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Augmented Reality for Operator Support in Norwegian Shipyards

A Study of Applications, Benefits and Challenges

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Global Manufacturing Management
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Preface

The work for this thesis was conducted in the spring of 2019. It is the final part of the 2-year master's programme in Global Manufacturing Management at the Norwegian University of Science and Technology (NTNU). The thesis was written at the department of mechanical and industrial engineering. The thesis marks the end of 18 years of education and the beginning of a new chapter.

I would like to thank everyone that has helped me in the work with this thesis. Including my supervisor Marco Semini for giving good advice and seeing the solutions when challenges occurred, Jo Strandhagen my co-supervisor for good feedback and motivational words. I would also like to thank all the people I was in contact with at the Ulstein group, for interesting discussions and for giving me a better insight into the world of shipbuilding.

I would like to thank my fellow students and especially my office mates that has helped make Valgrinda a place that I have good memories of, even in stressful times.

Trondheim, June 2019

Bendik T. Hjartholm

Bendik Thune Hjartholm

Summary

The Norwegian maritime industry has long traditions and today it contributes to 8% of Norway's GDP. With the high labour costs in Norway it is important that the production of ships is as cost effective as possible.

With the research and development of new digital technologies in the Industry 4.0 domain it is interesting to see how they can be applied in different industries and what benefits they could bring. With augmented reality being one of these technologies that are gaining much interest for industrial applications it is interesting to investigate how it could be applied in shipbuilding and more specifically to support the operators in the ship production. To investigate this, the following research questions were formulated:

> RQ1: How can AR-based operator support be applied in the production processes present in Norwegian shipbuilding?
>
> RQ2: What are the potential benefits and challenges that can be expected from the introduction of AR-based operator support?

The scope of this thesis is limited to the production processes, and more specifically the production processes that are present in Norwegian shipyards.

As a part of the research a case study of a Norwegian shipyard was conducted. This case study was used as a supportive tool and as a basis for identifying and getting a first-hand view of the production processes that are commonly performed by Norwegian shipyards. The literature study identified 14 general production processes in the building of a ship. As Norwegian shipyards typically offshore parts of the production to other countries, typically in Eastern Europe these 14 processes do not reflect the work that is performed in Norwegian shipyards. Through the case study and the literature study it was found that the Norwegian shipyards typically performed one of three strategies: block-outfitting, dock-outfitting or quay-outfitting. Because the case company normally performed dock-outfitting this strategy was given the most focus. The production processes that are typically performed by a shipyard following performing dock-outfitting are: prefabrication, dock-outfitting, quay outfitting, "warehouse, transport and material handling" and dimensional control and inspection.

RQ1 is answered in chapter 4 which identified potential applications in the production processes. Some of the most prominent applications were; dynamic instructions, visualisation of drawings and assembly instructions, directions, comparison between what was designed and built. RQ2 is answered in chapter 5 which investigated the potential benefits and challenges of adapting an AR system in a shipyard. Among the most important improvements that could be expected from the introduction of an AR-based operator support tool is a reduction in the time spent reading and studying drawings, instructions, specifications and manuals in the prefabrication, outfitting and dimensional control and inspection. In warehouse, transport and dimensional control the information needs are different from the more technical disciplines and as such the expected improvements were quicker location of parts and reduced errors in picking compared to static systems such as paper or PDF. The main challenges identified are related to the cost of the technology and the IT infrastructure, the human aspect of introducing the technology including privacy concerns and challenges related to the technology itself such as issues with tracking and the battery-life of the devices.

The main conclusion of this thesis is that the technology has very promising potential for future applications. Existing research has already established that the technology can bring many benefits in industrial applications and with the evolution of the technology and the software it seems likely that the technology will be a part of the future shipyard.

Sammendrag

Den norske maritime industrien har lange tradisjoner og i dag bidrar den maritime industrien med 8% av Norges BNP. Med de høye lønnskostnadene i Norge er det viktig at produksjonen av skip er så kostnadseffektiv som mulig.

Med tanke på forskningen og utviklingen av nye teknologier innenfor emnet Industri 4.0 er det interessant å se hvordan disse nye teknologiene kan bli anvendt i forskjellige industrier. Med AR som en av teknologiene som har fått mye oppmerksomhet for forskjellige bruksområder i industrien er det interessant å utforske hvordan det kan brukes i skipsbygging, og mer spesifikt for å støtte operatørene i produksjonen av skip. For å utforske og svare på formålet i oppgaven dette ble de følgene forskningsspørsmålene formulert:

> RQ1: Hvordan kan AR basert operatørstøtte anvendes i produksjonsprosessene i norsk skipsbygging?
>
> RQ2: Hva er de mulige fordelene og utfordringene som kan forventes av å introdusere et AR basert system for operatørstøtte?

Omfanget av oppgaven er begrenset til produksjonsprosessene og mer spesifikt de produksjonsprosessene som er utført i norske skipsverft. Videre ble det også gjort en avgrensing av produksjonsprosessene til de prosessene hvor det er sannsynlig at operatørene kan oppleve fordeler ved å ha AR-basert støtte.

En casestudie av et norsk skipsverft ble gjennomført og ble brukt for å støtte opp forskningen i tillegg til at den ble brukt for å identifisere og få et direkte innblikk i produksjonsprosessene som vanligvis utføres ved norske skipsverft. Gjennom litteraturstudien ble 14 generiske produksjonsprosesser ved byggingen av skip identifisert. Ettersom norske skipsverft setter ut deler av produksjonen til andre land, vanligvis i Øst-Europa, så gjenspeiler ikke disse 14 prosessene det arbeidet som blir utført ved norske skipsverft. Gjennom casestudien og litteraturstudien ble det klart at norske skipsverft følger en av tre strategier: seksjonsutrustning, dokkutrustning eller kaiutrustning. Ettersom caseselskapet vanligvis utfører dokkutrustning av skrog er dette strategien som har blitt gitt mest fokus i studien. De vanligste produksjonsprosessene som utføres ved dokkutrustning er: prefabrikasjon, dokkutrustning, kaiutrustning, «lager, transport og materialhåndtering» og dimensjonskontroll og inspeksjon.

Kapittel 4 svarer på RQ1, og mulige bruksområder i produksjonsprosessene ble identifisert. Av de mest markante bruksområdene var dynamiske instruksjoner, visualisering av tegninger og monteringsinstruksjoner, rutebeskrivelser og sammenligning mellom hva som er designet og hva som er bygget. Kapittel 5 svarer på RQ2 og undersøker de mulige fordelene og utfordringene ved å innføre AR-basert operatørstøtte i et skipsverft. Blant de mest fremtredende fordelene som kan forventes ved bruk av AR-basert operatørstøtte er en reduksjon i tid brukt på å lese og forstå tegninger, instruksjoner, manualer og annen informasjon som AR kan vise i prefabrikasjon, utrustning, dimensjonskontroll og inspeksjon. Innen lager, transport og materialhåndtering er det informasjonsbehovet ulikt og dermed er de forventede forbedringene knyttet til raskere lokalisering av deler/utstyr, raskere plukking og reduksjon i feil i plukking av varer sammenlignet med statiske og papirbaserte systemer. De største utfordringene som blir

identifisert i kapittel 5 er rettet mot kostnadene knyttet til teknologien og IT infrastrukturen som må være på plass, det menneskelige aspektet ved å innføre teknologien samt tanker angående personvern og utfordringer knyttet til teknologien i seg selv som sporing og batteritiden til enhetene.

Hovedkonklusjonen i denne oppgaven er at det er en lovende teknologi med et stort potensial for fremtidig bruk. Den eksisterende forskningen har allerede stadfestet at teknologien kan føre til mange fordeler i industrielle anvendelser og med den forventede utviklingen av teknologien videre virker det sannsynlig at denne teknologien kan være en del av fremtidens skipsverft.

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List of Abbreviations

AR	Augmented Reality
ATO	Assemble-to-order
CODP	Customer Order Decoupling Point
CPS	Cyber-Physical System
ETO	Engineer-to-order
GDP	Gross Domestic Product
HMD	Head Mounted Display
HVAC	Heating, Ventilation and Air Conditioning
IAR	Industrial Augmented Reality
IoS	Internet of Services
IoT	Internet of Things
MBI	Model-Based Instructions
MR	Mixed Reality
MTO	Make-to-order
MTS	Make-to-stock
NTNU	Norwegian University of Science and Technology
NVA	Non-Value Adding
NVAR	Non-Value Adding but Required
OECD	Organisation for Economic Co-operation and Development
OPP	Order Penetration Point
OSV	Offshore Support Vessel
PSV	Platform Supply Vessel
SART	Smart Augmented Reality Tool
SKU	Stock Keeping Unit
USD	United Stated Dollar
UVE	Ulstein Verft AS
VR	Virtual Reality
WP	Work package

1 Introduction

This section will introduce the main topics of the thesis. It will start by describing the background and motivation for the study, then define the research problem and the research questions. Finally, it will give the scope of the research and outline the structure of the thesis.

1.1 Background and motivation

The maritime industry has long traditions in Norway and it remains an important industry to this day contributing to about 8% of Norway's GDP (Helseth et al., 2019). There are only a handful of European countries that still have an active shipbuilding industry, and there are several factors that has contributed to the survival of the Norwegian shipbuilding industry, but one of the key reasons has been their ability to innovate and adapt (Helseth et al., 2019). The shipyards that are left in Norway are typically small and are mainly located on the west coast. One of the ways these shipyards have adapted is through outsourcing much of the work in the shipyards to stay flexible (Aslesen, 2008). Most recently it can be seen where most yards mainly catered to the offshore market and when this market crashed as a result of the fall in the oil price moved into building other types of vessels such as exploration cruise vessels (Helseth et al., 2019).

Because Norway is a high cost country it is essential that design and production of ships and equipment is as cost-efficient as possible and designed to be operated in a cost-effective, environment-friendly and safe manner (Maritim21 Strategy Group, 2016). An already highly competitive market has become even more challenging in the later years especially after China in 2006 identified shipbuilding as a strategic industry and within short time doubled its market share from 25% to 50% (Kalouptsidi, 2018). Norway has since the 1990s focused on building highly customized and technologically advanced vessels which can defend a higher price than for less advanced vessels built in markets where the costs are lower.

Shipbuilding is an example of an environment where several processes like design, procurement and production can be performed concurrently. In addition factors such as the size of the project, the individual customer requirements, new systems and technologies and having to deal with unpredictable events such as delays and order changes make shipbuilding a complex environment (Mello, 2015). This makes such an environment extremely uncertain and to a large degree, shipyards are depending on a well-educated, competent and independent workforce. Being an industry that is relying on a great deal of manual labour being as efficient as possible is important. This is the reason why shipyards such as Ulstein Verft are working towards being more efficient. Ugland and Gjerstad (2010) conducted a work-time study, which can be seen in Figure 1, that found that the operators on average only spent 27% of their time on value adding activities. When only 27% of the time is spent on value adding it indicates that there is room for improvement for the productivity. In countries where the cost of labour is lower low productivity numbers have a smaller impact than in Norway.

In the later years the interest and research Industry 4.0 and technologies that can improve productivity has increased. The term Industry 4.0 originated in the German research initiative Industrie 4.0 which were aiming to investigate what elements would be key to the future of the German manufacturing industry (Kagerman et al., 2013). With the technological advancements in recent years and the expected continuation of this development this could mean great changes in the way manufacturing is done. It is expected that this will lead to more customizable products produced more efficiently at a lower cost (Kagerman et al., 2013).

OECD (2017) states that the technological possibilities are continuously expanding and that over the next 10-15 years many technological changes will affect production. These technologies often affect each other and combining the different technologies increases their potential. Even with high investments into new production technology there will still be a great need for humans in the production. Shipyards are environments where the products are big and much of the work takes place inside the product which complicates the work and does not make full automation very likely in the near future. As a result, there is a need to look at other ways of improving the productivity and reducing the man hours spent. This means that other new technologies can be used to assist the workers in such environments.

The big focus on Industry 4.0 and increasing interconnectedness and automation of manufacturing has also led to the ideas of topics and concepts such as operator support and *Operator 4.0* and similar concepts are used to describe and promote a symbiotic relationship between humans and machines (Rabelo et al., 2018).

Romero et al. (2016) aimed to develop a typology for the operator in Industry 4.0 called operator 4.0. He described eight different augmentations that the future operator could be assisted by in performing his/her work. Among these eight augmentations is the augmented operator, which is an operator supported by augmented reality (AR). At its core the technology augments digital information on top of the real world that the operator sees.

AR is a technology that has been given much interest over the last few years as the technology has become more portable and powerful. Romero et al. (2016) states that AR can be considered a key enabling technology for improving the information transfer from the digital to the physical world for the operators. Having access to real time information displayed on top of the real world opens for many possibilities for a shipyard operator where the technology can help the operators spend more time on performing the tasks that are adding value and less time on the things that are not contributing any value. Giving an operator an augmented reality tool could for example allow the operator to instantly get the information s/he needs to perform his work, rather than him having to study a set of drawings or instructions to find what s/he needs.

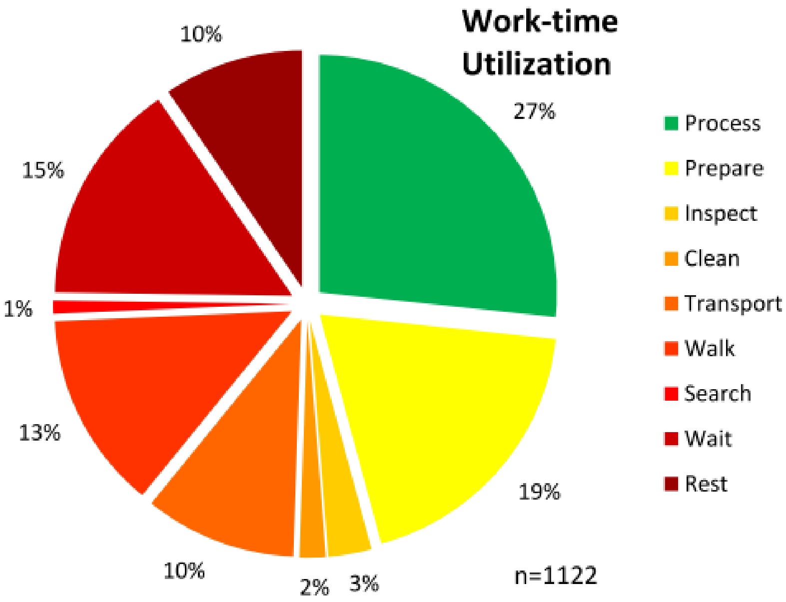

Figure 1: Work-time utilization in a shipyard from (Ugland and Gjerstad, 2010).

1.2 Problem description and scope

As stated in the background Norwegian shipbuilding is subject to competition from countries where the labour costs are much lower than in Norway. As a result, to stay competitive the Norwegian shipyards need to be more efficient than their foreign competitors to narrow the gap and remain competitive.

