and intelligent handling and operations in inaccessible areas
	Dynamic nature of the project site	Augmented Reality	Providing visualizations and guidance for navigating complex project sites
	Complexity of maneuvering around the site	Internet of Things	Real-time tracking and communication for efficient site navigation and coordination
Unforeseen Issues	Unpredictable nature of recycling projects	Big Data Analytics	Anticipating potential issues and complications by analyzing trends and historical data
	Unexpected complications during the	Additive Manufacturing	Quickly producing tools, spare parts, or other components on-demand

	dismantling process		to reduce delays and complications

Table 6: Identified challenges, potential Industry 4.0 technologies, and their solutions.

This table presents a clear and concise overview of the challenges and some potential Industry 4.0 solutions, making it easier to understand the connections between the challenges identified in the ship recycling yard and the potential of Industry 4.0 technologies to address these issues.

While Industry 4.0 technologies offer promising solutions to the logistical challenges faced by the ship recycling yard, it is essential to recognize that adopting these technologies may not be a straightforward process. The implementation of Industry 4.0 technologies can come with various barriers and in the next subchapter, some possible barriers to the adoption of these in a ship recycling yard context will be explored.

5.4 Barriers to Industry 4.0 Technology Adoption

There are several barriers to the adoption of Industry 4.0 technologies(Taş and Şener 2019). In the ship recycling yard, as indicated by the response from the case company representatives, one key challenge is the varying interest and comfort levels with digital tools among workers. Many prefer traditional methods due to familiarity, and this resistance to change could hinder the widespread implementation of Industry 4.0 technologies. Economic factors can also play a role in the adoption of new technologies. Uncertainties in economic benefit could be a factor when considering investing in new technologies that may not guarantee immediate and significant financial returns. This reluctance can slow the transition to greener operations, despite the potential environmental and operational benefits.

Potentially, offering guidance and assistance to enhance employees' self-assurance when utilizing digital instruments or technology might be a key step. Concurrently, it is possible that the development of reward schemes by official agencies could inspire businesses to adopt more technologically advanced approaches for safety reasons, even when the financial justification is not clearly evident. This would not only help them but also contribute to a more sustainable future for the industry.

6 Exploring Promising Industry 4.0 Technologies for Ship Recycling Yard Operations

This chapter aims to identify and analyze a selection of promising Industry 4.0 technologies that could potentially enhance the operations of AF Offshore Decom's ship recycling yard. Building upon the insights gained from the two previous chapters, this chapter offers a comprehensive analysis of the potential applications, benefits, and drawbacks of three selected technologies. The objective is to provide valuable guidance to AF Offshore Decom regarding the adoption of Industry 4.0 technologies within their operations. The following subchapters will delve deeper into specific Industry 4.0 technologies and their possible applications in the ship recycling yard logistics context, potentially helping to outline a roadmap for a successful digital transformation.

Quantifying potential improvements can be a challenging process, particularly when introducing new technology. In many cases, initial challenges may arise, and if the company and its employees do not observe immediate improvements, it is easy to lose faith in the solution and abandon it. Numerous examples exist of companies that have invested significant time, energy, and money into a solution, only for the implementation to fail.

Regarding some of the potential solutions discussed in the previous chapter, many of these technologies are still in the conceptual stage and require further development before they are ready for full-scale industrial application. Consequently, it is difficult to quantify the potential improvements they could bring to AF Offshore Decom's ship recycling yard operations. Some technologies have been tested in labs or on a small scale, often focusing on a single specific task. This narrow focus makes it harder to estimate the efficiency gains when applied to multiple applications or tasks in the context of the ship recycling yard logistics. However, chapter 5 showed that various Industry 4.0 technologies present promising possibilities for addressing the identified challenges and possibly enhancing operational efficiency in the recycling yard. A comprehensive examination of the specific benefits and potential drawbacks associated with each technology is essential to ascertain their feasibility and effectiveness within this context.

