Development of a Digital Transformation Roadmap (DTR) for the upstream oil and gas industry

by

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Thesis presented in partial fulfilment of the requirements for the degree of Master of Engineering (Industrial Engineering) in the Faculty of Engineering at Stellenbosch University

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Declaration

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Abstract

Development of a Digital Transformation Roadmap (DTR) for the upstream oil and gas industry

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In recent years, there has been much discussion with regard to opportunities presented by digital transformation in upstream oil and gas. However, despite the increased attention, companies have received little to no guidance on how to implement such a transformation in upstream oil and gas. Currently, literature on digital transformation in the industry focuses on specific aspects of the transformation; however no chronologically structured approach to implementing a holistic digital transformation encompassing all aspects is available. So how can the upstream segment implement digital transformation? This study's aim is to develop a holistic digital transformation roadmap to assist upstream companies in digitally transforming their business.

This investigation is conducted through a systematic literature review that focuses on digital transformation, upstream oil and gas and digital transformation efforts in other industries. By reviewing literature on these subjects, insights, best practices and implementation approaches of digital transformation are identified. These aid in the development of a proposed Digital Transformation Roadmap (DTR) for a holistic transformation of the upstream oil and gas industry. The DTR is then subjected to a validation process by leading industry professionals.

Uittreksel

Ontwikkeling van 'n digitale transformasiepadkaart vir die stroomop olie- en gasbedryf

("Development of a Digital Transformation Roadmap (DTR) for the upstream oil and gas industry")

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In onlangse jare is daar baie gesprek gevoer oor geleenthede wat digitale transformasie in olie- en gasbedryf bied. Ondanks die groter aandag, het ondernemings egter min of geen leiding gekry oor hoe om so 'n transformasie te implementeer nie. Tans fokus literatuur oor digitale transformasie in die industrie op spesifieke aspekte van die transformasie, maar daar is geen chronologies gestruktureerde benadering tot die implementering van 'n holistiese digitale transformasie wat alle aspekte omvat tans beskikbaar nie. Dus, hoe kan die stroomop segment 'n digitale transformasie ondergaan? In hierdie verband is die doel van hierdie studie om 'n holistiese digitale transformasie raamwerk te ontwikkel om stroomop ondernemings te help met die transformasie.

Hierdie ondersoek word uitgevoer deur 'n sistematiese literatuuroorsig wat fokus op digitale transformasie, stroomopwaartse olie- en gas en digitale transformasiepogings in ander bedrywe. Deur literatuur oor hierdie onderwerpe te hersien, word insigte, beste praktyke en implementeringsbenaderings van digitale transformasie geidentifiseer. Hierdie aspekte help met die ontwikkeling van 'n voorgestelde digitale transformasie raamwerk, of Digital Transformation

Roadmap (DTR), vir 'n holistiese transformasie van die stroomopwaartse olie- en gasbedryf. Die DTR is dan onderhewig aan 'n bekragtigingsproses deur toonaangewende professionele persone in die bedryf.

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- My family and friends for supporting and energizing me to keep going.
- The leading industry professionals who assisted in the validation of this work.
- Our Heavenly Father for giving me strength and reassurance that nothing is impossible for those who trust in Him.

The Author,
November 2021

Dedications

This thesis is dedicated to my parents, Danie and Frannette,
for their continued encouragement, love and support.

Contents

List of Figures

List of Tables

Nomenclature

AI	Artificial Intelligence
AM	Additive Manufacturing
ANN	Artificial Neural Networks
AR	Augmented Reality
ASR	Automatic Speech Recognition
AUV	Autonomous Underwater Vehicle
BOP	Blowout Preventer
CAD	Computer-Aided Design
CAPEX	Capital Expenditure
CDO	Chief Digital Officer
CFIHOS	Capital Facilities Information HandOver Specification
CIO	Chief Information Officer
CPS	Cyber Physical System
DBS	Digital Business Strategy
DT	Digital Transformation
DTR	Digital Transformation Roadmap
DTS	Digital Transformation and Sustainability
E&P	Exploration and Production
EFL	Electrical Flying Leads
FDP	Field Development Plan
FP	Fixed Platform

FPSO	Floating Production Storage Offloading
GA	Genetic Algorithm
GHG	Greenhouse Gas
GIIP	Gas Initially In Place
HFL	Hydraulic Flying Leads
HH	Henry Hub
HMD	Head Mounted Display
HSE	Health, Safety and Environment
IIoT	Industrial Internet of Things
IMR	Inspection, Maintenance and Repair
IOCs	International or Investor-owned Oil Companies
IoT	Internet of Things
IPIRs	In-pipe Inspection Robots
IS	Information Systems
KPI	Key Performance Indicator
M&A	Merger and Acquisitions
MUTC	Modified Unit Technical Cost
NGLs	Natural Gas Liquids
NIST	National Institute of Standards and Technology
NLP	Natural Language Processing
NOCs	National Oil Companies
OECD	Organization for Economic Co-operation and Development
OPEX	Operating Expenditure
PaaS	Platform as a Service
POC	Proof of Concept
PPDM	Professional Petroleum Data Management Association
PSO	Particle Swarm Optimization

RFID	Radio-Frequency Identification
ROI	Return on Investment
ROV	Remotely Operated Vehicle
SA	Simulated Annealing
Saas	Software as a Service
SDU	Subsea Distribution System
STOIIP	Stock-Tank Oil Initially In Place
TC	Total Cost
UAV	Unmanned Aerial Vehicle
UR	Ultimate Recovery
UTA	Umbilical Termination Assembly
UTC	Unit Technical Cost
VR	Virtual Reality
WEF	World Economic Forum
WRFM	Well, Reservoir and Facilities Management
WSNs	Wireless Sensor Networks
WTI	West Texas Intermediate

Chapter 1

Introduction

This chapter serves as an introduction to the research undertaken, providing background to the study, along with where this research fits in with the existing body of knowledge. This is followed by the problem statement, the research objectives and aims, and the delimitations of the study, in order to provide boundaries within which the research will be conducted. Next, the research approach and methodology are discussed. They describe the methods used to provide a solution to the problem statement. Lastly, the chapter concludes with an outline of the thesis.

1.1 Background

Industrial revolutions, characterized by radical changes to work processes and technologies, have drastically transformed industries. Currently, digital transformation is a major focal point, revolutionizing economies, industries and even society itself. It has emerged as a result of the accumulation of a substantial volume of digital technology innovations. Figure 1.1 illustrates the combinatorial effects of new digital technologies, which are accelerating the pace of change. There is widespread recognition among leaders in most industries that the role of digital technology is rapidly shifting from being a driver of marginal efficiency to an enabler of fundamental change innovation and disruption (Accenture and World Economic Forum, 2016). In broad terms, digital transformation refers to a managed holistic organizational process of change driven by, built on, or enabled by digital technologies, altering how organizations conduct business (Osmundsen *et al.*, 2018).