As there is an increasing interest in Industry 4.0 and the possibilities the digital technologies that are associated with it brings, it is interesting to investigate how these technologies can be applied in different industries. Due to the high degree of manual work in shipyards it is highly relevant for many shipyards to investigate how these technologies could be used to assist their operators.

This thesis will investigate the areas in Norwegian ship production where AR can be applied as an operator support tool to help the operators reduce the time spent looking for and analysing information. The goal is to see how and where AR can be used as an operator support tool in the production of ships in Norway. A necessary part of answering how it can be applied as an operator support tool in the production is to understand what processes the ship production in Norway consists of and what needs the operators have for the different processes. In addition to investigating *how* it can be applied and *where* it can be applied maybe the most important question for a shipyard is *why*. Therefore, the thesis will also aim to investigate the benefits and challenges that such technology would bring to the operators and the shipyard. This leads on to the research questions that has been formulated for this thesis.

1.2.1 Research questions

RQ1: How can AR-based operator support be applied in the production processes present in Norwegian shipbuilding?

RQ2: What are the potential benefits and challenges that can be expected from the introduction of AR-based operator support?

1.2.1.1 How the research questions were answered

The case study contributed in three ways, it was used to identify and understand relevant problems to be addressed in the study, to get a first-hand experience of the different production processes that are present in Norwegian shipyards and to generate discussions about the potential of AR.

The research questions were answered through the use existing literature that describes different applications of AR used for operator support. The first research question is answered in chapter 4, where different applications, both designed for shipbuilding and other industries are coupled with the production process they could improve.

The goal behind the second research question is to investigate and compare the current way the processes are performed and how they could be performed with AR-based and assess the benefits and challenges this could bring for the operators and the shipyard. This research question is answered in chapter 5, where improvements that are experienced either in lab experiments or in larger scale testing are evaluated. In addition, some improvements from the solution overall are highlighted. The chapter also describes some of the challenges that are present with AR-based operator support, regarding both issues related to the people that will be using it, the technology and the cost of the solutions.

1.2.2 Scope

The aim for the thesis is to investigate the potential applications of AR for operator support in a Norwegian shipyard. In this project only the applications in the production of the ships will be studied. Furthermore, as already identified by Semini et al. (2018) Norwegian shipyards typically perform different levels of offshoring of parts of their production. All the shipyards studied performed either Norwegian block outfitting (strategy II), Norwegian dock outfitting (strategy III) or Norwegian quay outfitting (strategy IV) which are illustrated in Figure 2. The scope of this study will be to focus on the production processes that are performed in Norwegian dock outfitting and in Norwegian quay outfitting. As a result, the production processes that are associated with Norwegian block outfitting and complete Norwegian production are considered outside of the scope of this thesis.

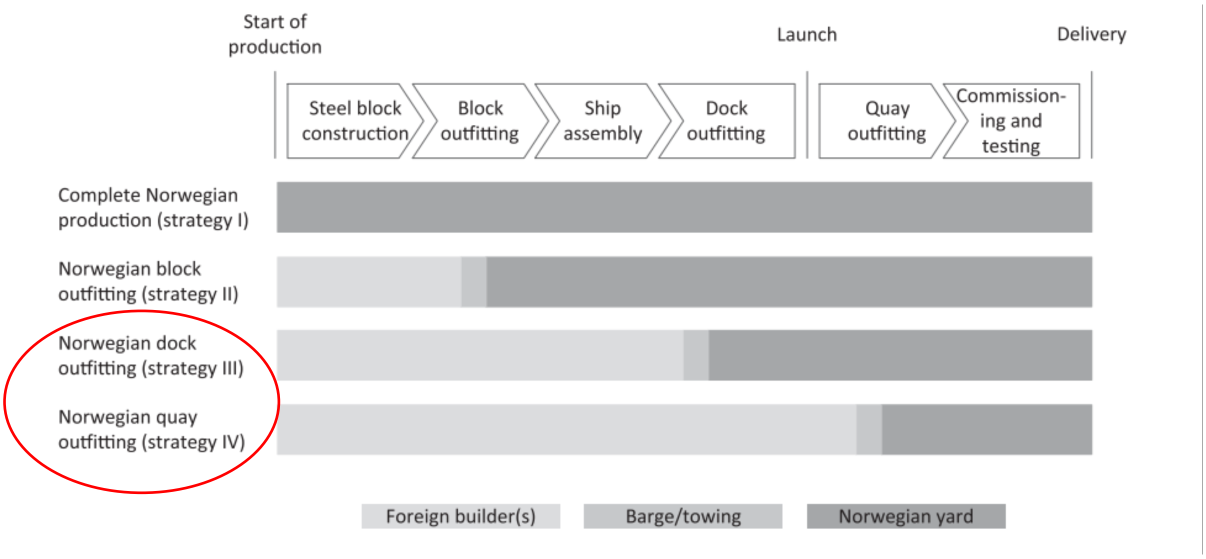

Figure 2: Different offshoring strategies for Norwegian shipbuilding (Semini et al., 2018). Strategy III and IV are circled.

1.3 Structure of thesis

As can be seen in Figure 3 the structure of the thesis starts with the introduction and the definition of the research questions. Chapter 2 describes the methodology of the thesis and gives an overview of the case company for this thesis. Chapter 3 gives the theoretical background of the thesis before the research questions are answered in chapter 4 (RQ1) and chapter 5 (RQ2) respectively. Chapter 6 provides some recommendations for the case company and other Norwegian shipyards. Finally, chapter 7 provides the conclusion of the thesis as well as the contributions, limitations and future research.

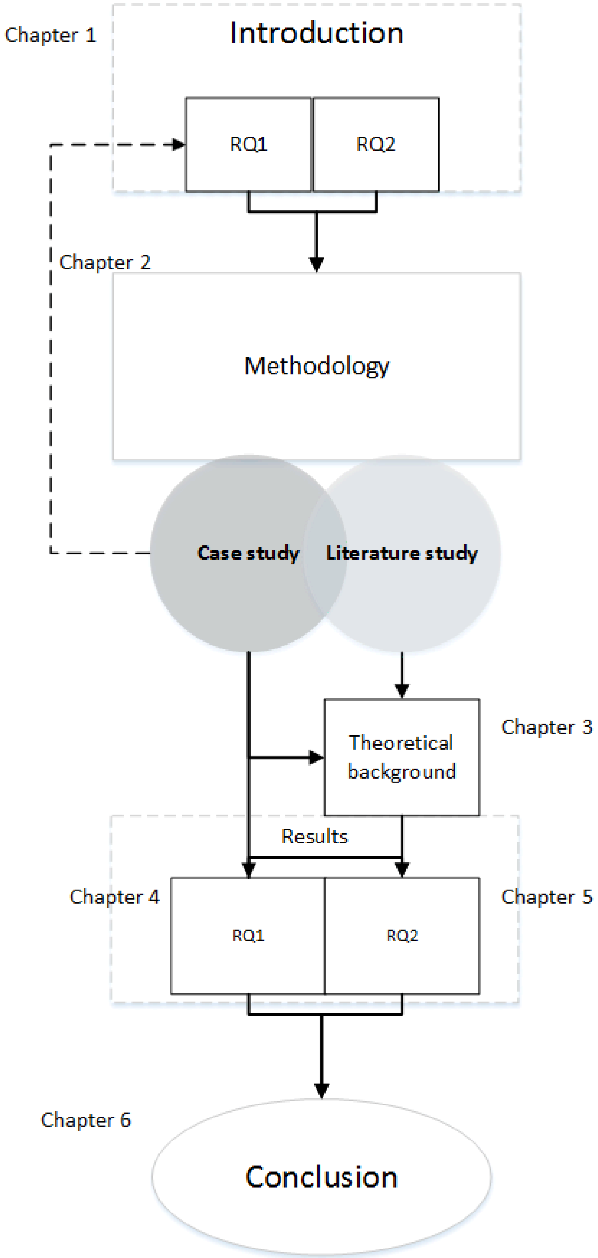

Figure 3: Structure of thesis

2 Methodology

This section will describe the way the research has been approached and give a description of the methodology used in the work with this thesis. It will also give an insight into why these methods have been selected as appropriate for the research.

There are two main ways to approach the data collection in research, qualitative and quantitative. Even though these approaches are different it is not uncommon that case research involves both qualitative and quantitative methods (Croom, 2009). Where quantitative approaches use mathematical and statistical tools to manage the analysis of numerical data qualitative approaches are concerned with constructing, interpreting and perception (Croom, 2009). For this study the qualitative approach is applied as it is of importance to understand and explain the current state for operators in shipbuilding to see in what ways AR as operator support can be applied and what benefits and challenges it could bring.

This master’s thesis consists of two parts, one theoretical part based on a literature study and a case study.

2.1 Literature study

This section will describe what the literature study for this thesis consists of and how the literature was found.

A fundamental part of academic research is to review the existing academic literature in the field of interest (Croom, 2009). It should be done to gain a thorough awareness and understanding of the field in which the research is conducted to position it on the academic map (Ridley, 2012).

The purpose of conducting a literature study was to investigate topics and theory that were relevant for the work in this thesis. At the offset of the work a search for existing literature in the topic was conducted to investigate what research already existed and whether any of it were researching the same as the proposal for this study. In addition to search for existing literature a literature study was conducted on the main areas of this thesis more specifically ship production, operator support and augmented reality. Understanding the industry, people and technology in focus was an important part of building the foundation for the thesis work. As the goal of the literature study conducted in this thesis work was to get familiar with the topics it has not been a systematic review of all relevant literature. After the initial study the searches for literature became more specific directed towards specific research questions and applications of AR as operator support.

2.1.1 Data collection

To find relevant literature multiple databases has been used: most prominently Google Scholar, Oria (NTNU's library search engine) and Research Gate. In addition, the use of Mendeley as a reference management software has meant that relevant articles are suggested based on the topics already in the database. Some of the most used keywords and combinations are listen in Table 1. However, as the topics of AR and Industry 4.0 are relatively new, and the development moves along quickly other sources than traditional academic articles have also been used. This has mainly been news articles and reports/whitepapers.

The starting point of the literature study was therefore the most relevant and most cited articles that appeared in the search.

Table 1: Some of the most important keywords used in literature study

<table>
<tr><td>Keyword set 1</td><td>Keyword set 2</td></tr>
<tr><td colspan="2">Operator support in shipbuilding</td></tr>
<tr><td>Shipbuilding
Ship production</td><td>Operator support
Augmented Reality
Operator 4.0</td></tr>
<tr><td colspan="2">Augmented Reality</td></tr>
<tr><td>Augmented reality</td><td>State of the art
Operator support
Operator instructions
Industrial applications
Industry 4.0</td></tr>
<tr><td colspan="2">Shipbuilding</td></tr>
<tr><td>Shipbuilding
Ship production</td><td>Production processes
Processes
Norwegian</td></tr>
<tr><td colspan="2">Operator support</td></tr>
<tr><td>Operator support
Operator 4.0</td><td>Augmented reality</td></tr>
<tr><td colspan="2">Industry 4.0</td></tr>
<tr><td>Industry 4.0</td><td>Review</td></tr>
</table>

	Elements Technologies

The keywords shown in Table 1 from the top down are only a selection of the keywords used to find articles. From the top it starts with the most general search that was made to see what literature was existing on the topic, to searching for articles that are more specific for each topic. In this case with focus on shipbuilding, operator support and AR. In addition to the use of keywords, citations were used to find relevant literature. For key articles both articles cited and citing articles were used to find relevant literature.

When searching for articles, if the resulting article seemed like it had relevance to the study, first stage was to read the abstract. After reading the abstract the article is either discarded or move on to the next step where the article is studied more in detail through skimming through the introduction conclusion and headlines. If the article was still of interest it was then read more in depth.

Some examples of criteria that was used in the selection of literature in this study:

- Does the article deal with augmented reality (MR/VR was sometimes also of interest)?
    - Does the article either describe a specific application of AR or describe the technology?
        - Can this be relevant/applicable in a shipyard/as operator support?
- Does the article include operator support?
- Does the article deal with the topic of shipbuilding?
    - Does it describe the production processes? If yes, is it a production process that is performed in Norwegian shipyards?

If the article contained one or more of these topics it was included for further analysis and it was used for building up the theoretical background.

The number of citations were used as an indication for the validity and how acknowledged the articles were, however within this topic many of the articles are very recent and as a result the number of citations for these articles was typically fairly low. Croom (2009) argues that citation searches are generally only useful for articles that are older than 2 years and due to the fact that the lead time for many journals is about 18 months and as a result it will take that long before an article appears as a reference. Based on this the number of citations was not put much weight on for articles that were newer than 1,5-2 years.

2.1.2 Search for existing literature

The existing literature on the applications in shipbuilding is limited. A search in the Scopus database with for the key words "Augmented reality" OR "operator support" OR "Operator 4.0" AND "Shipbuilding" OR "ship production" gives 20 results. Out of these 20, 8 can be dismissed as not being relevant for the topic of this thesis. 2 of the articles are an earlier version of the finished article among the 20. Finally, 2 articles are about maintenance and 2 are about early steel work which is typically not performed in the Norwegian shipyards meaning that out of the 20 articles only 6 out of the 20 articles are directly relevant to the topic of this thesis. Only two of the articles are addressing more than one application area for augmented reality in a shipyard. This shows that although there is much research into the topic of AR how it can be applied in an industry such as shipbuilding is limited.

Furthermore, the literature that was found through the search and was relevant for the topic was to a large degree superficial. Most of them mentioned areas where AR could have an impact, but none had studied the potential improvements that could be achieved through the use of the technology.

2.1.2.1 Existing literature

The existing literature could be divided into two groups. Specific applications of AR in a shipyard and more generally possible areas it could be applied in a shipyard.

Table 2: Relevant articles found in search for existing literature.

Specific applications	General areas
(Morikawa and Ando, 2019)	(Blanco-Novoa et al., 2018)
(Kim et al., 2018)	(Fraga-Lamas et al., 2018)
(Fernández-Caramés et al., 2018)	(Morais et al., 2018)
(Oh et al., 2015)	

Out of the articles listed in Table 2 the most relevant ones for the topic of this thesis are (Blanco-Novoa et al., 2018; Fraga-Lamas et al., 2018) which are both a part a research project where the goal is to develop a Shipyard 4.0. The goal of that project is to take the foundations of Industry 4.0 that gives birth to the "smart factory" and apply them in a shipyard to make a "smart shipyard" (Fraga-Lamas et al., 2016). As stated by Navantia: "*Navantia's transformation passes through the improvement of its tools and processes of the whole value chain and through the renovation of its production sites, fully including them in a new Digital Ecosystem: The Shipyard 4.0. This change into "Smart Factories" is carried out focusing on four field of action: Equipment and products, applications, people and enterprise.*" (Navantia, 2019).

This means that there is research on similar topics, however neither of these articles goes into the specific applications in a shipyard and evauluate the effects these applications could have in a shipyard.