6.1 Towards a Solution of Promising Industry 4.0 Technologies

This subchapter will focus on the selected technologies, additive manufacturing, augmented reality, and automated simulations, or more specifically, digital twin technology. Their potential to address more specific logistical challenges at AF Offshore Decom's ship recycling yard will be explored. The criteria and rationale for selecting these technologies will be discussed, as well as their possible applications, advantages, and disadvantages in the context of the case company.

The selection of chosen technologies hinged on a curated set of criteria that included their potential to innovatively address specific logistical challenges, capacity for operational enhancements, and proven effectiveness in analogous sectors.

Additive manufacturing, with its transformative potential to rapidly fabricate essential components and spare parts on-site, presents a unique solution to mitigating equipment downtime and reducing dependency on external suppliers. The capacity of AM to enable on-site production of custom parts could substantially streamline the operations in the ship recycling yard, enhancing adaptability and cost-efficiency.

Augmented reality was selected for its wide-ranging applicability in fostering improved communication, enhancing workforce training, and aiding in equipment maintenance. The technology's ability to provide real-time remote assistance, visualize complex processes, and facilitate interactive stakeholder collaboration makes it an ideal tool for addressing both workforce and spatial constraints in ship recycling operations.

Digital twin technology, recognized for its unique capability to virtually simulate the physical ship recycling yard, offers accurate planning and scenario testing opportunities. The technology's ability to experiment operational changes in a safe digital environment before their physical implementation can mitigate the adverse impacts and result in more efficient operations.

These specific technologies were chosen not just for their individual strengths but for their collective potential to holistically address key logistical challenges of the ship recycling yard. It is hoped that the implementation of these technologies would contribute to an operational metamorphosis at AF Offshore Decom's ship recycling yard, driving improvements in efficiency, and project execution.

6.1.1 Additive Manufacturing

In recent years, additive manufacturing, has gained significant attention across various industries. Its prevalence in industries such as aerospace, automotive, and healthcare has been widely recognized due to the advancements in AM techniques and improvements in material properties, which have widened its applicability(Taş and Şener 2019). While the maritime industry has seen limited AM utilization to date, it is predicted that its application will progressively expand in the near future.

Current uses of AM in the maritime industry primarily revolve around prototype development, manufacturing primary structural components for yachts, and producing spare parts(Taş and Şener 2019). One promising application of AM is in ship recycling yards, where it could serve as a transformative solution to minimize delays and downtime caused by the process of obtaining essential equipment spare parts. The ability to promptly create custom components and spare parts on-site using AM techniques, such as 3D printing, can significantly reduce dependencies on external suppliers and extended waiting times, thus improving operational flexibility(Taş and Şener 2019).

(Kostidi, Nikitakos et al. 2021) delved into the unique challenges and opportunities presented by additive manufacturing. They identified several potential benefits, including cost reductions, service improvements, and a decrease in storage space requirements. However, actualizing these benefits within the context of ship recycling yard operations depends on various influencing factors.

One of the most critical concerns is the assurance of quality for 3D printed parts. Given that these parts can play a crucial role in operational safety and functionality, they must conform to strict quality standards(Kostidi, Nikitakos et al. 2021). Interestingly, logistical considerations can make even inexpensive items expensive due to the associated transportation costs. This suggests that 3D printing of such items may present a cost-effective method to enable simpler repairs or parts, thereby contributing to the maintenance of operational efficiency (Kostidi, Nikitakos et al. 2021).

However, capitalizing on the advantages of AM comes with its own set of challenges. As (Kostidi, Nikitakos et al. 2021) detailed, these challenges encompass not only quality assurance but also the cultivation of relevant expertise, trained operators, ensuring the availability of suitable materials, and equipment costs. For a successful transition to AM, the establishment of clear objectives and an effective quality assurance system for produced spare parts is essential. Moreover, it is critical to secure top-level support within the organization to sanction the introduction of AM and allocate the necessary resources(Kostidi, Nikitakos et al. 2021).