Today's companies are dealing with challenges in rapid decision-making for increased productivity. An example of this can be given from the transformation process towards automated machines, processes and services, which leads the coordination and connection of distributed complex systems (Lee *et al.*, 2015). According to a report published by Deloitte (2018), physical

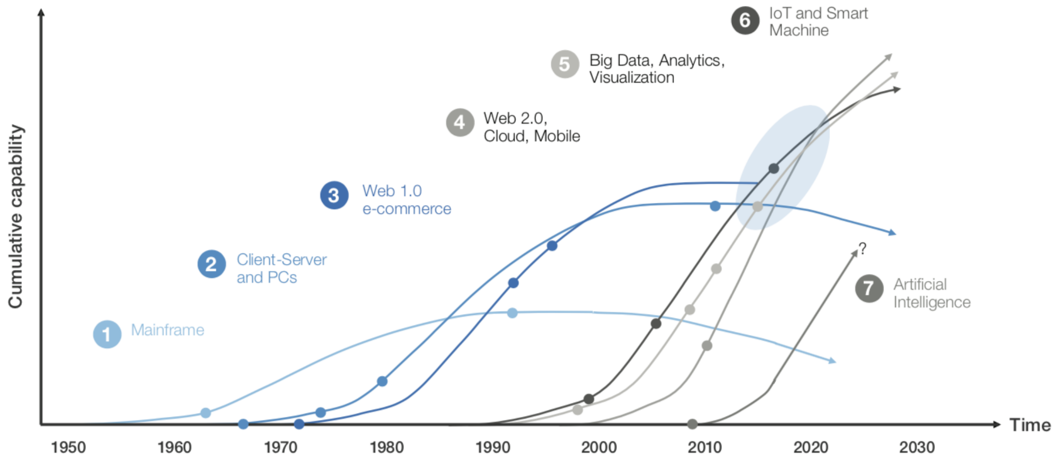

Figure 1.1: Combinatorial effects of new digital technologies (Accenture and World Economic Forum, 2016)

and digital technologies are merging through analytics, artificial intelligence (AI), cognitive technologies and the Internet of Things (IoT) to create digital enterprises that are both interconnected and capable of more informed decision-making.

The potential benefits of going digital are clear – increased productivity, boosted innovation, safer operations, new value streams and cost savings. Digital technologies are helping almost every industry rewrite its operational landscape; however, the oil and gas (O&G) industry is lagging behind. Despite the barrage of digital advancements, upstream O&G companies have been slow to seize the opportunity. Upstream oil and gas Exploration and Production (E&P) companies around the globe have experienced declining capital efficiencies, as production has not kept up with development costs. This is due to many reasons, including the need to look for oil in challenging "frontier areas" and increasingly deeper waters (ultra-deep environments), increased project complexity, difficulty obtaining drilling rights and acreage, surging input costs, oil and gas price volatility and difficulty delivering projects on schedule and within budget (Tideman *et al.*, 2014). Digital transformation has the potential to transform the upstream oil and gas industry, allowing data-driven solutions for better decision-making, improved asset management, enhanced efficiency, and ultimately reduced costs.

Today, environmental impact is a major focal point, especially with advancements in renewable energy and electric power innovations. Society has become impatient with the oil and gas industry due to environmental and sustainability agendas becoming increasingly critical of the industry. This places the oil and gas industry in the spotlight, forcing change. Public scrutiny over greenhouse gas emissions and environmental impacts of O&G companies are causing great unrest, forcing E&P companies to find innovative solutions to reduce their environmental footprint as well as increasing the transparency of operations. For example, the multinational oil giant Royal Dutch Shell has been the latest company to be investigated, resulting in imposed greenhouse gas emission reductions of 45% by 2030 compared to 2019 levels (Boffey, 2021). A solution to this criticism and scepticism is to obtain and distribute interoperable data which can be achieved through digital transformation. Digital transformation also has the capability of reducing negative environmental impacts. Professor Klaus Schwab, founder and executive chairman of the World Economic Forum, stated in his book, The Fourth Industrial Revolution:

> *"The world has the potential to connect billions more people to digital networks, dramatically improve the efficiency of organizations and even manage assets in ways that can help regenerate the natural environment, potentially undoing the damage of previous industrial revolutions"* (Schwab, 2016).

In recent years, there has been much discussion with regard to opportunities presented by digital transformation in upstream oil and gas. However, despite the increased attention, companies have received little to no guidance on how to implement such a transformation in upstream oil and gas. In addition, there are barriers to its realization, for example, unfit regulatory frameworks, lack of standardization and collaboration, infrastructure gaps, resistance to change and lack of executive trust in new technologies (World Economic Forum, 2018). Simultaneously, the disruptive nature associated with rapid transformation also poses a major source of uncertainty and risk.

Once executives have agreed to implement full scale digital transformation across the industry, there are specific steps to be followed to ensure that the digital transformation is managed and executed successfully. However, a knowledge gap currently exists regarding implementation procedures encompassing a holistic transformation process. There is much debate in literature regarding the impact of digital transformation, the requirements, the affected business dimensions and how to initiate the transformation process.

The purpose of this study is to determine the requirements, best practices and implementation approaches for the digital transformation of upstream oil and gas. This research is necessary to breach the gap in the digital maturity of the upstream segment of the oil and gas industry by developing a structured and systematic Digital Transformation Roadmap (DTR) to guide upstream oil and gas companies in undergoing digital transformation.

The roadmap is developed by reviewing peer reviewed literature on digital transformation and the upstream oil and gas industry. This is done in an effort to gain an understanding of the requirements for upstream oil and gas, to identify the drivers and objectives, success factors, barriers to implementation and implications of digital transformation. In addition, a comprehensive investigation into the methods utilised in the process of digitally transforming other industries will provide insight into developing the implementation roadmap which will generate the greatest value for upstream oil and gas, while reducing the risk and disruption associated with undergoing a transformation on such a scale.

1.2 Problem Statement

The value of technical data, the quality thereof and the value contained therein, are exponentially being realized by senior leadership in the entire oil and gas industry. Almost every operating company in the industry has "digital transformation" as a strategic objective, and words like "data science", "machine learning" and "artificial intelligence" are taking the industry by storm. The World Economic Forum (2017) (WEF) quantifies the potential to be in the order of trillions of U.S. dollars.

The industry has a chance to move from incremental, digitally driven operational improvements to a broader embrace of digital technologies (World Economic Forum, 2018). The oil and gas industry has not utilized the full potential of digital transformation, which has provided other industries with unparalleled opportunities in value creation. However, the transition of data structures, software, governance and business processes and, more importantly, how digital transformation is to be implemented in the upstream segment to capitalise on this transition and tap its value, remains elusive. Currently, literature on digital transformation in the industry focuses on specific aspects of the transformation; however, no chronologically structured approach is available to implementing a holistic digital transformation encompassing all aspects. This leads to the problem statement:

There is no structured and systematic implementation roadmap available that incorporates all required business elements to support a holistic digital transformation of upstream oil and gas.

1.3 Aims and Objectives

The main aim of this thesis is to develop a Digital Transformation Roadmap (DTR) for the upstream oil and gas industry. This aim is broken down into sub-goals resulting in a series of research objectives. The research objectives are outlined below:

(1) Gain an understanding from literature of the different segments of the oil and gas industry.
(2) Gain an in-depth understanding on the upstream segment and the stage-gate process of delivering capital projects.
(3) Investigate the dynamics of the O&G industry, such as oil and gas price volatility, supply and demand factors and the impacts of these on the O&G industry.
(4) Develop a thorough definition for digital transformation based on peer-reviewed literature.
(5) Investigate the drivers and objectives of digital transformation.
(6) Identify the building blocks, or dimensions, of digital transformation.
(7) Identify success factors and best practices of digital transformation.
(8) Investigate digital transformation approaches in other industries.
(9) Identify trends, common elements and similarities in implementation procedures which can be used for digital transformation of the upstream oil and gas industry.
(10) Formulate the Digital Transformation Roadmap (DTR) for digital transformation of upstream oil and gas.
(11) Validate the implementation roadmap through interviews with carefully selected industry experts.
(12) Draw conclusions from the study and present limitations and possible topics for future research.