2.2 Case study

Case research has long and consistently been one of the most powerful research methods in operations management (Voss et al., 2002). One of the reasons case research has had such a big impact in operations management is due to the growing frequency and magnitude of changes in technology and management and therefore field-based research has become increasingly important (Voss, 2008). The case method is a suitable method when *how* and *why* questions are asked and the focus is on contemporary events (Yin, 2009). Eisenhardt (1989) states that theory building case studies are a suitable tool when little is known about the phenomenon under investigation.

The case study in this project was mainly used as an exploratory case study. It was used because it gives valuable insight into the way shipyards of today are working and how shipyards see themselves and work towards the future. The case study conducted in the work with this master's thesis served three main purposes:

- It was used to identify and understand relevant problems to be addressed.
- Give a hands-on understanding of the different processes that are performed in Norwegian shipyards.
- Generate discussions about the potential of AR to increase the efficiency of the processes.

2.2.1 Data collection

The case study was particularly used in the work with RQ1, which is about the different applications of AR as operator support in a shipyard.

The work with the case study started with the specialization project in the autumn of 2018 where the first visit to the case company was conducted. The topic for the specialization project was different types of operator support and as a result some of the information collected for that project was also relevant as input for the research objectives of this thesis. The visits to the case company consisted of presentations of the company, discussions on the topic and unstructured interviews.

During the work on the master's thesis another visit was made to the case company. This visit was of a similar nature to the one in the autumn with a workshop, presentations, in depth discussion and a visit to the shipyard. The visits to the shipyard have provided valuable input. Observing the production environment present in a shipyard was of a great value for the research conducted in this thesis. In addition to the meetings at the company's headquarter some meetings were held with the deputy managing director of Ulstein International at NTNU in Trondheim throughout the semester.

The personnel at the case company were mainly in the management and as such they had a good overview of the company in addition the yard development consultant was present at the first visit. Especially the discussions with the yard development consultant, which had experience from the yard as well as working on systems to improve the productivity in the shipyard gave valuable input to the work with this thesis.

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

- Deputy Managing Director of Ulstein International
- Yard development consultant for Ulstein Verft
- Senior business analyst for Ulstein International (X2)

2.3 Case company - Ulstein Verft AS

2.3.1 Ulstein Group ASA

Ulstein Group ASA is the parent company of a group of maritime companies that are specialized in ship design and maritime solutions, shipbuilding, power and control and shipping. This includes the shipyard Ulstein Verft AS in Ulsteinvik. The company dates back to 1917 when it started as a mechanical workshop in Ulsteinvik where they still have their headquarters. Today the group employs about 1000 people, however the number of employees is varying depending on the workload and in the shipyard, many are sub-contractors.

2.3.2 Design portfolio

Historically the shipyard built many different types of vessels, however up until the oil crisis of 2014 they were mainly building vessels for the offshore oil and gas industry, an example can be seen in Figure 4 which shows a vessel with Ulstein's characteristic X-BOW® design. When the oil price went down the demand for these types of vessels decreased and there was a need to adapt. As a result, the design portfolio is more diverse now than it was a few years ago. Today the design portfolio consists of (Ulstein, 2019):

- Cruise vessels
- Vessels for offshore wind
- RoPax vessels
- Vessels for oil and gas (mainly OSVs)
- Other vessel designs such as tugs, offshore mining, dredging and rock dumping

A result of the changes in the market they are now producing vessel types they have limited amount of experience building. Where they had many years of expertise on building technologically advanced offshore support vessels (OSVs), moving into the building of passenger vessels and other segments means that there are other requirements than for OSVs. This has resulted in new challenges in areas where they before could rely on people's experience and expertise, they can no longer do so to the same degree.

Ulstein along with other Norwegian shipbuilders specialized in specialized and highly customized vessels for each customer. In this approach the engineering and design of a vessel starts after the specific customer is involved in the process. Today they are applying a multi-strategy approach where they offer the customized designs as well as a set of standardized designs where concepts are established and design and engineering is already performed to a large degree before a customer is known (Semini et al., 2014).

Although they can still offer this service they are moving towards a more standardized vessels where more of each design can be used again. Ulstein has a catalogue of premade designs that they can offer customers with different variations and some customization. They also design vessels from scratch in cooperation with customers. The advantage of offering ships with readymade designs is that they can learn and improve the building and planning. More standardized ships allow for shorter lead times as there will be less need for engineering. There will be less uncertainty, especially in the early phases as the design is more or less finished and less customization is possible. Furthermore, and maybe most importantly it allows the yard to divide the cost of development on more vessels.

Figure 4: Launching of Polar Onyx from the dry-dock at UVE. An offshore construction vessel built with Ulstein X-BOW®. (Photo by: Tonje Øyehaug Ruud)

2.3.3 Ulstein Verft AS

Figure 5: Ulstein Verft AS from the air. (Photo: Tonje Øyehaug Ruud)

2.3.3.1 Facilities

The shipyard is located in Ulsteinvik in western Norway and can be seen in Figure 5. By international standards the shipyard is considered compact as everything is within walking distance in the yard. The yard has a covered dry dock that is 55 meters wide and 140 meters long covered or up to 225 meters with the outside dry dock. The yard also has two quays where ships can be further outfitted once the work that requires the dry dock is finished. Within the shipyard Ulstein group has their headquarters as well as the design offices.

2.3.3.2 Ship production at UVE

UVE does not produce their own hulls at the yard in Ulsteinvik. The steel work involved in producing the hulls expensive to do in Norway and as a result the hulls are produced in third party yards outside Norway, typically in Eastern Europe. The hulls are assembled and launched in the third party and are then towed to the shipyard in Ulsteinvik. Following the offshoring strategies developed by Semini et al. (2017) shown in Figure 6, UVE uses strategy III, Norwegian dock outfitting.

As a result of the offshoring of the building of the hull UVE is a shipyard mainly catered towards outfitting. This means that the processes are limited compared to fully integrated shipyards that perform all tasks from raw material to completed vessel.

2.3.3.3 The production processes in Ulstein Verft AS

The production processes that are performed at UVE for ships that are being can generally be put into the following categories:

1. Prefabrication – Mainly pipes of pipes
    a. The pipe fabrication workshop has a relatively high degree of automated processes.
2. Dock outfitting
3. Launching
4. Quay outfitting

In addition to the main production processes UVE also has some support processes that support all the steps. The two main ones are dimensional control and inspection and warehouse and transport of material.

2.3.3.4 Operator support in UVE

UVE is working towards becoming more efficient and facilitating for their operators. One of the initiatives they have taken to facilitate for their operators is to prepare kits for outfitting tasks or work packages. In these kits all necessary parts and tools are provided for the operators where the tasks take place. This means that if the kits are correct the operators should not have to walk away from the working area to get tools or materials. This is one of the approaches used to increase the value adding time by reducing the time spent walking and searching for materials and tools. This means that the operators can spend more time on their area of expertise and less time on collecting parts and tools.

UVE are also currently working on projects that are compatible with AR technology. In these project AR are not the main focus, but it is seen as a supplement that could be useful. They are also investigating for areas where the technology could bring improvements. Especially in the area of reducing the time spent making, reading and communication drawings is seen as an area where the technology could be useful in the future. Their focus is towards the managerial side and foremen is seen as the target group at this stage. The foreman could use the AR solution to more easily visualize information such as keeping track of what is completed, what parts have arrived and are ready for installation etc. Allowing the foreman to have a colour coded view of the different systems of the ship could help improve the efficiency. Developing concepts such as this is seen as a way to build UVE’s reputation as a modern and technologically advanced shipyard towards customers and suppliers.

3 Basic theory on Norwegian shipbuilding and Industry 4.0

This section will describe the theoretical background that is studied and applied in this thesis. The topics presented are selected as relevant theoretical background based on the problem description and the research questions presented in chapter 1.2.

The focus of this chapter has been towards a two main areas, shipbuilding and AR as operator support. Therefore, this chapter will first present a theoretical background that gives an insight into shipbuilding and the production processes involved and more specifically shipbuilding in Norwegian shipyards. The next part will start with a definition of Industry 4.0 and describe some of the core concepts and takeaways. From there the term Operator 4.0 which is a part of the umbrella term Industry 4.0 will be described before moving into the background, definitions and key features of augmented reality.

3.1 Shipbuilding

Originally when ships were made of wood they were constructed in a berth or slipway. Today berths and slipways are still used, but rather than being the construction site it is rather an assembly area where prefabricated sections of the vessel are assembled (Curley and Staff, 2011).

A shipbuilder is the party that makes a deal with the client to deliver a vessel to the client of a stated sum with specific dimensions, capabilities and qualities (Curley and Staff, 2011). The shipyard is the builder of the ship is not necessarily a part of the same company as the shipbuilder.

As ships are big and costly products they are following the framework by Olhager (2010) either a make-to-order (MTO) or engineer-to-order (ETO) products. These two production strategies are characterized by the fact that they do not start the production of the product before a customer order is received and agreed to (Ji et al., 2007). The difference between MTO and ETO is that for an MTO product the engineering stage is already performed by the company which means that the degree of customization possible is lower than for ETO where the engineering stage starts with the customer order which allows for a larger degree of customer specifications.

Due to the size of the project it is natural that a shipbuilding project is complex. However, there are also other elements than just its size that increase the complexity such as individual customer requirements, incorporation of new systems or technologies that have never been used before, work with new companies and unpredictable events (Mello, 2015).

Because of the long lead time and large degree of engineering, especially for very customer specific vessels (ETO) the procurement and building of a vessel typically takes place while the engineering is still being conducted. If the customer is involved in the process and in addition suggests changes this can cause changes in the engineering and specifications.

3.1.1 The production processes in shipbuilding

The processes performed in shipyards vary depending on what kind of the strategy the shipyard applies. A classic fully integrated shipyard, that produce the whole vessel perform more processes than a shipyard that focus on the outfitting of already built hulls or blocks. Norwegian shipyards typically purchase the steel hulls or blocks from foreign yards where the labour is cheaper. However, the amount of work done to the hulls or blocks at the foreign yards can vary from shipyard to shipyard, and sometimes from project to project. Such yards are often referred to as “assembly” yards (Andritsos and Perez-Prat, 2000). In such cases the main tasks are typically to coordinate and perform selected parts of the outfitting.

Separating the processes and deciding what is its own process can be difficult. Some processes are similar but have different responsibilities while some are highly dependent on specialized disciplines.

Andritsos and Perez-Prat (2000) breaks down the generic shipbuilding production processes into 12 production processes:

1. Raw material reception and preparation
2. Marking, cutting and conditioning of steel plates and profiles
3. Fabrication of 2D blocks
4. Fabrication of 3D blocks in workshop
5. Pre-erection: assembly of 3D blocks and subassemblies into erection units
6. Prefabrication of pipes, supports, modules
7. Pre-outfitting
8. Blasting and painting/coating
9. Erection and outfitting in the dry-dock or slipway
10. Outfitting in dock (incl. piping, wiring, machinery etc.)
11. Finishing and outfitting onboard the floating vessel
12. Commissioning and sea trials

In addition to these twelve processes there are two supportive processes performed for the processes above.

13. Transport and handling
14. Dimensional control and inspection

3.2 Norwegian shipyards

The shipbuilding industry is still important for Norway, and only a few European countries still have an active shipbuilding industry despite this being an important industry for many countries in the past (Helseth et al., 2019). The last few years the industry has been heavily affected by the drop in the oil price that lead to a decrease in demand for vessels for offshore oil and gas. For years the building of vessels for this industry stood for around 80-90% of the activities in Norwegian shipyards (Helseth et al., 2019). This has led to big losses in last few years and has caused them to investigate new markets such as cruise and passenger vessels.

Although there is a great deal of standardised shipbuilding most products have a high degree of customization with short series (Hagen and Erikstad, 2014). A high degree of customization and the fact that ships are expensive products with a long through-put time means that they are classified as either ETO or MTO products. Hagen and Erikstad, (2014) states that most Norwegian yards are set up as ETO companies where each new vessel is treated as a new project, however over the last few years it seems to have been a change towards building more standardized designs and fewer "one-offs" but the typical organization of the shipyards has not changes much.

As a result of the increasing global competition the Norwegian yards has shifted their focus from manufacturing the entire ship, to having the hulls, either complete or in blocks, produced in yards outside of Norway and perform different degrees of outfitting on these hulls in their yards in Norway. The degree of work performed abroad and in Norway varies, but because of the significantly lower labour costs, widely available competence and easy quality controls most steel processing and welding is performed in Eastern European countries (Semini et al., 2018).

The level of offshoring can be put into four categories, shown in Figure 6; complete Norwegian production (I), Norwegian block outfitting (II), Norwegian dock outfitting (III) and Norwegian quay outfitting (IV) (Semini et al., 2018). There are no shipyards that currently perform strategy (I), however there are yards performing one or more of the other strategies. Which strategy a shipyard follows affects how much work and what work is performed in the yards.

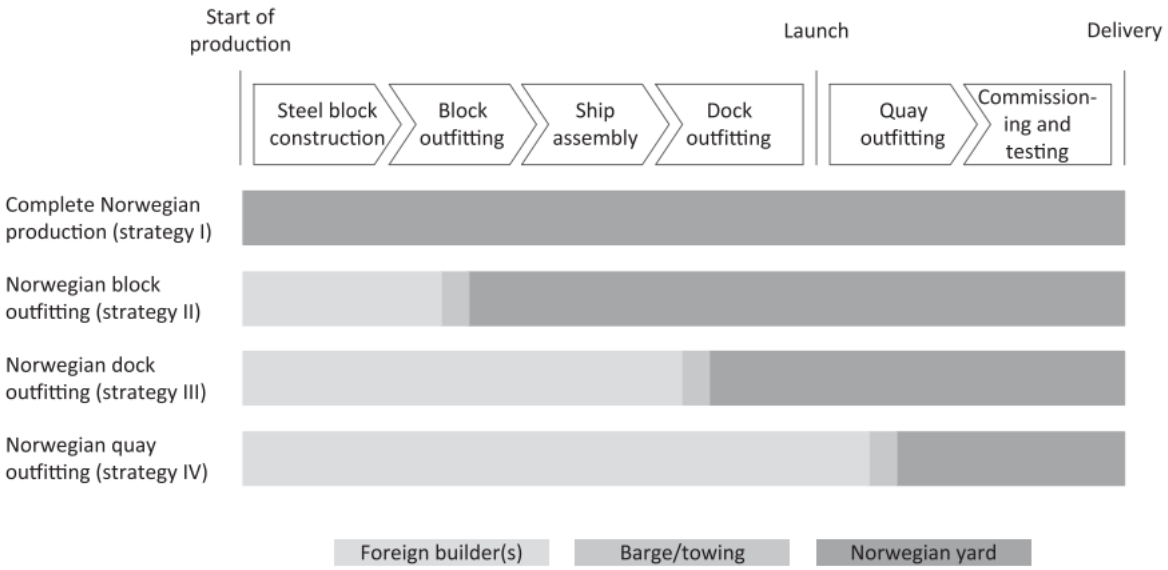

Figure 6: Four Norwegian ship production strategies the difference being how much is performed at a foreign builder and a Norwegian yard from (Semini et al., 2018).