6.1.2 Augmented Reality

Augmented reality technology, although several decades old, has seen major advancements in the past decade, making it increasingly applicable in industrial settings. The portability of AR, thanks to smartphones, tablets, and lightweight, long-lasting head-mounted displays, has enabled its transition from laboratory settings to on-site applications(Li, Nee et al. 2017). This technological evolution has piqued the interest of production companies, leading to varied applications of AR across sectors, including gaming, sports, and tourism (Syberfeldt, Danielsson et al. 2016). Nevertheless, despite numerous studies on AR, its practical industrial applications are still relatively few, with the most common uses reported in maintenance, product development, and assembly operations.

In the context of ship recycling, human expertise significantly influences key operations such as metal inspection, cutting, maintenance, and material handling. AR has the potential to augment these tasks by providing workers with digital instructions in real-time(Pournara and Konstantinidis). Integration of AR devices like headsets or smartphones with digital management platforms can offer a seamless flow of information about impending tasks and details about parts scheduled for recycling. Such an integrated system could minimize human errors and enhance overall operational efficiency(Pournara and Konstantinidis).

One significant challenge in developing an effective AR solution for industrial use is the need for robust tracking performance to ensure the delivery of stable and accurate information to users(Li, Nee et al. 2017).

Building on these insights, the subsequent section of this subchapter will explore potential applications of AR within a ship recycling yard operations context, proposing novel ways to leverage this technology to address existing challenges and drive operational efficiency.

Remote Assistance: AR can enable remote experts to provide real-time assistance to workers on-site. This could potentially save time by not having the experts to travel to the yard physically.

Visualization and Planning: AR can be used to visualize complex processes and layouts, facilitating better planning and optimization of the recycling yard operations. This can help address the challenge of capacity and space constraints.

AR-based Training and Skill Development: AR can be used to create interactive training programs to deliver immersive training experiences for the workforce, improving their understanding of complex processes and safety procedures. This can help address the challenges of workforce constraints.

AR-assisted Maintenance and Repair: Augmented reality can be used to provide real-time information on equipment status, maintenance requirements, and repair procedures. By overlaying digital information onto the physical environment, AR can help technicians perform maintenance tasks more efficiently, mitigating downtime and improving overall operational efficiency.

AR-enhanced Stakeholder Collaboration: By providing a shared, augmented view of the ship recycling process, AR technologies can facilitate better communication and coordination among various stakeholders.

6.1.3 Digital Twin

In an industry where unscheduled downtimes or ineffective information management can lead to substantial operational costs, this technology can offer improved operational performance and strategic risk and planning management. It is set to reduce costs by enhancing information management and facilitating expert collaboration, thereby mitigating the potential for costly errors and rework.

The digital twin, a component of cutting-edge digital solutions, represents a cloud-based, virtual mirror image of an asset. This image, accessible at any time, integrates data from a variety of software platforms. It plays a crucial role in the digital asset ecosystem, paving the way for the application of advanced predictive analytics(Mauro and Kana 2023).

The adoption of a digital twin can reshape project operations at a fundamental level. It eliminates the siloed approach, often employed by different teams, of generating information and models, which can cause delays in accessing current information for crucial decision-making processes. In contrast, the digital twin presents a collaborative platform where real-time data and analyses are consistently accessible by the team working together. This can allow for early conflict detection on projects and enhanced efficiency in operations(DNV 2023).

From this it seems like ship recycling yard operations stand to gain from the integration of digital twin technology. AF Environmental Base Vats handle a plethora of projects, each with its unique set of data sources and models. This approach, where specialized teams more or less can conduct analyses separately, can lead to inefficiencies and uncertainties due to the potential lack of access to the most recent information for critical decision-making processes. The digital twin, representing a virtual replica of the yard or projects, can streamline many stages of the recycling process by integrating data and models. This integration enhances information accessibility and facilitates more accurate and timely decision-making.