Section 1.6 provides a thesis outline to show in which chapters the research objectives are to be accomplished.

1.4 Delimitations

It is important to set boundaries for the study in order to avoid being distracted from the topic and to keep focus throughout the study. The focus of this study is to develop a structured implementation roadmap for digital transformation of the upstream oil and gas industry. This decision to focus on the upstream aspect of the industry arose from the complexity and size of the entire oil and gas industry.The entire O&G industry is too broad focus on the digital transformation of all segments. Focusing on one segment of the industry provides a suitable research project fulfilling the requirements of a Master's Degree. The upstream segment is chosen due to its high level of activity in searching for, recovering and producing crude oil and natural gas as well as socio-political issues. In addition, the upstream segment is associated with high risk due to unpredictable results, safelty and environmental issues. Lastly, technology drives all aspects of the upstream industry, adding to its capital intensive nature. Initially, the roadmap was focused on digital transformation of Major Capitals Projects (MCPs). It was soon found, however, that digital transformation must be implemented on an organizational level to create the correct context for MCPs. Thus, the scope of the study was expanded to upstream oil and gas. The World Economic Forum (2017) states that digital transformation in the oil and gas industry could unlock approximately $1.6 trillion of value for the industry, its customers and wider society. Therefore, it is assumed that digital transformation will generate significant value for the upstream oil and gas segment and that the industry understands that value.

1.5 Research Approach and Methodology

The approach of this investigation will be qualitative, based on comparative analysis techniques. Key concepts and terminology in the problem statement will be identified and investigated in a qualitative literature review. First, literature on upstream oil and gas is reviewed to provide the necessary knowledge on the industry and how it functions. Secondly, literature on digital transformation is reviewed to formulate a definition for the study and to provide knowledge and understanding of enablers and requirements of the transformation process. Thirdly, identifying similarities in digital implementation approaches made by other industries with more advanced digital integration will provide the necessary tools to develop a strategy and implementation roadmap for digital transformation of the upstream oil and gas industry. Thus, a third literature search on digital transformation in several industries is conducted to identify trends, elements and common approaches in implementation procedures.

The knowledge obtained from these three separate literature reviews will be used to systematically develop a digital transformation roadmap to guide upstream oil and gas companies in undergoing a digital transformation process. In addition, any prerequisites to using the roadmap will be identified.

The findings will be presented to leading industry professionals at several companies in the oil and gas industry during which they will be asked to provide both inputs and evaluations of the proposed solution. These consultations will be used to validate the research together with providing recommendations for possible future research which is to be listed in the conclusion. The input-output process of this study is shown in Figure 1.2.

In this regard, the research presents:

- An overview of the oil and gas industry, including a detailed analysis of the upstream segment;
- An investigation into digital transformation fundamentals;
- A comparative analysis of digital transformation in other industries;
- A Digital Transformation Roadmap (DTR) specifically suited to digital transformation of upstream oil and gas.

All research conducted will be in accordance with Stellenbosch University's Policy on Research Ethics.

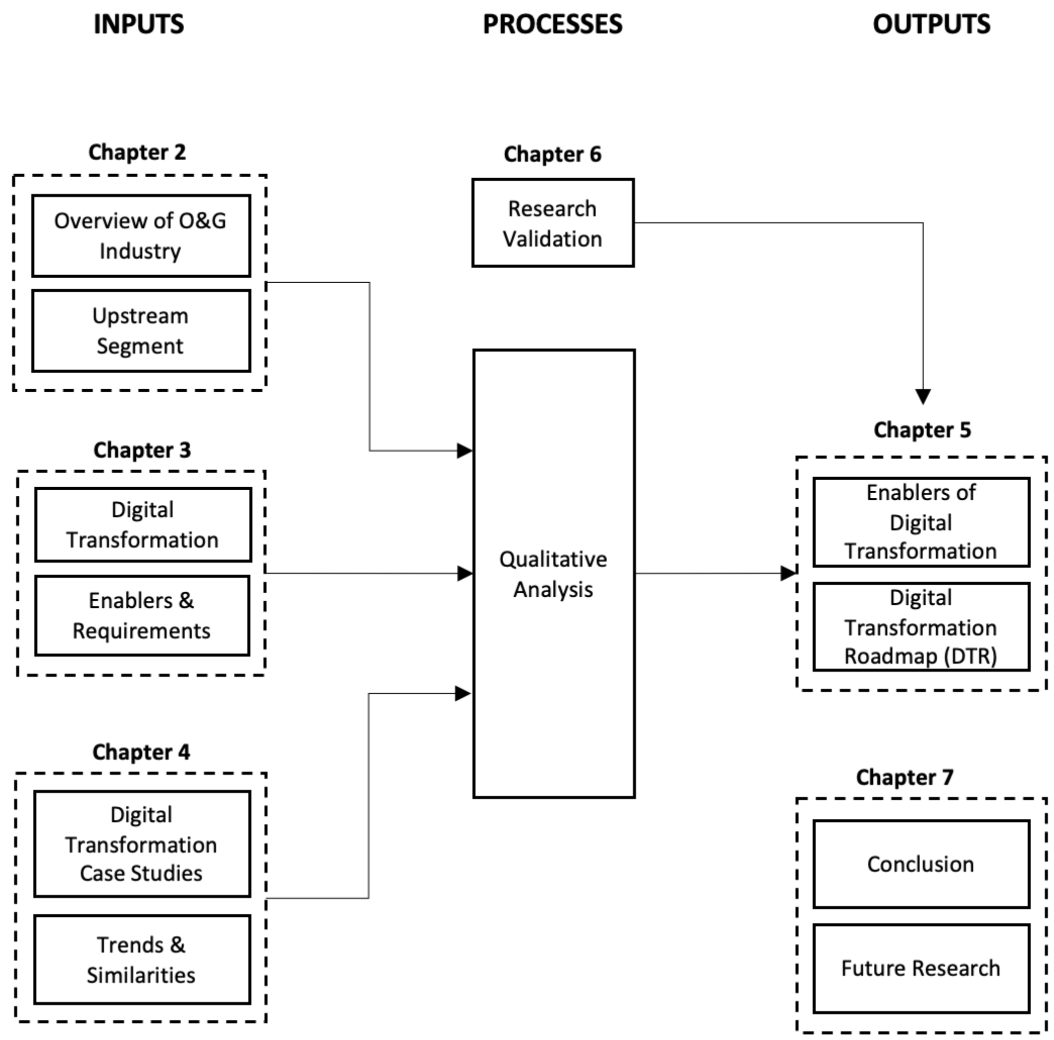

Figure 1.2: Input–Output Process

1.6 Thesis Outline

This section provides a summary and breakdown of the layout and content of each chapter in the thesis.

Chapter 1: Introduction

Chapter 1 introduces the study by establishing the background to the research and the problem statement. This is followed by the research objectives and aims, along with the delimitations. Finally, the research approach and methodology as well as an outline of the thesis are presented. The outcome of this chapter is to provide background on the purpose and the need for the research, and what is intended to be achieved during the study.

Chapter 2: Overview of the Oil and Gas Industry
First, the fundamentals of the oil and gas industry are discussed to gain an understanding of its different segments. Next, the upstream segment, which is the central focus of the study, is discussed in depth. Lastly, the dynamics of the O&G industry are discussed. The outcome of this chapter is to provide the necessary knowledge on the O&G industry and particularly the upstream segment as obtained from literature.