Typically, the level of automation in the outfitting of these ships is low and requires a great deal of manual work. However, in the workshops and fabrication there can be a higher level of automation. There are several factors as to why the Norwegian shipyards has a low level of automation in the outfitting of ships.

Groover (2008) give six situations that suggest manual labour is preferred over automating. Two of these were highly customized products and the company is operating in an industry with fluctuations in demand.

For shipyards their product is often highly customized, which means that programming robots to do the task is both costly and time consuming. Because humans are more flexible than automated machines this can be an advantage in a manufacturing environment like this. Humans are more flexible than robots that need to be programmed and controlled.

Shipbuilding is also an industry where demand fluctuates. This is clear from the graph in Figure 7 from (Helseth et al., 2019) showing the turnover (blue) and the operating profit margin (orange). There are periods where demand is higher than yards can deliver and periods with low demand where the capacity is much higher than demand. A manual workforce is more flexible to variations in demand. By investing in automated equipment, a company will also increase their fixed costs, while manual labour can be more flexible.

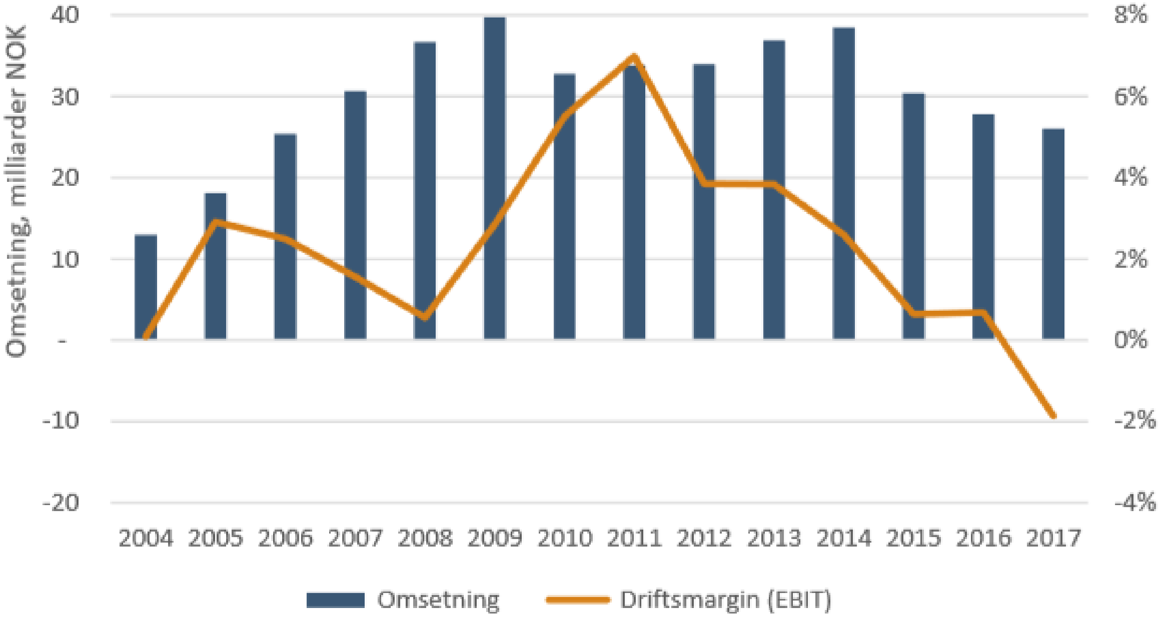

Figure 7: Turnover (blue) and the operating profit margin (orange) for the Norwegian shipyards 2004-2017 *(Helseth et al., 2019)*.

3.2.1 The production processes in Norwegian shipyards

Because of the different strategies applied by Norwegian shipyards there is certainly a difference in the processes performed at the different yards. Some processes are not relevant for all yards, but the processes selected in this section tries to give a picture of all the production processes that are relevant for Norwegian shipyards.

Using the 14 production processes described in 3.1.1 as a foundation some of them can be excluded as they are either not typically performed by Norwegian shipyards or they are processes where it is unlikely that operator support tools will make a big impact. As Norwegian shipyards perform either block outfitting, dock outfitting or quay outfitting (as seen in Figure 6) based on a study of the offshoring strategies employed by Norwegian yards by Semini *et al.* (2017) process 2-5 can be eliminated. This is done on the basis that they are all focusing on the fabrication of blocks which rarely performed in Norway as most steel work is performed in low cost countries (although there are examples of critical modules or sections being built in Norway) (Semini et al., 2018). As most of the steel work is performed abroad it is a limited amount of raw material reception and preparation, although there is some of this related to especially pipes. The case company Ulstein does perform dock outfitting of completed hulls that are towed to Norway. The typical production processes for a shipyard performing strategy III is shown in Figure 8. Even though there are some Norwegian yards that are performing erection of blocks in their yard the processes that will be described further will focus on strategy III, which starts with outfitting in the dock.

Even though “Commissioning and sea trials” are performed in all shipyards before a vessel is delivered, it is not it is not really a production process and therefore it will not be a part of the processes that will be described in depth in the next section. This means that the general production processes that are performed in Norwegian shipyards (although not all processes are performed in all shipyards) and that will be described more in depth are:

1. Prefabrication
2. Pre-outfitting of blocks
3. Blasting and painting
4. Outfitting in dock (dock-outfitting)
5. Finishing and outfitting on-board the floating vessel (quay-outfitting)
6. Warehouse, transport and material handling
7. Dimensional control and inspection

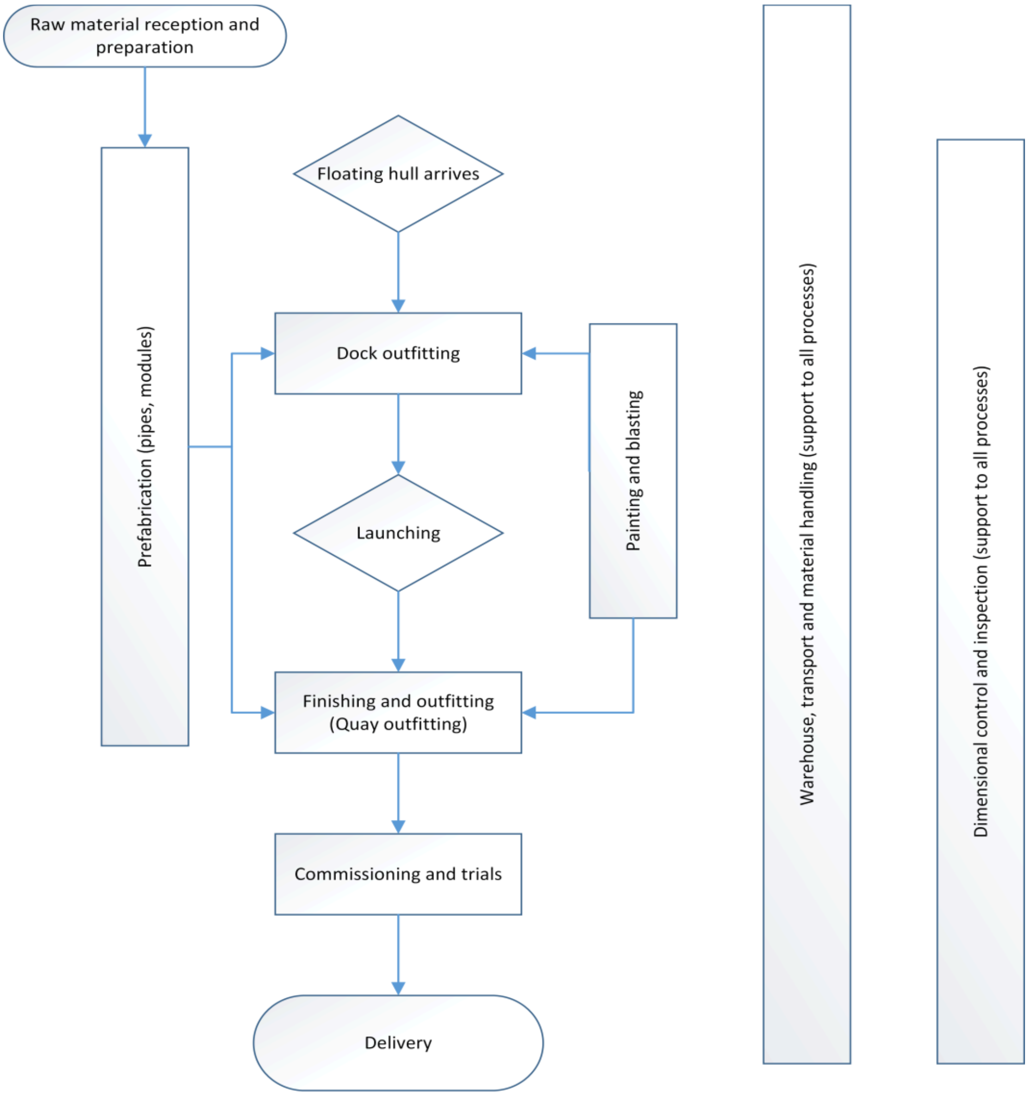

Figure 8: The production processes that are performed in a shipyard following strategy III (dock outfitting) like the case company (Adapted from (Andritsos and Perez-Prat, 2000)).

3.3 Description of the production processes

This section will aim to give a description of some of the most common processes in Norwegian ship production. The descriptions are based on Hagen and Erikstad (2014) and Hagen et al. (1996) in addition to observations made during the visit to case company. How these processes typically are performed in shipyards and the most relevant information needs for performing it. The information requirements in the different processes are summarized in Table 3.

As stated in the scope and following what is common for the case company this thesis will look at the production processes typically present in Norwegian dock outfitting and Norwegian quay outfitting. This means that the production processes that are associated with complete Norwegian production and Norwegian block outfitting will not be described in the following sections.

3.3.1 Prefabrication

Prefabrication is typically the first production stage. What is prefabricated and how much is prefabricated differ from yard to yard. Pipes are a typically prefabricated, but not all shipyards have a pipe fabrication shop but rather purchase it from a supplier. Prefabrication is an especially important process for yards that produce blocks and perform pre-outfitting. Because of the different strategies used by Norwegian shipyards not all of them do pre-outfitting in their yards as they have the blocks or hulls produced in yards abroad and therefore do not have the same amount of prefabrication as other yards.

For some yards much of the prefabrication and pre-outfitting is performed at the foreign yards. Prefabrication is a broad process in the sense that it really describes everything that is produced to later be installed in a ship. What is prefabricated depends on the yard. Typically, the main objectives and tasks in this process is to produce pipe spools or steel outfitting elements and prepare it for outfitting.

These finished products are labelled, sorted and collected for later phases. The products from this stage are key for later production and therefore it is important that the quality and dimensions are correct. For this it is required that the Work Package (WP) and design dimensions are correct.

Required documents (information):

- Isometric drawings
- Spool drawings
- NC data (Numeric control)
- Foundation drawings

3.3.1.1 Prefabrication of pipes

Pipes are generally produced in its own workshop and will result in the following products:

- Shaped pipes (threaded, bent, cut, joined and grinded)

- Welded pipes and pipe spools
- Mounted pipes and pipe spools
- Treated surface, pressure tested and weld-controlled pipes and spools

Parts arriving at the pipe fabrication shop typically have identification numbers and are collected and sorted based on part type and parts. The information needed is mainly fabrication drawings and should be the main component of the WP. Specifications such as material and measurements should be a part of the drawing if they are needed. Procedures/instructions for welding and assembly should be a part of the work package.

Piping design is one of the more labour-intensive activities in shipbuilding projects. A Typic industry practise is that only pipes with a diameter larger that 50mm in outer diameter are given special design, the reason being that smaller pipes are easier to manufacture (cutting and bending etc.) on site.

Assembly and testing of pipes are performed in the pipe shop and in the zones where they are fitted. Because the pipe fabrication shop supply parts for later phases it is also important that the operators are well informed regarding deliveries and plans.

3.3.2 Pre-outfitting of blocks

Pre-outfitting is typically outfitting that has to be done early in the construction because it would be difficult and expensive to it later in the construction process. Wärtsilä defines it as: *"The installation of both outfit and machinery items in a large structural assembly units prior to these units being erected in the ship."* (Babicz, 2015).

This process therefore mainly applied to shipyards that orders sections or blocks from foreign shipyards and weld these together to make a complete hull. For the yards that has the complete hulls made abroad some pre-outfitting is performed there. The main purpose of this phase/process is to pre-outfit the vessel with pipes, equipment, cabling etc. Assembly drawings and documentation are key components of the work instructions for the operators in this process. The main reason for pre-outfitting is that easier access and shorter distances means great savings in the time spent.

Information:

- Arrangement drawings
- Assembly drawing
- Isometric drawings
- Equipment specifications

3.3.3 Dock outfitting

The main objective of dock outfitting is to perform the work that is necessary to launch the ship and to perform the outfitting tasks that are suitable for dock conditions. As many yards buy hulls that are already floating the main outfitting tasks for the dock is then what is below the waterline and other tasks that requires the hull to be in the dock. When the ship is launched it will be outfitted to a large degree with partially completed zones and systems. The degree of outfitting performed in the dock should generally be maximized as it usually has the best facilities, however the capacity in the dock is generally the bottleneck in shipyards and therefore the time in the dock is generally something the shipyards try to minimize if the demand is high.

The work in this phase is generally based on functional zones, focusing on the systems rather than the geography.

Information/documents:

- Arrangement drawings
- Equipment specifications
- Isometric drawings

The typical information in this phase is work packages consisting of assembly drawings and arrangement drawings. The drawings will be based on the scope of the work package typically a function zone. In addition, there should be procedures and installation instructions from the supplier which are good tools for the operators in this phase.

The operators are typically organized in teams/groups that are responsible for their own area and will consist of different disciplines based on the scope of the work package.

3.3.4 Finishing and quay outfitting

With quay outfitting the objective is to finish the outfitting of the floating vessel and to test functions before the vessel is ready for sea-trials. The outcome of the quay outfitting should be the completed ship and systems that are tested. If the scheduled outfitting degree is met through the project the workload in the last phase should be adequate allowing for a stable work environment and avoiding the need for bringing in more people to finish the phase.

The work package will be equal to work package for outfitting at dock, but a larger share of the work will be performed in functional zones. Testing of systems is an important part of the work in this phase and for that reason it is important that forms and procedures for testing are in the work package. This phase includes the area outfitting of a specific area at the quay. Duration of the phase is determined by the completion level of the product from the previous phase. Efficient dock outfitting requires that the areas from the previous phase are ready for dock outfitting. After the vessel is moored at the quay, all transport routes and helping tools will have to be restored. Work in this phase will primarily involve the completion of areas and functional zones. Quay outfitting will end up with a completion of the outfitting and a vessel that is tested and ready to be delivered.

Information/documents:

- Arrangement drawings
- Assembly drawings/instructions
- Manuals

- Equipment specifications
- Isometric drawing

Typically, the work package at this stage consist of assembly drawings and arrangement drawings. Furthermore, assembly instructions and manuals are important in this phase. Most of the function testing will take place at this stage. Following the plans for testing is important to avoid delays (assuming that all planned outfitting at earlier stages is finished).