The innovative approach to make a virtual replica of the yard can optimize resource utilization, potentially supporting more profitable and sustainable operations. The digital twin can also be used to test different scenarios and assess the potential impact of various operational changes before their implementation in the physical yard. This application can address the challenges of inadequate planning and forecasting and enable a proactive approach to managing demand fluctuations. Furthermore, by simulating the yard's layout and operations, digital twins can assist in identifying optimal locations for material storage, equipment placement, transport routes and waste management. This can lead to efficient utilization of available space and resources, thereby enhancing the overall operational efficiency.

6.2 AF Offshore Decom's Perspectives on Proposed Technologies

In this subchapter, a summary of a meeting with representatives from AF Offshore Decom will be presented. It will elaborate on the company's response to the alternatives, exploring their perspectives, reservations, and enthusiasm. The discussion was insightful and highlighted the operational constraints, cost considerations, and potential benefits associated with each alternative within the context of real-world operations. The representatives feedback provides a practical lens through which the proposed solutions can be evaluated, thereby enriching the analysis and conclusions drawn in this thesis.

To enhance our understanding of the potential impact and required effort of implementing each proposed alternative, an Impact-Effort diagram for each solution is provided. The dots on the diagrams were placed based on the insights and opinions of the representatives from AF Offshore Decom, adding an important layer of industry perspective to this evaluation.

The Impact-Effort diagram can be a strategic tool used for decision-making, providing a clear visual representation of the potential benefits or "impact" and the estimated resources or "effort" needed for each proposed alternative.

The vertical axis of the diagram represents the impact, referring to the extent to which the proposed alternative could improve operations at the yard. This could include factors such as increased efficiency, cost savings, enhanced safety, or improved productivity. The horizontal axis represents the effort, which includes the resources required to implement the solution—be it monetary investment, time, or human resources.

The positioning of each alternative on the diagram was done by the representatives from AF Offshore Decom. This placement provides a clear understanding of their perception of the potential return on investment and the resources that would be required to achieve it. This hands-on evaluation by the industry professionals serves as a valuable aid in determining the most feasible and beneficial alternatives for their operations.

With the utility of the Impact-Effort Diagram explained and acknowledging that the evaluations provided are rooted in the industry insights of AF Offshore Decom representatives, let's now delve into the first proposed alternative: Additive manufacturing.

Additive Manufacturing: During a discussion with representatives from AF Offshore Decom, the potential of additive manufacturing was acknowledged for its potential application in their offshore operations more than the application in the recycling yard itself. AM could offer a viable solution for fabricating smaller items that would otherwise incur considerable costs and delays when transported via helicopter or supply boat during offshore campaigns. Currently, the company transports containers stocked with spare parts and tools to the offshore site; however, the absence of a specific part can disrupt operations due to the subsequent delay in delivery, so to be able to produce it on-site seems like a promising solution.

Despite the potential benefits offshore, the implementation of AM at the yard was viewed as limited. The representatives noted that the typical ordering and delivery time for spare parts to the yard is approximately two hours. Furthermore, they expressed concerns regarding the material quality of 3D printed parts and high cost of AM machinery, questioning whether the value derived from its use would justify such an investment. The primary advantages of employing AM were identified as the production of specialized equipment and to investigate if it was possible to reduce costs associated with consumable parts for tools that are frequently utilized in large quantities at the yard.

In figure 12, the Impact-Effort diagram for additive manufacturing is presented.