Chapter 3: Overview of Digital Transformation
The fundamentals of digital transformation are discussed in Chapter 3. This includes the development of a definition for digital transformation, explaining the drivers and objectives, and the building blocks, core components, infrastructure and practices that need to be in place to embrace digital change. This is followed by discussing success factors to consider and the implications of digital transformation.

Chapter 4: Digital Transformation in Other Industries
Chapter 4 investigates other industries' approaches to digital transformation through the use of case studies. Trends, common elements and similarities in digital transformation approaches are investigated and identified. The outcomes of this chapter are to determine if there are general approaches to developing a digital transformation roadmap and undergoing digital change.

Chapter 5: Digital Transformation of Upstream Oil and Gas
Chapter 5 consolidates all the previous chapters to develop a Digital Transformation Roadmap (DTR) specifically suited to upstream oil and gas. The DTR is the final deliverable of this study.

Chapter 6: Validation of the DTR
The research validation procedure is explained and presented in Chapter 6. This is accomplished by conducting interviews with carefully selected industry experts from around the globe.

Chapter 7: Conclusion to the study
Chapter 7 draws conclusions from the study and presents limitations and future research opportunities.

Appendix A - Literature on New Digital Technology
Appendix A provides literature on the application of new digital technology which is referred to throughout the thesis.

1.7 Chapter Conclusion

Chapter 1 introduces the study by establishing the background to the research and the problem statement. This is followed by the research objectives and aims, along with the delimitations. Finally, the research approach and methodology as well as an outline of the thesis are presented. Chapter 1 provides background on the purpose and the need for the research, and what is intended to be achieved during the study.

Chapter 2

Overview of the Oil and Gas Industry

This section will provide an overview of the oil and gas industry together with explanations of its accompanying terminology and processes, which are prevalent throughout this thesis.

2.1 Value Chain

The oil and gas industry's value chain is divided into three separate segments, namely the upstream, midstream and downstream segments as shown in Figure 2.1. These segments refer to an oil and gas company's location within the oil and gas value chain. Some companies are considered to be integrated oil and gas companies because they combine the activities of two or three of these segments.

2.1.1 Upstream

The upstream segment of the oil and gas industry, also known as the Exploration and Production (E&P) sector, is responsible for all the activities related to searching for, recovering, and producing hydrocarbons, i.e. crude oil, natural gas and Natural Gas Liquids (NGLs). The upstream segment determines the location of prospective wells, their design and construction, as well as being responsible for the operation and management of the wells as efficiently as possible in order to receive the greatest Return On Investment (ROI) while maintaining the safest and smallest operational footprint.

The exploration for oil and natural gas and their production involve a series of high-risk, high-cost and high-technological activities and processes. These activities include geological surveys, magnetic surveys, gravitational surveys, seismic surveys, laboratory studies, geochemical studies, exploratory

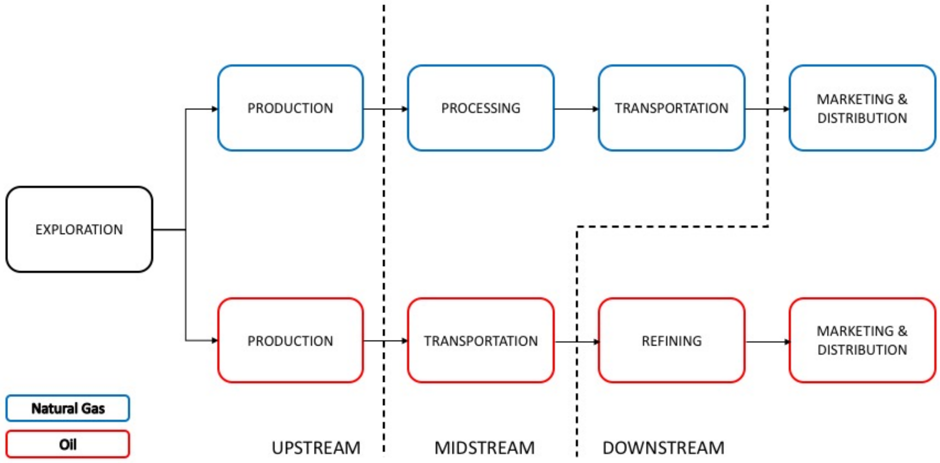

Figure 2.1: The oil and gas industry value chain, adapted from Devold (2009).

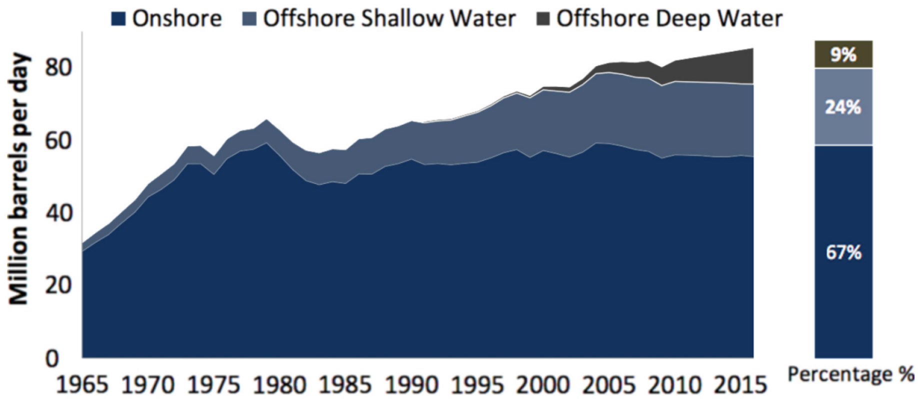

Figure 2.2: Onshore versus offshore oil production map (Ferentinos, 2013)

drilling and well testing (Chowdhury and Esposito, 2016). The results of well testing determine if further exploration and production will commence; the well is abandoned if no oil or natural gas are found. Further exploration and production activities include the drilling of appraisal wells, exact positioning of the field, and assessing the commercial viability of oil and natural gas reserves (Chowdhury and Esposito, 2016). If the reserves are economically viable and the decision is made to continue with development of the field, the field development plans are constructed, a development well is drilled, relevant infrastructure is constructed (e.g. production and surface facilities) before production commences. The activities relating to offshore E&P are much more complex.

Since most of the major onshore oil fields are in declining production and the overall supply of crude oil from onshore reserves has levelled-out (Sandrea and Sandrea, 2010; Höök *et al.*, 2009), the focus is moved to offshore production in order to match the soaring demands of the supply chain. Currently roughly 30% of the global oil production originates from developing offshore fields and deepwater reserves are also contributing to an estimated 9% as shown in Figure 2.2 (Sandrea and Sandrea, 2010; Ferentinos, 2013). Interaction with the industry has suggested that the balance has shifted back to onshore production due to a shale boom in the Permian and other similar fields, coupled with the risk aversion of low prices. However, a brief search of peer-reviewed literature could not confirm or contradict this statement.

The shale boom refers to the development of technologies, such as hydraulic fracturing and horizontal drilling, which has enabled the extraction of large gas reserves trapped in shale and other gas-bearing rock formations (Trembath *et al.*, 2012). These unconventional resources of oil, natural gas and other hydrocarbons were generally viewed as unrecoverable due to the low porosity and permeability of the rocks within which they are contained (Jackson *et al.*, 2014).