The operators in this phase will mainly be working in groups that commission areas, but it could also be requirements for specialist in function- and quality testing of system-oriented zones. Operators have fellow responsibility to accomplish outfitting and testing according to plans, operators should for that reason have good knowledge to any plans. It is important that number of operators is adjusted through the process and adapted to work tasks left for the project.

3.3.5 Painting and blasting

The objective for this process is to prepare the surfaces, blast and paint them. This can be done both for outfitting details, sections and blocks and the finished hull. The main information in the work package needed for this phase is the paint specifications, surface treatment and application method.

3.3.6 Warehouse, transport and material handling

The warehouse(s) in a shipyard are responsible for keeping track of all the components and materials needed for prefabrication, constructing and outfitting of the ship. Everything from steel that is used for the pipe fabrication to finished products purchased from suppliers. This means that there is a complex material flow, where it is important to keep track of all the materials that are produced within the facility as well as purchased products. The warehouse has to keep track of all these components that will go into the ship. Because of the project based inventories where parts might be unique to one project and cannot be used for other projects the material flow and storage can be more complex than for warehouses dealing with the same materials and components each time. Gergova (2010) studied the warehouses in Ulstein Verft and it was estimated that around 20 000 different stock keeping units (SKUs) where being stored at that time. These SKUs where split into three different categories: tools necessary for the production process, accessories which are standard units and outfitting components which are large in volume and often suited for specific projects. The large outfitting component were sometimes stored at different warehouses around the yard or outside due to their size.

Tasks:

- Receiving
- Storage
- Picking
- Shipping/transport

Picking of materials are typically done from paper lists by warehouse operators (Blanco-Novoa et al., 2018). Storage and receiving of materials is done through the shipyards ERP system (this can be through hand held scanners or paper) but the operator is still the one locating, picking/storing and registering the items that are picked/stored.

Information needs:

- Picking lists with part numbers
- Location/destination

3.3.6.1 Kitting

Kitting is the action of preparing a “kit” for a certain task in the outfitting of the ship. Kitting is a principle for materials feeding that is popular in different kinds of assemblies (Hanson et al., 2017). Kitting has also been applied in settings such as construction and in shipbuilding, however the name might vary, for example Toyota has called in Set Parts Supply (SSP) (Jainury et al., 2014).

The kit should contain all necessary material and information for the operators. The idea is that all material should be available for the operators at the location they are working and by that reducing the time spent preparing for a task and getting the necessary material and parts.

3.3.7 Dimensional control and inspection

It is a supportive activity to all production processes where the most important part of dimensional control and inspection is to make sure what is produced has the right quality and that mistakes are avoided. Correcting errors is expensive and therefore it is important that things are done right the first time.

Information needs:

- Arrangement drawings
- Equipment specifications
- Isometric drawing

3.3.8 Summary

Table 3 gives a summary of some of the most important information needs in the different processes. As can be seen the different processes are typically relying on different sets of drawings as well as other information such as specifications and numerical control data. The warehouse/material related tasks are the ones that stand out with having quite different information needs from the other processes.

Table 3: Typical information needs in the different processes.

Process	**Information need**
Prefabrication	• Isometric drawings • Spool drawings

	• Numerical control data • Foundation drawings • Specifications (ex. Material, treatment and type of weld)
Pre-outfitting	• Arrangement drawings • Assembly drawings • Equipment specifications • Isometric drawing
Erection and outfitting in dock	• Arrangement drawings • Assembly drawings • Equipment specifications • Isometric drawing
Outfitting (dock)	• Arrangement drawings • Assembly drawings • Equipment specifications • Isometric drawing
Finishing and quay outfitting	• Arrangement drawings • Assembly drawings • Manuals • Equipment specifications • Isometric drawing
Painting and blasting	• Paint specification • Application method • Surface treatment
Warehouse, transport and material handling	• Picking list with part numbers • Location and destination • Drawings/instructions that might be a part of the kit. (for kitting) • Is everything arrived and ready for picking?
Dimensional control and inspection	• Arrangement drawings • Equipment specifications • Isometric drawing

3.4 Industry 4.0

“The term “Industry 4.0”, or the fourth industrial revolution, refers to the use in industrial production of recent, and often interconnected, digital technologies that enable new and more efficient processes, and which in some cases yield new goods and services.” -(OECD, 2017)

Industry 4.0 is the name given to the expected revolution in production based on the rapid development in new technologies and available computing power. The term originated from a the German "Industrie 4.0" working group which looked at the potential of the new emerging technologies in the German industry (Kagerman et al., 2013). Because this is a relatively new term there are other terms used to describe some of the same concepts. In the US the term "smart factory" is more popular than the term industry 4.0, however in many cases the terms are used to describe the same or similar concepts. As the name suggests it is seen as the fourth industrial revolution following mechanisation, the production line and automation as the three previous industrial revolutions as can be seen in Figure 9.

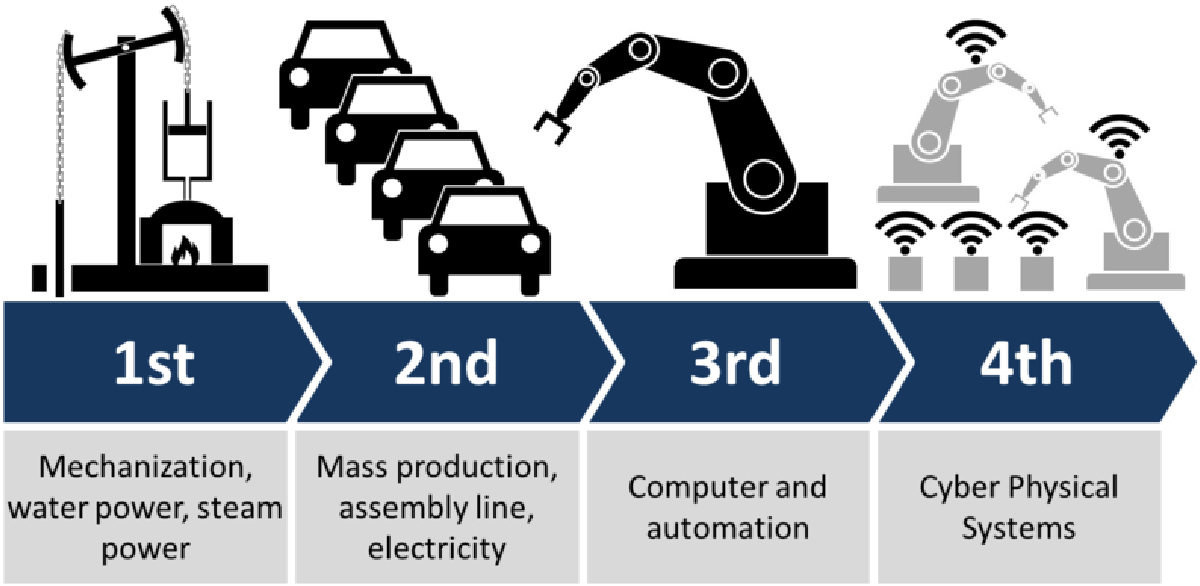

Figure 9: The four industrial revolutions

There are many different definitions of the term Industry 4.0 and what it entails. Consultant companies all have their own definitions that slightly differ. Lasi et al. (2014) concludes that Industry 4.0 describes changes in the manufacturing systems that are primarily IT-driven.

The main components of industry 4.0 are also somewhat difficult to give a clear definition of. One part of it are the differing definitions, but there are also many concepts that are closely connected. In their literature review of Industry 4.0 Hermann et al. (2015) identified four main components of Industry 4.0:

- Cyber-Physical Systems (CPS)
- Internet of Things (IoT)
- Internet of Services (IoS)

- Smart Factory

These four components will be described more in detail.

3.4.1 Cyber-Physical Systems (CPS)

Cyber-Physical Systems are part of the foundation for the expected revolution. Lee (2008) describes a CPS as integrations of computation with physical processes where computers and networks control the physical processes. It can be seen as the merge between the physical and digital level (Lasi et al., 2014).

CPS allows businesses to create global networks that can incorporate all of their production facilities, warehouses and machinery. The CPS in this case would comprise of smart machines, storage systems and facilities that can exchange information autonomously and trigger actions and control each other (Kagerman et al., 2013). Lee et al. (2015) states that a CPS consists of two main functional components:

1. Advanced connectivity that allows for real-time data acquisition from the physical world
2. Intelligent data management, analytics and computational capability that constructs the cyber space.

3.4.2 Internet of Things (IoT) and Internet of Services (IoS)

The Internet of Things (IoT) and the Internet of Services (IoS) are closely connected, therefore this subsection will provide a brief introduction to both terms. (Kagerman et al., 2013) states that IoT and IoS are the drivers for the fourth industrial revolution as they make it possible to create networks that can incorporate the whole manufacturing process and create a smart factory. As stated in 3.4, it is one of the four components of Industry 4.0 found by Hermann et al., (2015).

IoT is what allows "things" (for example machines) and "objects" such as sensors, RFID, actuators and phones to interact with each other and cooperate (Hermann et al., 2015). Similar to IoT, IoS allows services to be connected in networks. IoS allows the services of companies, CPS and humans to be available over the internet to be utilized by other participants, both internally and across company borders (Hermann et al., 2015).

3.4.3 Smart factory

"A smart factory can be defined as a factory where CPS communicate over the IoT and assist people and machines in executing their tasks." (Hermann et al., 2016).

The smart factory is the fourth and final key component. The smart factory is a factory that is context-aware and assists people and machines in executing their tasks (Lucke et al., 2008).

3.5 Operator support and Operator 4.0

With the increasing interest in research of topics such as Industry 4.0 and smart manufacturing, another term has been gaining increasing interest in the latest years. The idea of the role of the operator in these environments have been given several names and one of the most popular ones is operator 4.0. While simple operations while be automated, there are cases where the human experience is non-substitutable (Kong et al., 2018). While manufacturing will definitely change with the advancements of technology there will still be people working in manufacturing and production, but their tasks will be more advanced and often require more information than they used to. Mrugalska et al. (2016) highlights the importance of the human role even in automated and partially automated systems. While Holm et al. (2016) discusses the change from the historical operator, to the current and what will be required by the future operator.

Because the terms like I4 has only been around for a few years there are many terms that are used to describe the same or similar concepts. This thesis will focus on the term Operator 4.0 as the future operator in an I4 environment.

Romero et al. (2016) describes eight different augmentations that could be a part of or combined into the future operator:

1. Super-strength operator (exoskeleton)
2. Augmented operator (AR/MR)
3. Virtual operator (VR)
4. Healthy operator (wearable tracker, to monitor health and stress levels, breaks etc.)
5. Smarter operator (Intelligent personal Assistant)
    a. Softbot (Advances in Production management systems)
6. Collaborative operator (Collaborative robot)
7. Social operator (social networks)
8. Analytical operator (Big data analytics – continuous improvement, shop-floor control etc.)

Some of these augmentations are closer and further away from being ready for use in an industrial setting. For example, the super-strength operator it mainly a concept at this point although there is research into exoskeletons for industrial use these are still a long way from being ready for implementation.

The augmented operator is the one that will be in focus for this thesis. The idea behind the augmented operator is to improve the transfer of information from the digital to the physical world. An augmented operator would have access to additional information on top of the real world he/her sees.

Out of these eight augmentations described by Romero et al. (2016) this thesis will describe more in depth what could be a part of an augmented operator. Section 3.6 will cover vision technologies and AR more in depth.

3.6 Vision technologies

This section will start with a short introduction to vision technologies in Industry 4.0 and will then cover augmented reality (AR) more in depth.

As a shift towards operator support and industry 4.0 vision technologies has been given increasing interest. Mittal et al. (2017) defines holograms, virtual reality (VR) and augmented reality as vision technologies, which again is a cluster within smart manufacturing. These technologies are all vision technologies but are generally applicable in different scenarios in manufacturing process. VR is a great simulation tool that has great potential in the design phase, while AR allows the user to interact with computer generated information on top of the real world (Nee and Ong, 2013).

3.6.1 Augmented reality (AR)

There are several definitions for AR. One of the most used definitions is presented by Azuma (1997), which gives three characteristics of augmented reality which are:

1. Combines real and virtual
2. Is interactive in real time
3. Is registered in three dimensions

Fite-Georgel, (2011) defines AR and industrial augmented reality (IAR) as such:

1. AR = an environment in which virtual components have been added to or replace some aspects of the reality.
2. IAR = Industrial augmented reality, applying augmented reality to an industrial process.

Fite-Georgel (2011) poses a broader definition than Azuma (1997), mainly to include photo-based augmentations which would be excluded by the definition proposed by Azuma. For simplicity this thesis will be following the definition proposed by (Fite-Georgel, 2011).

AR has been around for several decades already, however, the technological development in the last decade or so has made it more relevant for industrial application. AR no longer needs to be used in connection to a desktop computer and is now a very portable technology. With smartphones, tablets and head mounted displays (HMDs) with an acceptable weight and battery life it is possible to take augmented reality out of the labs and to be used on site (Li et al., 2017). This development has led to an increased interest in this technology by production companies. Today there are already a number of applications of AR and it can be seen in different areas such as games, sports and tourism (Syberfeldt et al., 2016a). However, while there are many studies on the topic of AR there are still few practical industrial applications mentioned. The main industrial applications to be found in literature are maintenance, product development and assembly operations.

First of all, augmented reality is a part of the mixed reality spectrum showed in Figure 10 that goes from the physical reality at one end of the spectrum to a digital reality at the other end of the spectrum. Everything in between can be considered mixed reality. Because augmented reality allows the user to see the real world with virtual objects superimposed in it, it lies closer to the physical world than a digital reality on the spectrum. Virtual reality on the other hand which aim to create a completely digital reality where the user is immersed and cannot see the world around him lies on the other end of the spectrum.

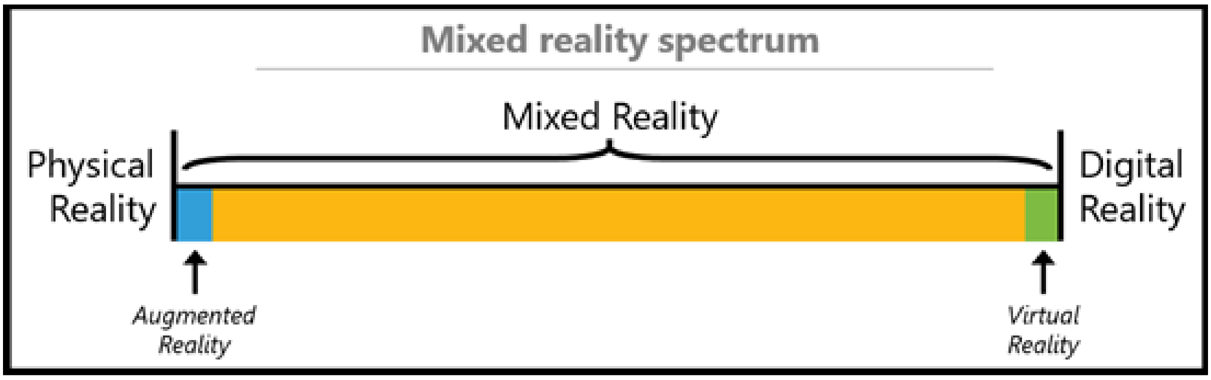

Figure 10: The mixed reality spectrum (Bray et al., 2018).