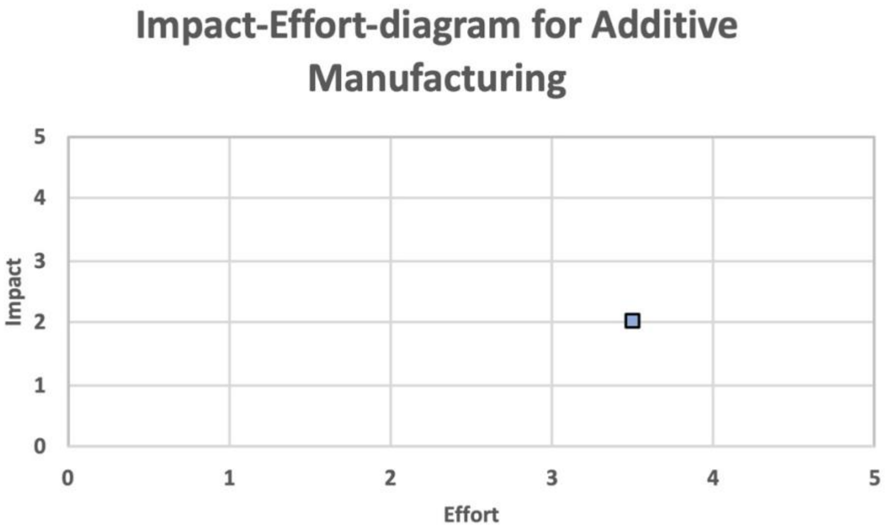

Figure 12: Impact-Effort-diagram for additive manufacturing.

The representatives from AF Offshore Decom placed the dot for AM at an impact of 2 and an effort of 3.5, indicating a moderate level of potential benefit but requiring a relatively high degree of effort or investment. This reflects their view that while AM could be useful, particularly in offshore scenarios, the cost and complexity of implementation might outweigh the benefits. It suggests that a significant investment of resources would be necessary for AM to become a viable option, and the returns may not be substantial enough to justify that investment.

Augmented Reality: The potential of augmented reality to improve the understanding of incoming projects was a significant point of discussion. Currently, a team travels to survey incoming projects, taking photographs and video footage. However, these materials often prove insufficient for detailed planning, which is typically undertaken by operations personnel responsible for the recycling process. The full scale and complexity of the projects only become fully apparent when they are physically present at the yard, often necessitating adjustments to the initial plans which is very time consuming.

AF Offshore Decom representatives suggested that early 3D visualization of projects could obviate the need for expensive and environmentally unfriendly site visits. Therefore, AR could be a valuable tool in conducting surveys, engineering tasks, and facilitating discussions on concepts with experienced operators. The team envisions considerable potential for AR, also during the tendering phase, where it could be used to provide clients with a visual representation of the project cycle.

In Figure 13, the Impact-Effort diagram for augmented reality is presented.

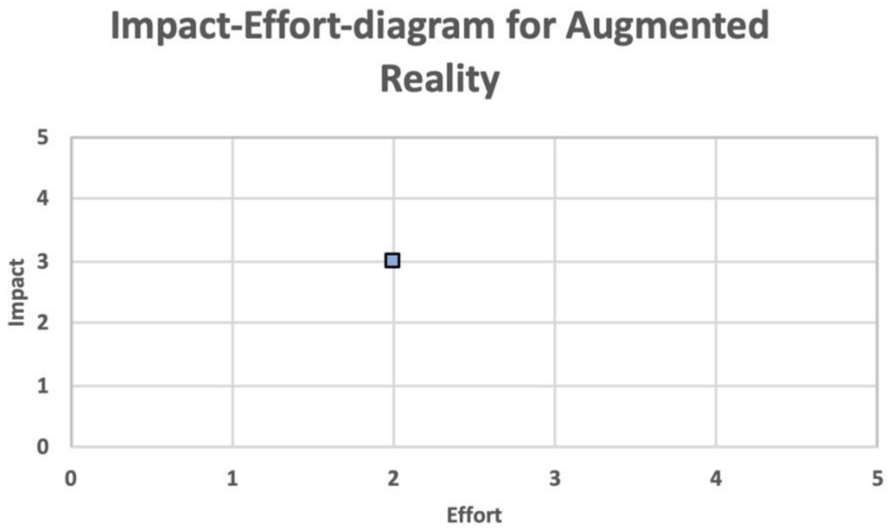

Figure 13: Impact-Effort-diagram for augmented reality

For AR, the dot was placed at an impact of 3 and an effort of 2, indicating a higher potential benefit with a moderate level of effort. This shows that the representatives believe AR could bring some improvements to their operations, particularly in terms of project visualization and planning. The lower effort score suggests that implementing AR might be less resource-intensive than for example AM, thus potentially offering a better return on investment.