Hydraulic fracturing and horizontal drilling

Hydraulic fracturing, also known as 'fracking', is the process of injecting water, sand, and chemical lubricants under high pressure into a bedrock formation via a selected section of the wellbore to fracture the bedrock, and in the process to obtain oil and gas from underground reservoirs (U.S. Geological Survey, 2019). The injected substances also keep the induced fractures open for gas recovery (Trembath *et al.*, 2012). Figure 2.3 shows a comparison of hydraulic fracturing and horizontal drilling compared to conventional natural gas production. The hydraulic fracturing occurs when the concrete casing of the horizontal section is perforated with small explosive devices and the mixture is pumped through the holes at high pressure (5 000 psi) to fracture the rock up to 300 m from the pipe (Sovacool, 2014).

The process of hydraulically fracturing gas-bearing formations is a controversial topic. Public concerns about the environmental impact have accompanied the rapid growth in shale oil and shale gas production. These allegations include local air quality degradation, the potential for groundwater and surface water pollution, increased Greenhouse Gas (GHG) emissions, increased frequency and magnitude of earthquakes, ecosystem fragmentation, and various other impacts on communities (Jackson *et al.*, 2014). On the other hand, the benefits of fracking include an abundance of supply, lower natural gas and oil prices, cleaner environmental footprint and economic development (Sovacool, 2014). A major benefit of shale gas and oil is that there is a lot of it. The U.S. Energy Information Administration (EIA) assessed 48 shale gas basins in 32 countries around the globe and concluded that the resource is in great

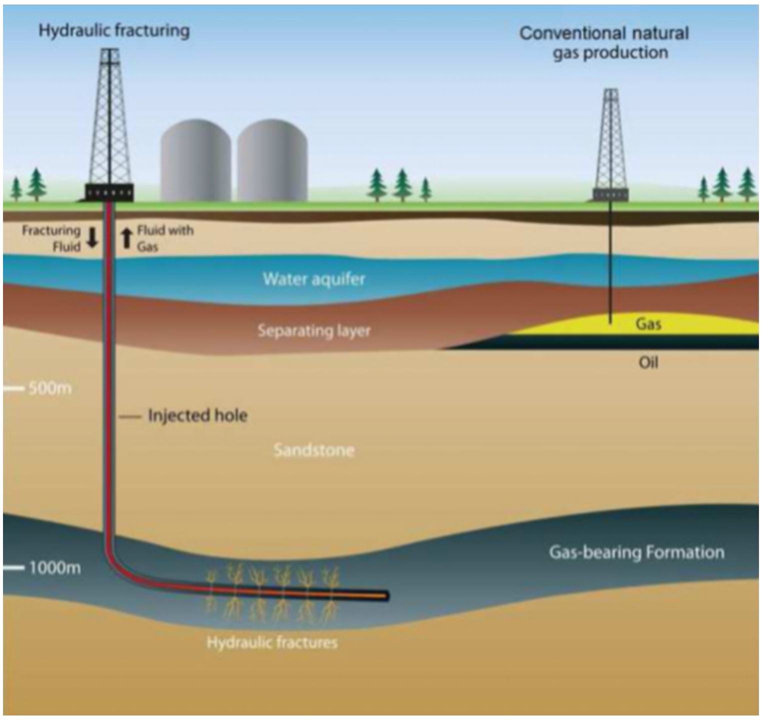

Figure 2.3: Horizontal drilling and hydraulic fracturing (Sisinni *et al.*, 2018)

abundance. Figure 2.4 illustrates the global basins with assessed shale gas and shale oil deposits (Kuuskraa *et al.*, 2013). In addition to being an abundant resource, a key driving force behind shale gas production is its affordability. It is on average 50–66% cheaper than production from new conventional gas wells (Deutch, 2011). Shale gas production has severe negative environmental effects as stated previously; however, shale gas has lower emissions of sulphur oxides, nitrogen oxides and mercury compared to coal and oil (Sovacool, 2014). Lastly, shale gas production leads to economic development – employment, job creation, infrastructure, revenue streams and taxes.

Due to the controversy surrounding hydraulic fracturing, it is not included in the scope of this study. However, a brief overview is necessary to contribute towards the overall understanding of the current technology and processes employed in oil and gas E&P. Hydraulic fracturing is a process of onshore production, but regardless of this, conventional onshore exploration and production is what is investigated.

Offshore production processes are complex due to the high risks and great difficulties involved in extracting oil and natural gas during subsea production (Shukla and Karki, 2016*b*). Safety risks, high capital expenditures, environmental concerns, and logistical and engineering complexities are just some of the many challenges oil and gas companies face in the process of accessing and extracting hydrocarbons from offshore reserves. Offshore platforms are gener-

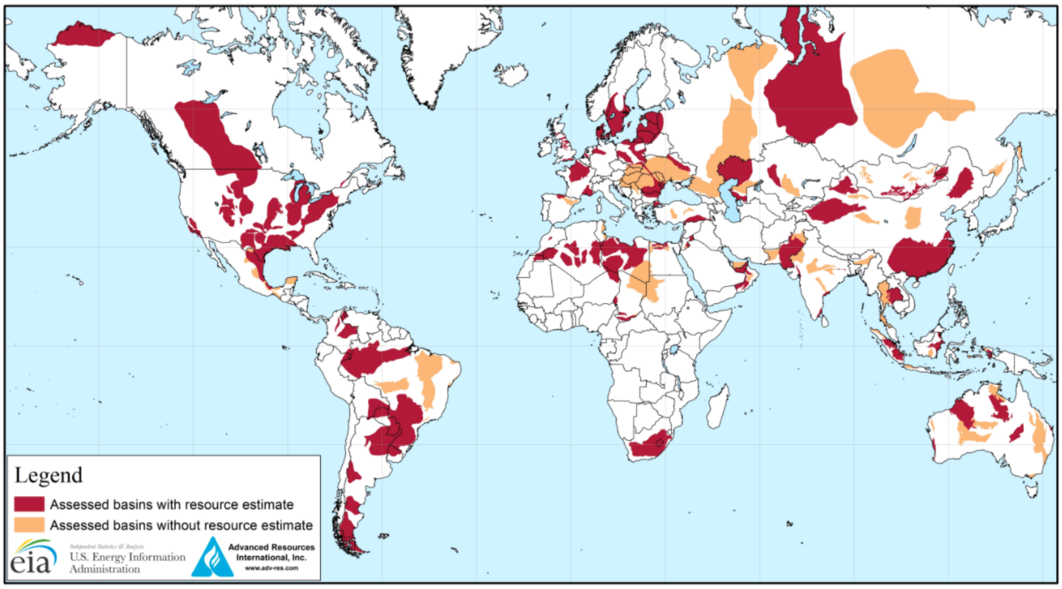

Figure 2.4: Global basins with assessed shale oil and shale gas deposits as of June 2013 (Kuuskraa *et al.*, 2013)

ally located on the continental shelf; however, technological advances have led to recent trends in drilling and production in deep water environments and even ultra-deep water (Sharma, 2019). Deep water is usually defined for an offshore region where the water depth is between 300 *m* and 1 500 *m* (between 1 000 *ft* and 5 000 *ft*). Regions with depths exceeding 1 500 *m* are referred to as ultra-deep water (Wu, 2018). There are many other factors beyond the obvious environmental conditions, such as production methods, infrastructure and logistical requirements, which distinguish offshore E&P projects from conventional (onshore) E&P. This section aims to describe the fundamentals of offshore E&P.

2.1.2 Midstream

The midstream segment is outside the scope of this study, thus it is not necessary to provide an in-depth overview of this segment. However, a brief explanation is provided to give an overall perspective of the oil and gas value chain. The midstream segment of the oil and gas supply chain is responsible for gathering, transporting and storing hydrocarbons. The product is transported from the upstream production or processing plant to the downstream refinery or end user (Brun and Kurz, 2019).