3.6.1.1 General hardware components

There are some hardware components that are common for all AR systems, this includes a processor, display, accelerometer, gyroscope, GPS and camera. This is highly common in things such as the mobile phones and tablets of today which means that AR can be used on normal every-day devices.

3.6.1.2 AR in industrial applications

One of the main challenges that exist in creating an AR solution that would work in industrial applications is the need for a robust tracking performance to deliver stable and accurate information to the users (Li et al., 2017).

3.6.1.2.1 The technologies

As AR is just a real environment with digital elements added there are several ways of achieving this with different technologies. The two most popular ways of creating the image is either through video of the real environment that has the virtual object overlaid or optical which projects the virtual objects directly onto the world the user can see. The main issue of using video is that there will always be some latency as the video image will have to be processed before being displayed to the user. Syberfeldt et al. (2017) reviews the different alternative ways of displaying AR shown in Figure 11. The different technological solutions are split in three main groups:

1. Hand-held (smartphone/tablet)
2. Head-worn (glasses)
3. Spatial

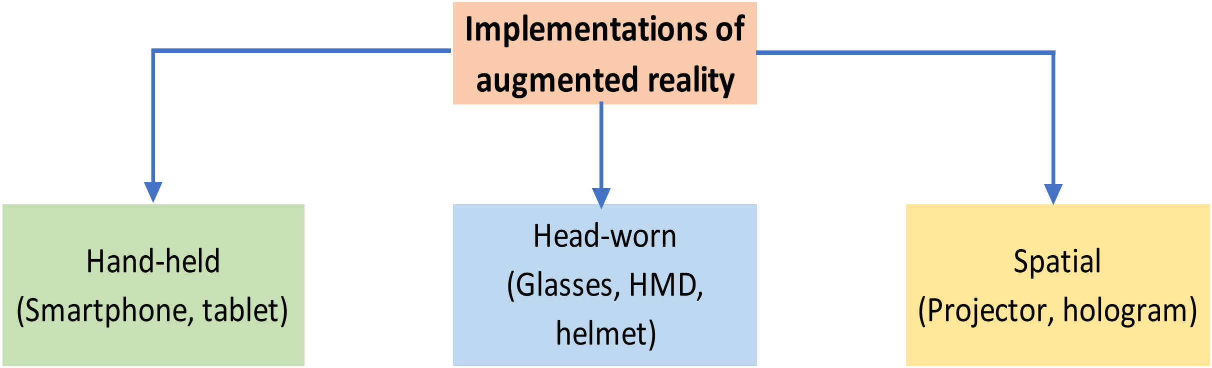

Figure 11: Different AR implementations. Adapted from (Syberfeldt et al., 2017).

Because of the broad definition of AR and the many technologies that could be considered AR it is often necessary to specify what technologies/solutions will be used. In industrial applications literature is split but often the hands-free operability and portability of head-worn technologies are seen as the most applicable. Figure 12, shows an example of an AR system where there the three different solutions for displaying the information is listed.

3.6.1.3 Tracking technologies

In addition to the solutions above which mainly differ based on what kind of visualization it is using Li et al. (2017) lists two other elements that needs to be in place for a complete AR system: tracking and registration. Especially tracking has been a topic of high interest in industrial applications as it is important that the system knows where it is and what it is looking at. Especially for tracking there are several solutions that are possible, typically it is either sensor based, vision based (marker) or a hybrid solution that combines the two previous solution.

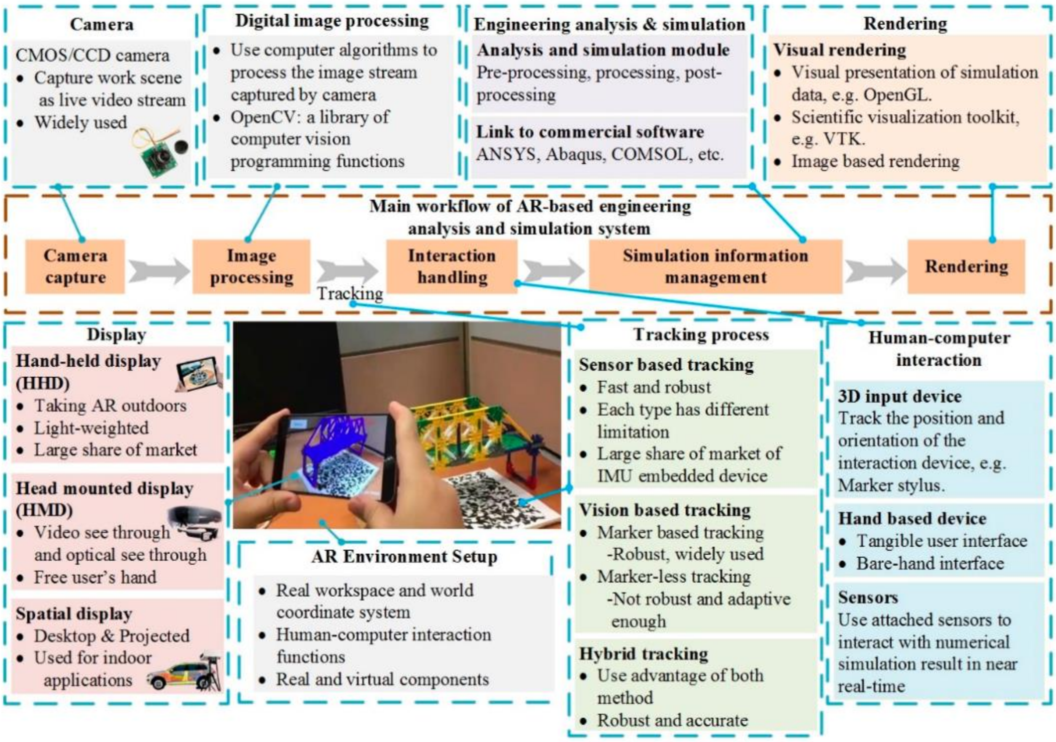

Figure 12: Example of a AR system from *(Li et al., 2017)*.

4 Potential applications of AR in Norwegian shipbuilding processes

This section will look at possible applications of augmented reality in the different production processes described in section 3.3. Table 3 summarize the most common information needs in the different production processes that were described in depth are performed today. The information needs will be used as the basis for identifying relevant AR-based applications for the different production processes. In addition to how AR can be applied to improve on the way the current information needs are conveyed and displayed this section will also aim to provide some applications that give the operators added information compared to the information they have today.

4.1 Selection of processes

The processes that were identified in section 3.1.1 and described in section 3.3 will in this section be evaluated and selected for further analysis based on their suitability for AR-based operators support.

As stated in section 3.2.1 the production processes that are performed in Norwegian shipyards are typically

1. Prefabrication
2. Pre-outfitting
3. Painting and blasting
4. Outfitting in dock
5. Quay outfitting
6. Warehouse, transport and handling
7. Dimensional control and inspection

While some shipyards perform these processes, most of them perform fewer. As the case company are performing the dock-outfitting strategy (strategy III) the processes that are performed in Norway for shipyards following that strategy will be the area of focus for this master’s thesis. This means that the processes of pre-outfitting and erection will not be covered in the following chapters. Furthermore, to simplify the structure the applications for the processes; dock-outfitting and quay outfitting will be treated as one process called outfitting due to the similar nature of the information needs and the tasks. The major difference between the two processes are when and where they are performed. Furthermore, painting and blasting will not be focused on as the information needs for the process are paint specification, application method and surface treatment. This information is mainly relevant in the preparation of the process and not while the work is executed and as such AR-based operator support is unlikely to have a big impact on the work.

This means that the production processes that will be focused on in the next section are:

- Prefabrication
    - With prefabrication of pipes as an example of a specific process. It is a common process and it is performed by the case company.
- Outfitting
- Warehouse, transport and material handling
    - Kitting will be used as an example of a process that can be a part of the warehouse, transport and material handling process. Not all shipyards perform kitting, but as it is a feeding policy used by the case company.
- Dimensional control and inspection

4.2 Applications in the production processes

4.2.1 Prefabrication

As described prefabrication is important in the construction of ships. As in the AS-IS section this will use the prefabrication of pipes as an example as this is important equipment in a vessel that often is produced by the shipyards.

4.2.1.1 Information and instructions

Typical information needs at the prefabrication stage:

- Isometric drawings
- Spool drawings
- Numerical control data
- Foundation drawings

Looking at the information and required documents for this process there are many instructions and drawings that the operator needs to keep track of in the fabrication of for example a pipe. The drawback of these situations is that it often takes time and requires the worker to switch focus from the work to a document or computer screen when there is a new step, or something needs to be checked. Having this information available in the field of view would likely allow the operator to spend more time on processing.

There is much research looking at ways that AR can be applied in different manufacturing settings. Syberfeldt et al. (2016a) proposes a solution where using an AR head mounted display (HMD) for displaying dynamic operator instructions can be one way of providing the operators with instructions and information within their field of view.

In a lab study where optical smart glasses are tested for operators inspecting partly finished engines it showed efficiency increase in performing the task (Syberfeldt et al., 2016b).

4.2.1.2 Prefabrication of pipes

The pipes can typically be put into two categories, pipes larger than 50 mm in outer diameter and smaller than 50 mm. As the smaller pipes are typically not given special design (industry practise) they are measured and fitted manually. In such scenarios it is often possible to do quite easily for experienced operators, but they could also benefit from using AR.

Olbrich *et al.* (2011) proposes an AR application for pipe layout planning. This can be highly useful as it can allow the operators to measure and see all bends and potential constraints easily while they are deciding on the layout of the pipes. This tool also has great applications if there would be any discrepancies between the engineering plans and what is built in the case of larger pipes as well.

Morikawa and Ando (2019) describes the new AR based system used at the Fukuoka yard for pipes. The system allows for instant identification of a pipe and it is based in markers that are added to the pipes during fabrication. The marker will follow the pipe all the way from fabrication to installation and it is connected to drawings and installation guides for the specific pipe. For the operators in the prefabrication of pipes it will mean easier identification of pipes, as well that the drawings and data for the pipes can be found easily by just scanning the marker with their AR hardware (whether it is an HMD, tablet or glasses). The system described by Fraga-Lamas et al. (2016) is described in a similar way, however the system is mainly for tracking pipes and is designed with AR in mind in the same way as the system described (Morikawa and Ando, 2019). This system should allow the operators to spend less time on identifying pipes and on getting the right drawings and installation guides for the pipes.

As the pipe fabrication is often automated to a certain degree having a system that allows for collaboration with these system could be a way forward. Makris et al. (2016) developed a tool that can aid operators in the collaboration with machines and robots. The system showed in Figure 13 consisted of AR glasses paired with a smartwatch that allowed the operator to control the information in the glasses as well as register when operations are completed. The system is designed to provide the operator with production- and process related information, as well as focusing on safety mechanisms for the operator. The tool they developed was designed for working in the automotive sector, but many of the elements presented could be applied in a shipyard.

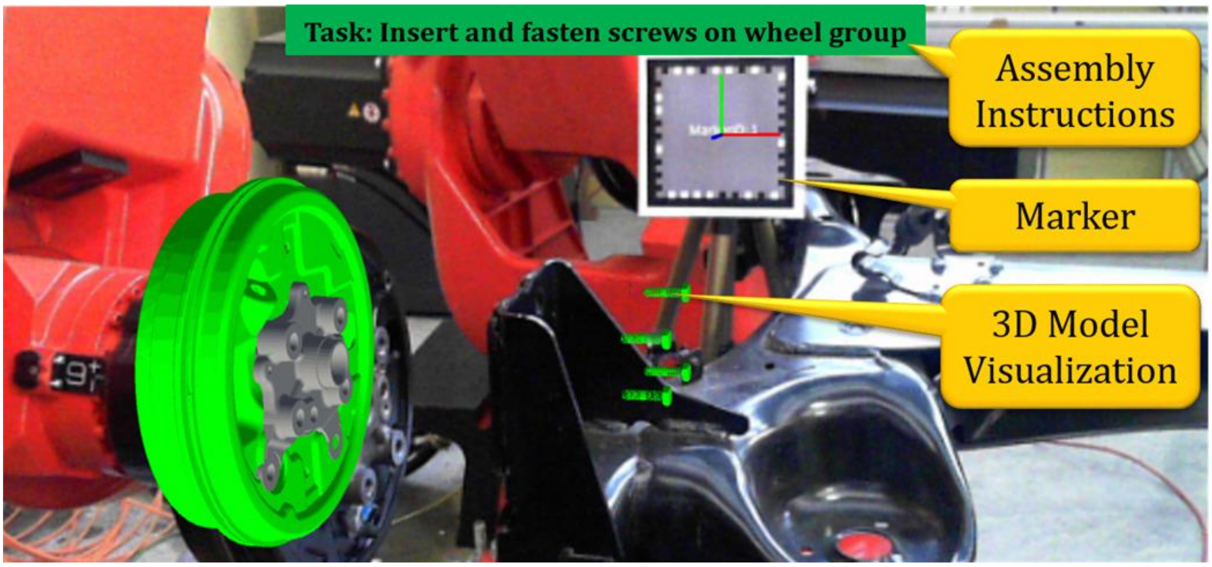

Figure 13: Image showing the augmentations over the real objects. From (Makris et al., 2016).

4.2.2 Outfitting

Because the basic principles and the information needs of the different types of outfitting are the same, what stage and where they are performed is the main differentiating factor in the different types of outfitting. Therefore, the outfitting processes are all combined into this subsection as the support tools and application can be very similar.

Typical information needs (from Table 4):

- Arrangement drawings
- Assembly drawings
- Equipment specifications
- Isometric drawing
- Manuals

Outfitting operations are mainly related to installation of different types of prefabricated or purchased equipment. As mentioned in Table 3 typically the required information and documents are arrangement drawings, equipment specifications (and instructions) and isometric drawings. Depending on what is outfitted on the ship further information might be required by the operator to perform his tasks. This information is normally paper based. The future state could be to make this information digital but making the information digital does not necessarily change much in the way work is performed. A digital drawing is still a drawing. What makes AR technologies interesting in this type of environments is that it can allow the operator to keep his normal view of the world with additional information in his field of view.

There is little literature that has tested applications in the environment you can find in a shipyard. However, there is much research into how AR can be used by operators in different kinds of assembly tasks where reading and understanding drawings, instructions, sequence and specifications are needed. However, there is much research in different areas and much of the existing research could be transferrable to shipbuilding.