Digital Twin: The team currently employs a 'very light version' of a digital twin, utilizing tools such as PowerPoint and Solidworks to visualize placements and create models. They expressed an interest in expanding this approach, potentially incorporating AI into their decision-making processes. While the team exhibited some skepticism regarding the value of maintaining a consistently updated digital twin for their operations, they acknowledged the potential benefits of employing AI for forecasting and planning in a digital twin environment. The application of a digital twin could prove particularly beneficial when contemplating modifications to the yard and prospective projects, facilitating simulations of logistics and investment decisions. However, the team remained uncertain about the frequency of use a digital twin would have in their day-to-day operations.

In Figure 14, the Impact-Effort diagram for digital twin is presented.

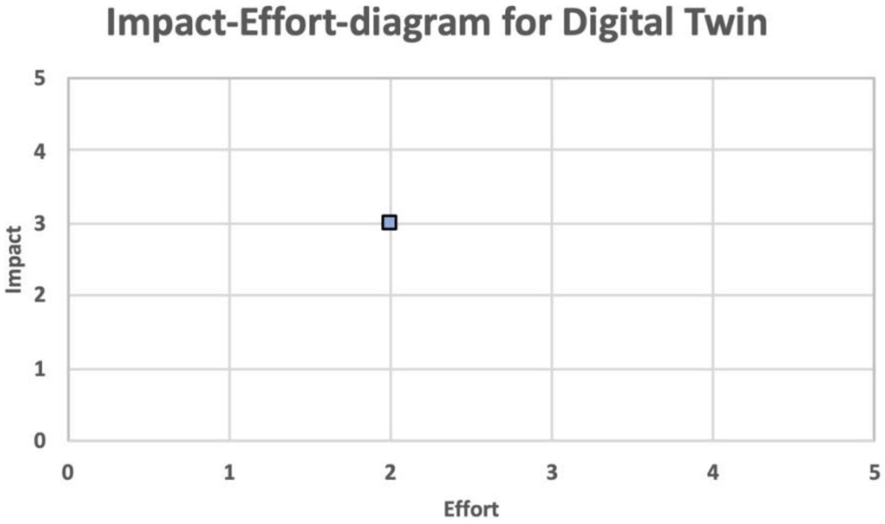

Figure 14: Impact-Effort-diagram for digital twin

DT received an impact of 3 and an effort of 2. This placement shows that the representatives see potential benefits in the use of DT, particularly for forecasting, planning, and decision-making. The effort score suggests that while the implementation of DT would require some investment, it might not be as resource intensive. This could make DT an attractive option, particularly given the potential benefits. However, the representatives expressed some doubts about the daily utility of a constantly updated digital twin, suggesting that while they see the value, they might not yet be fully convinced of its practicality for their current operations.

7 Discussions and Conclusion

In this discussion and conclusion chapter, the key findings from the previous chapters are synthesized to answer the research questions and provide a comprehensive understanding of the operational logistics and challenges of AF Offshore Decom's ship recycling yard, the potential of Industry 4.0 technologies to address these challenges, the promising technologies that could be further explored for their application in the yard's operations and a response from AF Offshore Decom representatives on the suggested technologies. Additionally, the chapter will address broader theoretical contributions, practical implications and recommendations, limitations, and further research directions, paving the way for future exploration of Industry 4.0 solutions in the ship recycling industry.

7.1 Key Findings

This subchapter synthesizes the key findings from the three research questions that were explored in this thesis and the perspective from AF Offshore Decom representatives on the suggested solutions.

Operational Logistics and Challenges: The first research question provided an in-depth understanding of the operational logistics of AF Offshore Decom's ship recycling yard. The yard operates systematically, focusing on efficient space utilization, simultaneous processing of multiple ships, and sustainable recycling practices. However, it faces several logistical challenges, including capacity constraints, transportation and handling difficulties, regulation navigation, coordination and communication issues, location-specific challenges, and unforeseen issues. These challenges underscore the complexities of ship recycling logistics and necessitate the potential for innovative solutions to enhance logistical challenges.