The processes involved in handling natural gas and oil differ. The safest, most economical and most reliable method for transporting natural gas is through pipeline networks. Raw natural gas typically exists in mixtures of hydrocarbons (e.g. ethane, propane, butane and pentanes), as well as carbon dioxide (CO_2), hydrogen sulphide (H_2S), nitrogen, helium, water vapour and other compounds. Before natural gas can be transported it has to be processed to separate all these hydrocarbons and fluids from the raw natural gas to produce "pipeline quality natural gas" (Devold, 2009). Oil is transported by means of trucks, rail cars, tanker vessels or pipeline networks; the method depends on the amount of oil and its destination.

2.1.3 Downstream

Similar to the midstream segment, the downstream segment is also outside the scope of this study, thus it is not necessary to provide an in-depth overview of this segment. However, a brief explanation is provided to give an overall perspective of the oil and gas value chain. The downstream segment of the oil and gas industry is responsible for refining and processing the crude oil into various higher-valued products and marketing and distributing the final products to the end consumer. These higher-valued end products include naphtha, gasoline, kerosene, jet fuel, diesel, fuel oil, waxes, asphalt and lubricants.

2.2 Upstream Oil and Gas

As stated previously, the upstream segment of the oil and gas value chain can be divided into onshore and offshore production. These production methods have many differences due to the vastly different environments in which oil and natural gas are extracted and produced; however, certain similarities do exist in the respective exploration and production processes. The steps and procedures involved in onshore and offshore production, from start to finish, are described in the following sections.

2.2.1 Onshore Production Infrastructure

There are various equipment and infrastructure required for onshore O&G production. This section will focus on the two most important aspects, namely wells and drilling rigs.

2.2.1.1 Wells

Wells are permitted or actual drilled holes in the ground designed to facilitate the exchange of oil and gases between underground reservoirs and the surface (Professional Petroleum Data Management, 2014). A well consists of several components as shown in Figure 2.5, namely:

(1) **Well Origin** – the location on the surface of the earth where the drill bit is planned to penetrate the earth, or does penetrate the earth.

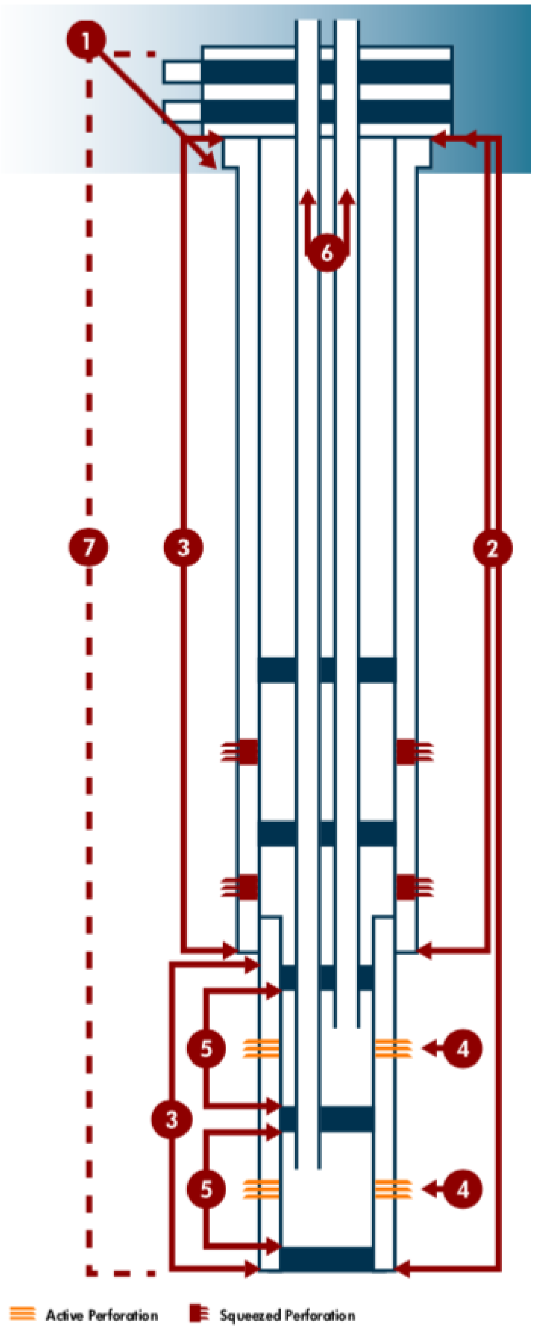

Figure 2.5: Well components (Professional Petroleum Data Management, 2014)

(2) **Wellbore** – the drill path from the well origin (start) to the point of termination (end).
(3) **Wellbore Segment** – a uniquely drilled interval in the well. It can be the initial interval from the well origin to a designated terminating point, or an extension of the wellbore.
(4) **Wellbore Contact Interval** – a specific measured depth range within the wellbore, which will place the wellbore in contact with an oil- and/or gas-bearing structure.
(5) **Wellbore Completion** – one or more wellbore contact intervals that forms a unit for the purpose of extracting oil and natural gas, or to inject fluids.
(6) **Wellhead Stream** – the flow of fluids (oil and natural gas, or other fluids in the case of an injection well) from the wellbore contact intervals to the surface or vice versa.
(7) **Wellhead Reporting Stream** – according to the Professional Petroleum Data Management Association (PPDM), "the wellhead reporting stream is a derived stream of fluids to support the allocation and aggregation of volumes" (Professional Petroleum Data Management, 2014).

2.2.1.2 Drilling rigs

The typical drilling rig platform includes a derrick (lifting device), mud circulation system, power generators, cementing equipment, and tanks (see Figure 2.6). Once drilling has started, drilling fluid and water are continuously pumped and circulated down the drill pipe and up through the annulus. This will balance underground hydrostatic pressure (Borthwick *et al.*, 1997), bring rock cuttings to the surface, cool the drill bit and lubricate the drill string (Jahn *et al.*, 2008).

Steel casings are inserted into completed sections of the well and cemented into place for well integrity and structural support. Blowout preventers (hydraulic actuated steel rams that can quickly close around the drill string or casing to seal off the well) are also installed to reduce the risk of blowouts in case of uncontrolled flow from the reservoir.

2.2.2 Offshore Production Infrastructure

There are various kinds of offshore structures that support drilling and extraction of oil and natural gas depending on factors such as water depth, type of well and environmental conditions (wind, waves and current). An offshore platform is a large structure facilitating workers and machinery needed to drill and/or produce and extract oil and gas from offshore reserves. A hierarchical structure is shown in Figure 2.7 of typical offshore project infrastructure. Well components have already been described in Section 2.1.1.1. This section will

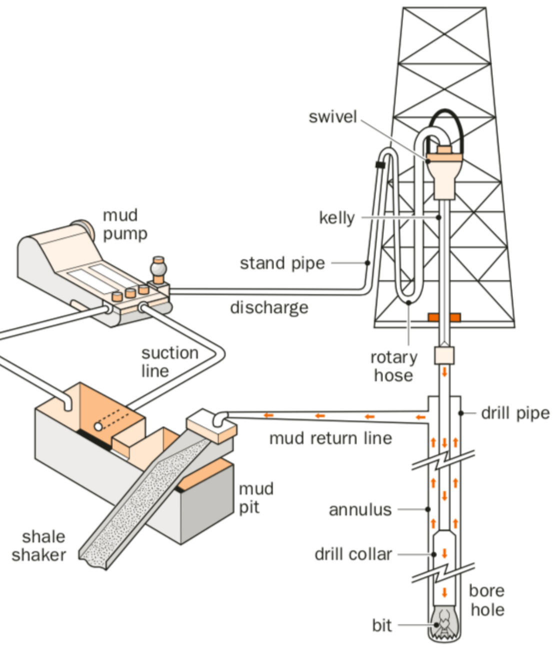

Figure 2.6: Typical drilling rig module (Borthwick *et al.*, 1997)

focus on drilling platforms, production platforms, subsea systems and transport infrastructure.