Airbus have started using smart glasses for their operators in the manufacturing as a way of increasing the efficiency (Wright, 2017). This solution is developed in collaboration with Accenture and its purpose is to enable precise positioning during the cabin installation marking process. The solution uses a camera to scan bar-codes that allows the operator to see the cabin plans and information based on the customer requirements for that specific aircraft. When the task is performed the location of the mark made by the operator is checked to validate the task. The glasses also display navigation icons and other AR elements. One of Airbus' operators states in the article by Wright (2017) that: *"The operation used to require three people and three days; now it requires one single operator and six hours."*

The system mentioned above that is used by Airbus is not unique, but it combines several elements in one solution which is not very common in the solutions developed for research purposes. There are many examples of applications that have been developed to help the operator visualize different types of engineering drawings. Because these drawings often get very complex and for the operator to visualize a three-dimensional figure from a two-dimensional drawing requires more time and cognitive load (Kashihara, 2009). Therefore, allowing the operators to visualize drawings through AR could allow for less time spent studying, analysing and understanding drawings. There are several researchers that have worked to develop AR applications that allow for this, one way to do it has been to develop an application that reads markers on a drawing that allows the operator to visualize what is on the drawing and rotate the view in 3D (Fiorentino et al., 2012; Girbacia, 2009; Uva et al., 2010). Fiorentino et al. (2012) also has the added benefit that it allows the operator to interact with 3D model, and move the different sub-assemblies in the model, which could be highly useful in outfitting tasks.

Gattullo et al. (2019) point out that documentation used in industry today is typically static either in the form of paper or PDFs and look towards the creating manuals that are suitable for an Industry 4.0 environment by looking to successful examples such as iFixit and their large use of visuals to describe the procedure.

Another example can be seen by Evans et al. (2017) which reviewed the Microsoft HoloLens for assembly instructions. The HoloLens is an example of an HMD which allows the operators to have both their hands free while getting having information within their field of view while working. This interface was controlled through hand gestures and it is likely the most suitable way, but there are examples of other ways to interact with the systems such as for example voice commands. Figure 14 shows an example of how an assembly station with an HMD could work.

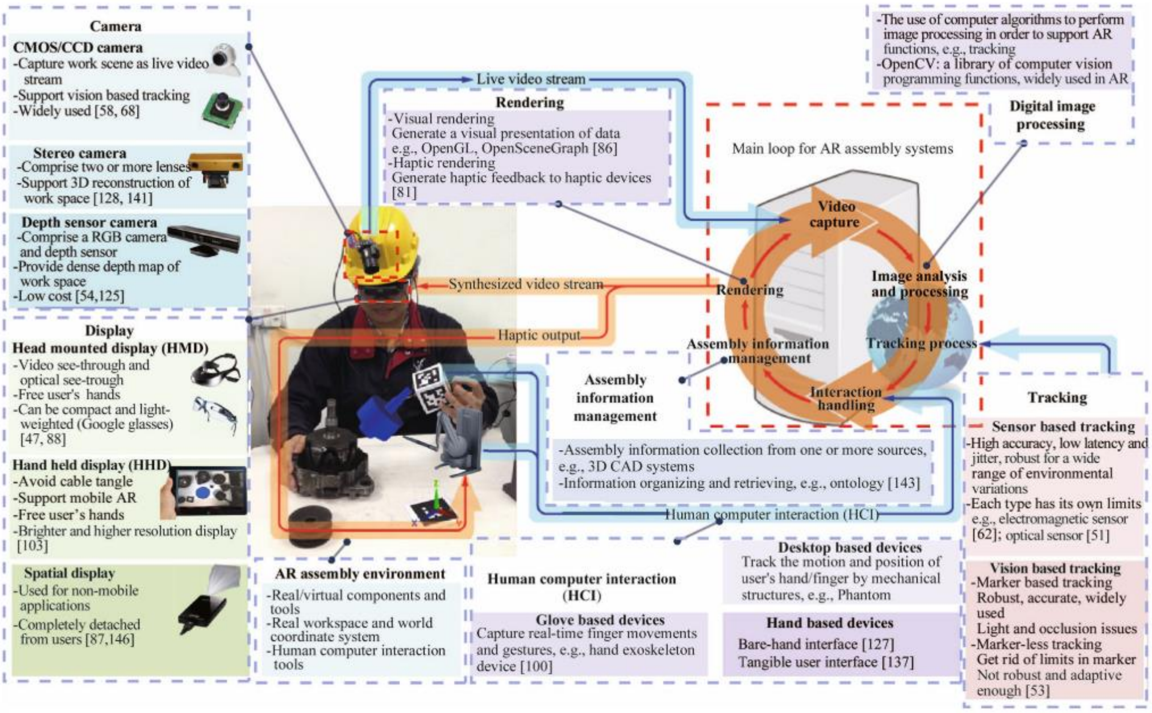

Figure 14: Example of an AR assembly environment ***(Wang et al., 2016)***

Syberfeldt et al. (2016a) developed a system for dynamic operator instructions that is automatically adjusted to the operator's level/skills. Although this system was designed for training of operators the idea of having a system that is adjusted based on the user is an interesting point for increasing the usefulness for the operator.

There are several papers looking at the applications of AR in the field of maintenance. Such as (De Crescenzio et al., 2011; Henderson and Feiner, 2011; Palmarini et al., 2018) which are all developing applications for displaying sequential maintenance instruction for the operators. While these are mainly targeted towards maintenance (assembly and dis-assembly) the main features are relevant for outfitting operators as they are working on assembly and installation work.

In addition to instructions and information for the installation there is also further possibilities for using AR in the outfitting of ships. One application that has been popular in different areas where hidden infrastructure is present is often referred to as "X-ray vision" (Liu and Seipel, 2018). The idea is that the operator can see elements that are hidden for example behind a wall. This can be things such as piping and electrical wiring. If there is a need to for example drill a hole or access something that is already installed it can be a huge benefit to the operator if it is possible to locate things that are not visible (Hugues and Cieutat, 2011; Liu and Seipel, 2018). This could be a useful feature for several disciplines such as in the installation of pipes and electrical work. In the case of the electricians this would allow the electricians to see elements such as already installed wiring behind walls or panels. It could also allow them to see other features that might be relevant for their tasks, such as where beams and pipes are located.

4.2.3 Warehouse, transport and material handling

Information needs:

- Picking list with part numbers
- Location

For warehouse and transport of equipment there are some information needs, but they usually do not require too much advanced information. The most important information is obviously what they are picking/delivering and where it is coming from and going to. As warehouse operations are present in most industries this is an area where there exists a fair bit of literature. One area where it has been conducted research is pick-by-vision supported by AR, as picking of items usually represents 55% of the cost of warehouse operations (de Koster et al., 2007). Typically the order picking in shipyards is done by paper as well which means that this is an area where it is likely that improvement can be made (Fraga-Lamas et al., 2016). As the amount of information needed is not the greatest even static information just displayed like text in the operator's field of view could be enough for the operators in picking tasks (Reif and Günthner, 2009). However, more sophisticated and more helpful solutions have also been developed for this purpose. Many of the pick-by-vision solutions utilize a way of guiding or showing the operator the location of the next item on the picking list. Hanson et al. (2017) developed a solution where a tunnel in the operator's vision guides him/her to the correct part. This allows the operator to always know where to go to pick the next item on the picking list.

Another example of a guidance system based on AR is proposed by (Subakti and Jiang, 2017). While not designed for an industrial application, rather it is designed as an indoor guidance system for campuses. It provides the user with general information such as a map, but also allows for location-based information such as directions to specific locations. This system uses markers as the method for determining the indoor positioning and is designed both for phone mode and HMD mode.

4.2.4 Kitting

Information needs:

- Picking list for tools and equipment
- Destination
- Drawings/instructions that might be a part of the kit.
- Have all the parts of a kit arrived and are ready for picking?

Kitting could benefit from AR in several ways. One of the ways kitting could become more efficient and reduce errors is through having kit information conveyed/displayed through AR. In a study where an application was developed for the Microsoft HoloLens for conveying such information to the operator using AR the results showed a slight reduction in picking times for batch preparation of kits compared to picking based on paper instructions (Hanson et al., 2017).

Pick-by-vision is one of the most popular approaches for order picking. This solution is one that could be relevant both in regular warehouse picking and in kit preparation, although sometimes the solutions differ between these two application areas. Often solutions can be shown as a tunnel in the operators vision that guides him to the correct part as shown in (Hanson et al., 2017; Schwerdtfeger and Klinker, 2008).

4.2.5 Dimensional control and inspection

Dimensional control and inspection is an important support process of all stages in the production of a ship. There are ways that that this could be supported by AR. There are examples of companies that already use this technology as a part of their quality control. Especially in industries where the demands for quality and safety are especially high. Airbus is one company that are using an augmented reality application named SART as a part of their quality control in the production of aircrafts (Airbus, 2016). This solution combines the real images of what is produced with digital mock-ups through a tablet equipped with a camera. Airbus claims that they reduced the time for their quality inspections of parts which can be between 80 000 and 120 000 from three weeks to three day after the MiRA system was introduced (Bonard and Cottet, 2015).

The smart glasses used in the marking for cabin installation is also a tool for dimensional control as it will check the operation made by the operator and validate it if it is made in the correct place. In addition to the reduction in time spent on control and inspection having AR as a support tool might facilitate the most important part of quality which is do it right the first time.

Applications that are not directly aimed at the control and inspection area but involving similar features could be adapted to work in this process. In literature related to maintenance applications there are several examples where the technology is used for checklists or inspection. De Crescenzio et al. (2011) developed and tested an application for the daily step by step inspection of an aircraft. As this is an extensive procedure that typically requires a manual and a check list, for the operator to have everything in his field of vision proved to be useful and it improved the efficiency of the task. The users were also positive to the solution as it would make this necessary task quicker and easier. Other examples similar applications have been developed by for example (Henderson and Feiner, 2011) and (Palmarini et al., 2018). Both articles describe solutions that can guide the user though the different stages of a maintenance operation such as a check or a repair.

4.3 Summary of potential applications

This short section will summarize the potential applications for AR-based operator support in the production processes present in Norwegian shipyards. Table 4 gives and overview of the applications that were identified for the different production processes in this chapter.

Table 4: Summary of potential applications in the production processes.

Processes	Applications
Prefabrication	Dynamic instructions Visualization of drawings Machine interaction **For pipes:** Pipe layout planning Pipe ID system (scanning can provide drawings and instructions)
Outfitting	Positioning and measuring for installation Visualisation of drawings, Assembly instructions, positioning/measuring, Dynamic instructions, "x-ray" vision
Warehouse, transport and material handling	Guidance system (to next item and to delivery point) Digital information displayed hands-free
Dimensional control and inspection	Instructions, built vs designed Check list (stepwise inspection)

5 Expected benefits and challenges with AR in Norwegian shipbuilding

This chapter will investigate what benefits and challenges implementation of the solutions identified in chapter 4 could have in a shipyard.

Quantifying potential improvements is a difficult process. Especially when it comes to the introduction of new technology. Often it is the case that there are challenges in the beginning and if the company and its employees does not see instantaneous improvements it is simple to lose faith in the solution and give up. There are many examples of companies where much time, energy and money has been put in a solution, but the implementation has failed.

When it comes to some of the potential solutions discussed in the previous section many of these solutions are conceptual and must be developed into more mature solutions before, they are ready to be applied in full scale industrial application. As such it is also hard to quantify the potential improvements that it would bring. Some of these solutions have been tested in labs or in small scale. Often, they have been focused on one specific task and this also makes it harder to estimate how being applied on more than one application/task would affect the efficiency of the operator.

5.1 Potential improvements

The research in this topic is very much based on research projects where solutions for specific tasks or problems are developed and are then tested, often in a lab or small-scale version of the environment it is intended for. There is little academic literature that really can quantify the potential improvements that can be expected in a full-scale implementation.

The typical improvement that can be expected in many of the production processes is a reduction in the time spent finding, reading and analysing drawings and manuals. Without exact numbers for how much time an operator (in the different processes) spends on this while working it is hard to quantify exactly how big savings could be expected. Therefore, using the existing literature where tests have been conducted comparing AR solutions with other solutions is used to assess the potential improvements.

Richardson et al. (2014) did experiments comparing model-based instructions (MBI) with tablet-based AR instructions, where the subjects had eight times higher first-time quality in assembly tasks. Furthermore, the results also showed a shorter time spent for the assembly task, in fact a 33% reduction in time. This is with an application that the operators have to divert their focus from what they are working on to check a tablet, therefore it would be realistic to think that HMD based technologies could allow the operator to complete the task in an even shorter time than with a tablet-based solution. Therefore, it could be expected that an application where the user had all the information in the field of view at any given time would have at least the same reduction in time or more.

Airbus is one company that has come a long way in developing solutions for their production of aircrafts. Their tool SART (Smart Augmented Reality Tool) delivered by their subsidiary Testia has been applied with great results (Bonard and Cottet, 2015). The solution where a digital mock-up is superimposed over what is actually built using tablet with camera and geolocation system, Airbus claims, has reduced the time spent on quality inspection of brackets from 3 weeks to 3 days.

Another application of AR used by Airbus is smart glasses worn by operators in the installation of cabins (Wright, 2017). The solution involves that the operator has a pair of smart glasses that scan barcodes through a camera that allows the operator to see information and specific cabin plans. This information is then used for marking in the cabin installation. In the news article it is claimed that the implementation har resulted in a big jump in efficiency. The task with marking cabin before the use of the smart glasses required three operators and three days to complete. With the use of the smart glasses this process only requires one operator and can be completed in six hours. Completing the same task only with 1/3 of the personnel and less than 1/3 of the time is a significant improvement.

5.1.1 Efficiency in shipyards

There are some existing productivity studies from Norwegian shipyards, although these are often confidential and are at best made publicly available years later. Ugland and Gjerstad (2010) conducted a study of work-time utilization that provided some interesting insight into the actual productive time among shipyard operators. The study concluded that on average only 27% of the working time was spent on processing and value adding activities. The rest of the time was spent on various non-value adding activities such as preparing, inspecting, cleaning, walking, waiting, transport and searching. They categorized 34% of the time spent as “Non-Value Adding but Required” (NVAR), which is comprised of tasks such as preparation, cleaning, inspection and transport and 39% as “Non-Value Adding” (NVA) including categories such as walking, searching, waiting and resting. The study paints a picture that shows that much time was wasted. The reasons are many and it can be hard to pinpoint the exact reasons. However, what does seem apparent is that even small improvements in different areas could result in huge gains in projects of the sizes that ships are.

Reaching a point with 100% value added time is impossible as there will always be need for preparations and cleaning etc., but even small improvements in the efficiency could have great impacts. If for example a vessel has a budget of 300 000 workhours and only 27% of that time is value adding it means that only 81 000 of those hours are adding value to that vessel.

This means that a vessel that has a budget of 300 000 hours only 81 000 of those hours are spent value-adding activities for that vessel. Just increasing the processing time with 1% might not seem like much, but it can quickly add up to many hours. Following the assumption that 81 000 hours is what is needed of processing time on the vessel and the efficiency is increased to 28%

in this example this will mean that the new budget of hours for the same vessel would be 289 285 hours. Or a reduction in 10 715 hours. If one worker is working 7,5-hour days with 230 working days this will equate to 1725 hours a year. This equates to about the hours spent from 6 workers for a whole year. This example illustrates that even small improvements could lead a lot of time saved in projects of this size.