Potential of Industry 4.0 Technologies: The second research question explored the potential of Industry 4.0 technologies to address the logistical challenges identified in RQ1. Several technologies, including intelligent robots, automated simulations, Internet of Things, cloud computing, big data analytics, augmented reality, and additive manufacturing, were identified as potential solutions to these challenges. These technologies can automate tasks, optimize space layout, improve transportation and communication, provide a centralized platform for data management, analyze data for resource optimization, provide visualizations for complex project sites, and produce tools or components on-demand.

Promising Industry 4.0 Technologies: The third research question identified additive manufacturing, augmented reality, and digital twin technologies as promising solutions that could be further explored for their potential application in AF Offshore Decom's ship recycling yard operations. These technologies offer unique capabilities that could enhance operational efficiency and adaptability. Additive manufacturing could streamline operations by rapidly fabricating essential components and spare parts on-site. Augmented reality could improve communication, enhance workforce training, and aid in equipment maintenance. Digital twin technology could offer accurate forecasting, planning and scenario testing opportunities by virtually simulating the physical ship recycling yard. However, their full-scale industrial application requires some further development and consideration of various factors.

AF Offshore Decom's perspectives: In the context of AF Offshore Decom's perspective on these technologies, the company recognizes the potential of these technologies but also acknowledges the practical challenges and considerations associated with their implementation. While the potential of AM to rapidly fabricate essential components and spare parts on-site was recognized, the implementation of AM at the yard was viewed as limited due to concerns about the material quality and high cost of AM machinery and the relatively short ordering and delivery time for spare parts to the yard. This made the implementation of AM less attractive for AF Offshore Decom. However, the primary advantages of employing AM were identified as the production of specialized equipment and the potential to reduce costs associated with consumable parts for tools that are frequently utilized in large quantities at the yard. AR was seen as a promising technology with wide-ranging applicability in fostering improved communication, enhancing workforce training, and aiding in equipment maintenance. Digital twin technology, with its unique capability to virtually simulate the physical ship recycling yard, offers accurate planning and scenario testing opportunities. This technology could be particularly appealing to AF Offshore Decom due to its potential to mitigate adverse impacts and result in more efficient operations. However, the complexity of creating a digital twin of a ship recycling yard could be a potential barrier.

7.2 Theoretical Contributions

This study offers valuable insights into the production processes and associated challenges in a Norwegian ship recycling yard, highlighting the unique operational characteristics present within this environment. In addition, it explores the potential benefits that could accrue from the integration of Industry 4.0 technologies within these processes. The research's findings are expected to prove valuable for organizations operating in this sector. By highlighting existing operational processes, elucidating common challenges, and outlining potential improvements arising from leveraging Industry 4.0 in ship recycling yard operations, this thesis contributes to a nuanced understanding of the transformative potential of digital technologies in this context.

The practical value and applicability of this research were strongly validated through the highly encouraging feedback from AF Offshore Decom, after their review of the thesis draft. They expressed significant interest in the findings, particularly highlighting the utility of Table 6. Additionally, the fact that they consider further investigation of the three proposed technologies in Chapter 6 attests to the real-world relevance and potential impact of this study. Such feedback not only serves as a testament to the quality of this work but also signifies its potential to positively influence operational practices within the yard.

7.3 Practical Implications and Recommendations

This research's findings offer practical implications for the broader ship recycling industry and provide useful insights for adopting and implementing Industry 4.0 technologies to enhance logistics. The benefits identified through the AF Offshore Decom's case study could potentially be extrapolated to ship recycling yards globally, paving the way for digital transformation in the sector.

Practical Implications: Some of the operational challenges identified are probably not unique to AF Offshore Decom, but likely ubiquitous across the ship recycling industry. Capacity constraints, transportation and handling difficulties, coordination and communication issues, location-specific challenges, and unforeseen issues are inherent to ship recycling logistics. Thus, the potential solutions provided by Industry 4.0 technologies hold broader relevance.