2.2.2.1 Drilling platforms

Exploration wells are often drilled by mobile offshore drilling rigs. It is important to distinguish between drilling rigs and production platforms. Drilling rigs are floating or floatable structures that can be moved between drilling locations. These structures are only involved in drilling operations, and are not present during the entire field life cycle. The type of drilling platform used depends on the water depth and drill site, as well as the conditions the platform will experience while drilling. Typical drilling platforms include:

- Flat bottom barge;
- Jack-up rig;
- Submersibles;
- Semi-submersibles;
- Drill ships.

In very shallow water (depths between 5-50 m) drilling can be performed by a flat bottom barge or submersibles. The buoyancy tanks of the submersible vessel can be flooded with water until the structure rests on the seabed. After

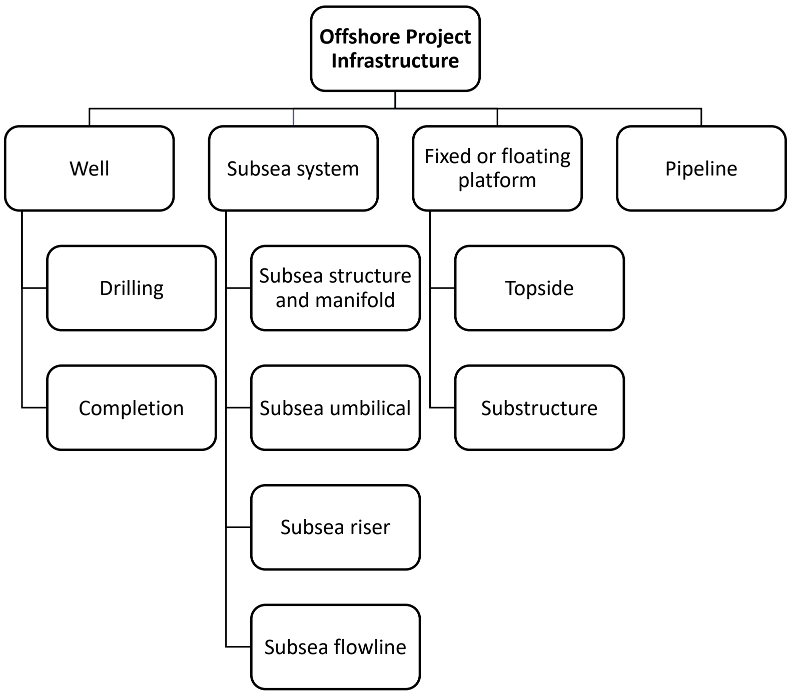

Figure 2.7: Hierarchical structure of typical offshore oil and gas project infrastructure, adapted from Rui *et al.* (2017)

drilling is complete, the water is pumped out and the vessel can be floated to a new location.

Jack-up rigs can be used in shallow waters with depths up to approximately 120 m. Upon being towed to the drilling location, the structure's three or four latticed legs are lowered to the seabed while the platform is jacked up so that it rests above the surface of the water. When drilling is finished the legs are raised, and the rig is towed to a new location.

Semi-submersible platforms are suitable for use in a wide range of depths, from shallow water to deep water up to approximately 1 500 m. The ballast tanks, or pontoons, are filled with water until the structure is partially submerged, which reduces the loading from wind and waves. The platform is then anchored to the seabed. Similar to submersibles, the water in the ballast tanks can be emptied and the vessels can then be moved to a different location.

Drill ships, which are ship-shaped drilling vessels, can drill in ultra-deep water up to approximately 3 000 m, sometimes even deeper. Dynamic positioning systems ensure that the drillship remains above the drill site.

Similar to onshore drilling rigs, offshore drilling rigs have drilling modules

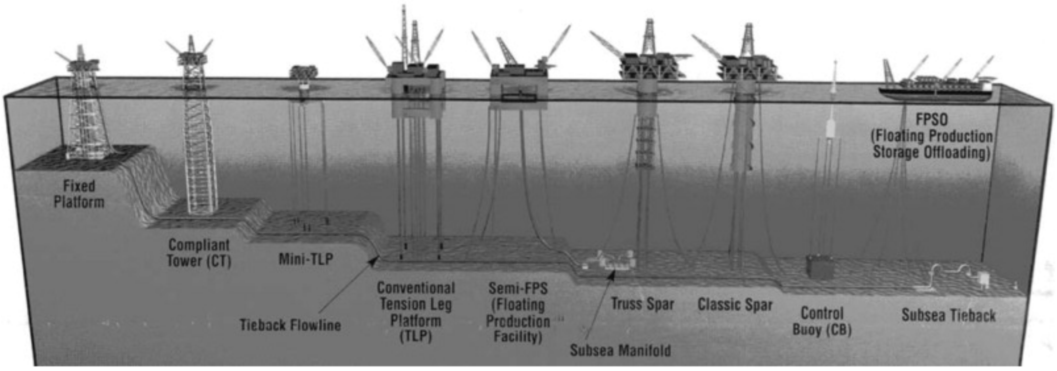

Figure 2.8: Typical offshore production platforms (Chakrabarti *et al.*, 2005)

consisting of a derrick for supporting the drill string and machinery to turn the drill bit.

2.2.2.2 Production platforms

In contrast to drilling rigs, production platforms are more permanent structures that are involved in the extraction and production of crude oil and natural gas from an offshore reserve. These structures are present over the entire life cycle of a well which could be between 20 and 50 years depending on the size of the hydrocarbon reserve. The type of production platform can be classified as a fixed production platform (attached to the seabed) or a floating production platform. The choice depends on the function the platform will perform and the conditions it will experience. All platforms consist of a topside, which houses different modules including the crew quarters and production facilities, and a substructure which supports the topside, and is mostly submerged in water. Typical production platforms are shown in Figure 2.8.

Fixed platforms

Fixed production platforms are shallow-water platforms that can be physically attached to the seabed. They contain platform wells, otherwise referred to as dry-tree production and drilling, meaning the wellhead systems (wellhead and Christmas tree) are located on the platform. Wellhead systems will be covered in the next section. Fixed production platforms include the following structures:

- Conventional Fixed Platform (FP);
- Concrete gravity platform;
- Compliant tower.

Conventional fixed platforms consist of tall vertical substructures made of steel members or concrete, supported by piles driven directly into the seabed, or which rely on weight to remain fixed in place. FPs are economically feasible for installation in water depths up to approximately 500 m (±1 650 ft) (Speight, 2014; Sharma, 2019).

Concrete gravity base platforms take advantage of the large size and heavy mass to support large facilities in water depths of up to 300 m (±1 000 ft). Another advantage is that the design facilitates the storage of crude oil and natural gas within the base of the structure. This type of platform was designed to withstand the heavy weather conditions and the great water depths often found in the North Sea.