Given that it is hard to get precise numbers on the distribution and the reasons behind the 73% of time spent on activities other than processing. Some of this time is for example spent on the reading and understanding of drawings, manuals and instructions. Depending on the task and processes the numbers will vary, but it seems clear that the use of AR-based operator support does allow for less time spent on such activities. Continuing the example of 1%, for one worker 1% of the day is 4,5 minutes (given a 7,5-hour workday). Assuming the average worker spends 4,5 minutes or more per day studying specifications, instructions or drawings if AR-based operator support allows this time to be reduced significantly a minimum of 1% increase in the productivity should be within reach. It is also worth noting although the time spent on drawings, instructions and specifications might be among the more substantial “time thieves” in the production processes. Typically, prefabrication, outfitting and inspection, there are also other applications as well that in combination with the visualization of drawings and instructions could help gain even further improvements.

5.2 Summary of benefits

The previous sections have identified some of the benefits and improvements that could be expected from the introduction of AR-based operator support in the different production processes. Table 5 is a summary of the different improvements that could be identified through the literature used.

Table 5: Summary of the potential improvements for AR-based operator support in the different processes.

Processes	Improvements
Prefabrication	• Less time spent reading drawings, and specifications • Quick identification of pipes
Outfitting	• Less time spent reading drawings, manuals and specifications • Airbus: 3 operators for 3 days --> 1 operator 1 day
Warehouse, transport and material handling	• Quicker locating of parts • Reduced errors compared to paper-based systems
Dimensional control and inspection	• Airbus: 3 weeks --> 3 days

	- More efficient inspection with instructions and visual aids rather than manual
General improvements	- Less time spent reading, analysing and searching for information. - Real-time updated information due to the information being digital rather than static.

5.3 The challenges

This section will highlight some of the challenges with implementation of such systems. It will start with some of the practical challenges related to the technology itself, then it will describe some of the issues related to how a solution could be implemented and finally it will mention some of the human factors that also have to be taken into consideration when looking at such systems.

5.3.1 Cost of AR solution

For all companies there is a balance between the potential improvements from investing and the cost of the investment. To assess the cost of such an investment is a project on its own.

The technology varies in price depending on the solution. While a tablet is not a very expensive investments the more advanced solutions like HMDs and smart glasses are more costly. As stated by Syberfeldt et al. (2017) the hand-held solutions are typically seen as less suitable for operators as they cannot use their hands for work at the same time as they are using the AR solution.

At the moment a large-scale investment seems unlikely as the cost would be high, for example Microsoft HoloLens is typically priced at around 3000 USD and the Google Glass Enterprise 2 is around 999 USD, so the technology is not cheap and investing in this kind of equipment for the employees is costly at the moment. However, the price of this kind of equipment is expected to go down in the future as the market grows and the technology matures.

In addition to the purchase of the AR display there is also a need for having an IT infrastructure in place that allows the devices to get updated information. Depending on the existing infrastructure this can be an expensive additional cost to the company. Starting from scratch it is a time consuming and costly project. Many business software developers are slowly getting integrations that allow for AR combability which means that systems that the business usually will have to pay for anyways allows for integration with AR. This means that the total investment needed will go down and likely mean that more shipyards are willing to try the solutions. However, for this to work on a big scale there is a need for a whole IT infrastructure to be in place.

5.3.2 The human aspect

An important point to take into consideration that is not always given enough though is the human aspect. Asking a person to either wear or carry around a digital tool all day poses several important questions.

The first and maybe the most important one is the operator’s wellbeing. Several studies show that a recurring issue is that wearing either glasses or HMDs for a prolonged period can cause discomfort such as eye strain and dizziness (Frigo et al., 2016; Uva et al., 2010; van Krevelen, 2007; Wang et al., 2016). This is an issue that needs to be evaluated thoroughly before such a system is implemented. If the system causes discomfort or issues for the user, it could cause opposition against the technology. This follows closely with the question whether it should be worn by all operators throughout the whole day or just while performing specific tasks.

There is also a question of how workers will react to be given instructions if this is a part of the solution. Operator support tools should help the operator get the information s/he needs at the right time, too detailed instructions are given to people without any consideration of their skills or knowledge it could result in the operator loosing motivation. Syberfeldt et al. (2016a) took this into consideration by making a system that allowed for dynamic instructions based on the skills and the knowledge of the operator.

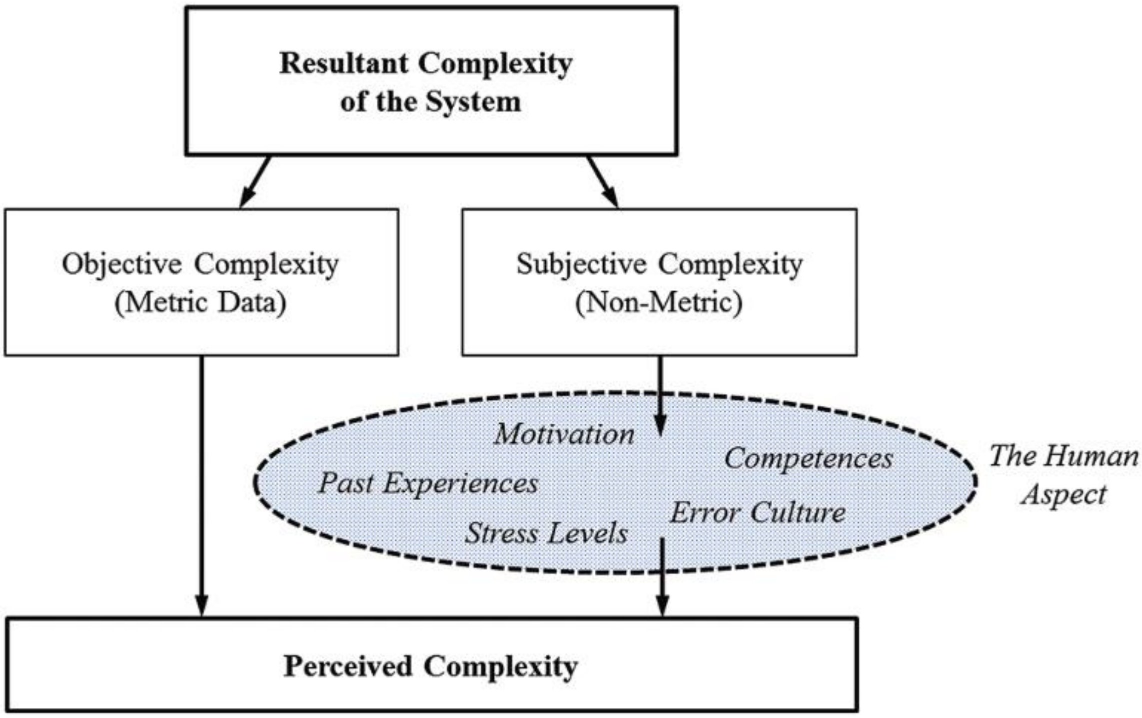

Figure 15:Percieved complexity and the role of the human aspect (Brinzer and Banerjee, 2018).

The system must also be intuitive, and the workers should see the value from using the system. Figure 15 from Brinzer and Banerjee (2018) shows how the perceived complexity of a system is a affected by several factors among the users such as motivation, stress levels and past experiences. This shows that there are many factors that should be considered when such systems are implemented, not just the system itself.

5.3.3 Privacy

The privacy of the operators is an issue that is also worth noting. Positive measures that can improve the productivity, well-being and safety measures but the tracking could pose privacy and legal implications (Romero et al., 2016). Wearing a head mounted display that is relying on tracking to work also means that it could be possible to track the workers and their movements very detailed. Making sure that the solutions are something that benefits everyone in the organization is important when considering such systems.

5.4 The technology

One of the most noted challenges in developing a robust AR solution for industrial applications is the tracking (Fite-Georgel, 2011; Fraga-Lamas et al., 2018; Reif and Günthner, 2009). This is regarding both the location of the operator, but the main challenge is the tracking of the environment around the operator. There are several approaches to tracking, and some give the worker more freedom than others. Markers on different parts and infrastructure will allow the system to more easily recognize the location and what the operator is looking at.

There are also other factors that are challenging due to the lack of maturity in the technology. The battery life is another issue depending on the solution. For tablets it is generally better than most glasses or HMDs which are generally good for a few hours, but few solutions existing today have the battery life to last a whole shift. For hand-held solutions such as tablets the battery life is not a big issue but for head-worn solutions such as glasses there is a trade-off between battery life and how comfortable it is to wear. A larger battery results in a bigger weight that can cause discomfort for the wearer.

6 Conclusion

The conclusion will address how the objectives and research questions of this thesis were answered and address the limitations, contribution and future research.

This master's thesis has explored the concept of AR-based operator support in Norwegian shipyards by evaluation potential applications in the different production processes present in Norwegian shipyards. It has also highlighted some of the potential benefits and challenges that can be expected if the technology is used in a shipyard. A case study of Ulstein Verft AS in Ulsteinvik was conducted. The case study was used as a background for identifying the different production processes as well as what information and challenges is typically present in these processes.

The first research question was *"How can AR-based operator support be applied in the production processes present in Norwegian shipbuilding?"* This research question was answered through studying existing literature for both applications that are developed with shipyards in mind, but also for applications that could be applied for the information needs present for the shipyard operators that are not necessarily developed with shipyards specifically in mind. The applications that were identified as applicable in the different production processes are summarized in Table 4. Some of the key applications are visualization of drawings, visualized instructions, comparison between designed and built, guidance and picking information for the warehouse.

The second research question were that were answered was: *"What are the potential benefits and challenges that can be expected from the introduction of AR-based operator support?"* The second research question identified improvements that had been achieved though published studies as well as examples like the solution used by Airbus which is using AR-based operator support in some of their processes and claims to have achieved great improvements as a result.

The main conclusion is that there seems to be many promising applications of AR-based operator support that could be applied in the different production processes in shipbuilding. Based on the limited research available it is hard to accurately assess potential improvements but most research indicates that there can significant improvements. However, the limited research into how it could be applied in a shipyard combined with the cost and the limited experience from use in industry it seems unlikely that a large-scale implementation will happen right away.

It seems clear that there is a huge potential in the technology. This is an area that continuous to be popular in research and there are several companies that work towards developing strong solutions for industrial applications. Implementing these technologies today would mean that the business is an early adopter which could be positive, but it would likely bring with it many challenges as the solutions that exist are limited and would likely require a great deal of specific development for the applications that are the most likely in ship production. The academic articles that exists on the topic shows promising results where reduced errors and less time spent searching for/understanding information are some of the key take-aways. However, there is a lack of large-scale testing of these applications.

What makes it seem really promising is that the companies that have implemented this technology in parts of their production processes seems to have benefitted from it. Airbus is the clearest example that according to their own statements have had huge improvements where tasks can be completed quicker and in some cases with fewer people. Although these numbers are only what is reported by the company themselves for a product one of their own subsidiaries are selling it does seem like the technology could bring benefits to at least some production processes.

6.1 Recommendations for the case company and other Norwegian shipyards

Based on the finding presented in chapter 4 and 5 some suggested approaches for the case company and other Norwegian shipyards that are moving towards technology from Industry 4.0. The case company and other shipyards that are interested in the emergence of technologies that facilitate operator support. As the technology is still at an early stage where large scale implementation is both expensive and risky it does not seem wise. A more sensible approach would likely be to start at a smaller scale where the solutions and the effects can be tested and evaluated. Ulstein has mainly seen it as a tool that could be useful at the foreman level. Although the findings from this project suggest that applying it on the operator level could bring improvements and benefits, starting with the test and use on a small scale such as for the operators seems like a reasonable starting point. It would keep the costs down as the number of foremen is limited and their use is different from what it would be among the operators.

The different processes and disciplines have different information needs which makes it difficult to generalize the potential improvements. Another suggestion as a starting phase could be to test a solution for a specific task or discipline in the real environment so it is easier to accurately measure the real improvement it could bring. Bonard and Cottet (2015) claimed great improvements for Airbus in inspection. Because of the similarity of the task, although it is stricter for aircrafts suggest that the inspection and dimensional control in a shipyard could be a process where the technology could be tested and evaluated.

As shown in Figure 11 there are several technological solutions that qualifies as AR. Typically the head-worn solutions have been the main focus for industrial applications as these allow the user to have the hands free for working while still having access to the information. This is the reason Syberfeldt et al. (2017) proposes the use of smart glasses for industrial applications. This is a good point, but it should not be the only factor in the decision. The implementation that is the most suitable is dependent on the task that the operator is performing. For some tasks a simple interface with for example touch controls could be more useful than having the hands free at all times, for example for inspection tasks such as the solution in (Bonard and Cottet, 2015). In addition, it could be more intrusive for the operator to wear a pair of glasses or a helmet with a display that is present all the time than a tablet that the operator only needs to look at when it is necessary.

There are also different solutions for how the AR should be utilized. Is it something that all operators need and should have or is it a tool that only selected members of a team or the foremen should have? One of the answers to this question could be that AR in the form of either goggles or tablets could be something that the operators can pick up when they need it from a booth or station. It could also be supplied as a part of a kit if it is a task where specific instructions are needed, or it takes place in an environment where it is important that hidden infrastructure is considered.

The most important recommendation is that it is important for the companies that consider these types of operator support to consider the challenges of implementing such a system. Involving the operators that will be the end users of the technology in what information it should display and how it should be used will be important. Making sure that they are involved and see the value of having a support tool like this will be a key point in a successful solution.

6.2 Contribution, limitations and further research

Contribution:

This master's thesis has contributed to further the topic of operator support and specifically in the way augmented reality can be of use for shipyard operators. It gives an insight into the different production processes that are present in Norwegian shipyards and how existing challenges and information needs in the different processes could be helped through the use of augmented reality-based solutions. The findings presented in this thesis could be of use for companies by highlighting some of the existing solutions within this segment, challenges and potential improvements that could result from taking advantage of this technology.

Limitations:

Conducting case studies can be challenging and there are many factors at play when working with a case company. In this project there was only one case company which means that the case study does not reflect all Norwegian shipyards, but rather the processes and strategies of one specific yard. Furthermore, the accessing the information that is needed for a project is not always possible and therefore the case study is used as a supportive tool.

Future research:

This thesis provides a wide overview of processes and potential applications in Norwegian shipyards and future research should go more in depth of the specific processes and test the effects and improvements it would make. What exists now is mainly data from small scale lab experiments and gathering data from applications in the actual production environment would provide valuable insight into both the actual performance as well as the challenges from bringing this technology into an environment that has typically been highly reliant of paper drawings and other documentation. Another interesting point that seems to lack research is how people will react to the introduction of such an intrusive technology. While there is research on how people react to new technology, especially with the introduction of IT systems, this technology could be more intrusive as it changes a person's view on the surrounding world. It would also be interesting to see a cost and benefit analysis that considers the expected improvements and the cost of a complete solution for AR-based operator support.

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