However, the full-scale application of these technologies necessitates consideration of various factors including their readiness for industrial use, digital comfort levels among workers, and economic feasibility. Therefore, their adoption should be strategic and considerate of these factors.

Recommendations: For practitioners in the ship recycling industry, the following recommendations are proposed for the adoption and implementation of Industry 4.0 technologies to improve logistics efficiency:

- Strategic Adoption: The adoption of Industry 4.0 technologies should be approached strategically, considering the specific operational logistics and challenges of the ship recycling yard. The technologies should be selected based on their potential to address the key challenges and enhance operational efficiency.
- Workforce Training: The successful implementation of Industry 4.0 technologies requires a skilled workforce. Therefore, training programs should be developed to enhance the digital skills of the workforce and increase their comfort levels with digital tools.
- Collaboration and Stakeholder Engagement: The implementation of Industry 4.0 technologies requires collaboration and engagement with various stakeholders, including technology providers, regulatory bodies, and workers. This collaboration can facilitate the successful integration of the technologies into the ship recycling operations.
- Continuous Improvement: The adoption and implementation of Industry 4.0 technologies should be viewed as a continuous improvement process. The technologies should be regularly evaluated and updated based on the evolving operational logistics and challenges of the ship recycling yard.

7.4 Limitations and Further Research Directions

Limitations: This study is primarily based on a single case, AF Offshore Decom's ship recycling yard. While the findings provide valuable insights, they represent the operational context of one specific recycling yard and may not directly apply to other yards with different operational contexts. Thus, the generalizability of the findings may be limited.

Additionally, the rapidly evolving nature of Industry 4.0 technologies means the potential solutions landscape is continually changing. Therefore, this thesis represents a snapshot of the current state of these technologies in ship recycling logistics, and it may not encompass future advancements or challenges.

Lastly, while this study provides a broad overview of Industry 4.0 applications in the ship recycling industry, it does not delve into detailed technical aspects or specific implementation strategies. This limitation opens avenues for future research.

Further research: The findings of this thesis suggest several avenues for future exploration.

- Deeper investigation into specific processes within ship recycling could reveal additional opportunities for improvement through the implementation of Industry 4.0 technologies.
- Human response to these potentially invasive technologies warrants further investigation. Strategies to manage potential resistance could be crucial for successful implementation.
- A cost-benefit analysis considering the anticipated improvements against the implementation costs could guide decision-making processes regarding technology adoption.
- Finally, empirical studies focusing on the practical implementation of these technologies, evaluating their real-world impact and potential barriers to adoption, would offer valuable insights. While this thesis explores the theoretical potential of these technologies, their effectiveness in practice and the challenges during implementation need further examination.

While this thesis has made strides in understanding the potential of Industry 4.0 technologies in a ship recycling yard, there is still much to be explored. Future research in these suggested areas could contribute to the academic discourse on this topic and provide practical insights that could guide the transformation of the ship recycling industry towards a more efficient, sustainable, and competitive future.

7.5 Conclusion

This thesis has investigated the complexities of ship recycling logistics and the potential of Industry 4.0 technologies to address these challenges, with a specific focus on AF Offshore Decom's ship recycling yard. The operational characteristics, challenges, and potential Industry 4.0 solutions were identified and explored in depth.

The study pinpoints additive manufacturing, augmented reality, and digital twin technologies as particularly promising for enhancing yard operations. However, the successful implementation of these technologies requires strategic planning and careful evaluation of industrial readiness, technical limitations, and cost-effectiveness.

This thesis enriches the academic discourse on the application of Industry 4.0 technologies in ship recycling and offers practical insights for the industry, based on the experiences of AF Offshore Decom. Despite the valuable insights provided, the generalizability of the findings may be limited due to the singular case study approach and the rapidly evolving nature of Industry 4.0 technologies.

The research underscores the potential of Industry 4.0 technologies to transform ship recycling operations. Yet, it also highlights the need for further in-depth research, strategic planning, and practical considerations for effective integration of these technologies, aiming towards a more efficient, sustainable, and competitive future for the ship recycling industry.

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