Compliant towers are similar to conventional Fixed Platforms (FPs) and extend to the seabed. However, unlike a FP, a compliant tower is designed to flex with forces from waves, wind and currents. It consists of a narrow, flexible tower and piled foundation and uses less steel for the same water depths (Chakrabarti *et al.*, 2005). Waves are deamplified and resonance is reduced through the use of flexible elements such as flex legs and/or axial tubes. Due to the costs associated with compliant towers, it becomes economically infeasible for installations in water depths exceeding 900 m (±3 000 ft) (Speight, 2014).

Floating platforms

Floating production platforms are suitable for use in deep waters, and have enabled an increased trend in deep water operations and further E&P in ultra-deep environments. These platforms include the following structures:

- Conventional Tension Leg Platform (TLP) and mini-TLP;
- Spar;
- Semi-submersibles;
- Floating Production, Storage, Offloading facility (FPSO).

A Tension Leg Platform (TLP) is a floating platform that is held in place by vertically tensioned tethers fixed to the seabed. The tethers, or tendons, prevent vertical and rotational motion; however, the structure is compliant in the horizontal direction, allowing lateral motion. TLPs possess many of the operational advantages of fixed platforms while reducing the cost of production in water depths up to approximately 1 500 m (4 900 ft) (Chakrabarti *et al.*, 2005). TLPs are economically competitive with compliant towers for water depths between 300 m and 1200 m (Wilson, 2003).

The spar platform consists of a large-diameter single vertical cylinder substructure supporting a topside deck. The cylinder does not extend all the

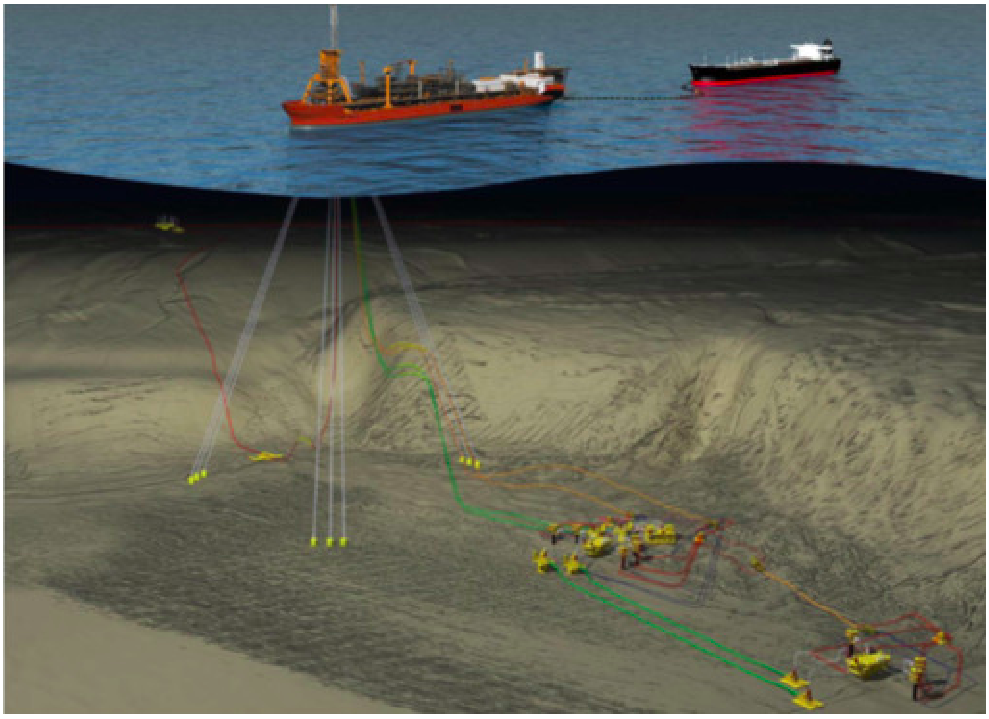

Figure 2.9: Typical FPSO platform with subsea systems (Lohr *et al.*, 2017)

way to the seabed, but is rather tethered to the seabed. The structure is designed so that its centre of gravity is lower than its centre of buoyancy, thus the spar platform is inherently stable (Chakrabarti *et al.*, 2005). According to Speight (2014), spar platforms are suitable for installation in water depths up to ±915 *m* (±3 000 *ft*).

Semi-submersible platforms, commonly referred to as 'semi-submersibles', are multi-legged floating structures with large decks. The legs are interconnected underwater with horizontal buoyant members called pontoons. Similar to other floating platforms, semi-submersibles are tethered to the seabed to prevent excessive changes to platform position. The pontoons contain ballast tanks which can be filled with water to provide stability during drilling or production operations, or emptied to allow manoeuvrability (Chakrabarti *et al.*, 2005). These structures are designed to act as both mobile drilling rigs and as more permanent production platforms. As offshore E&P moves into deeper waters, the use of semi-submersibles is becoming increasingly popular due to the structures allowing spacious topside facilities (Ma *et al.*, 2019). These structures have been used in water depths up to 3 050 *m* (±10 000 *ft*) (Simpson, 2017).

The last type of floating production platforms, a Floating Productions, Storage and Offloading (FPSO) platform, is a ship-shaped production vessel used for producing and storing crude oil and natural gas. FPSOs are designed to receive hydrocarbons from their wells, other nearby platforms, or subsea systems. A FPSO contains equipment on board to process hydrocarbons, as well as store the hydrocarbons until they can be offloaded onto a shuttle tanker for transportation to an onshore terminal (Ma *et al.*, 2019). Figure 2.9 illustrates a typical FPSO with a subsea system. FPSOs are particularly effective in remote or deep water locations where seabed pipelines are not cost-effective (El-Reedy, 2019), and for development of marginal or small fields where construction of a fixed platform is not cost-effective (Wang *et al.*, 2008).

Semi-submersibles and FPSOs contain subsea wells, otherwise referred to as 'wet-tree production and drilling', meaning the wellhead systems (wellhead and subsea Christmas tree) are located on the sea floor. TLPs and Spar platforms contain platform wells similar to the fixed platforms. Subsea wells and Christmas trees are part of subsea systems which are described in the next section.

2.2.2.3 Subsea systems

Subsea systems are installations that are completely submerged under the sea. They are used to produce oil and natural gas from locations which cannot easily be reached by directional drilling from an existing platform (Speight, 2014). The main components are the subsea wellhead and manifold, subsea umbilical, riser and flowline. Figure 2.10 illustrates a typical subsea production system. In addition to the main components mentioned, the suction pile, subsea Christmas tree (subsea Xmas tree), jumper (connectors), Electrical Flying Leads (EFL), Hydraulic Flying Leads (HFL), Subsea Distribution System (SDU) and the Umbilical Termination Assembly (UTA) complete the subsea production system.

The individual components of subsea production systems are described below:

(1) **Subsea Wellhead** – A structure that supports and seals the casing strings in the well, as well as supporting the BOP during drilling operations and the subsea Xmas tree after completion (Bai and Bai, 2018).
(2) **Subsea Xmas tree** – A vertical assembly consisting of a series of valves with gauges and chokes, which is attached to the top of the wellhead. It allows for adjustment in the flow of production fluids coming from the well, as well as injections to stimulate production (Chen, 2020).
(3) **Manifold** – Equipment used to gather production fluid from wells and send the combined fluid to the platform through flowlines and risers (Bai and Bai, 2018).
(4) **Umbilical** – Cables run from the topside platform to subsea Umbilical Termination Assembly (UTA) where it branches off at the SDU to each

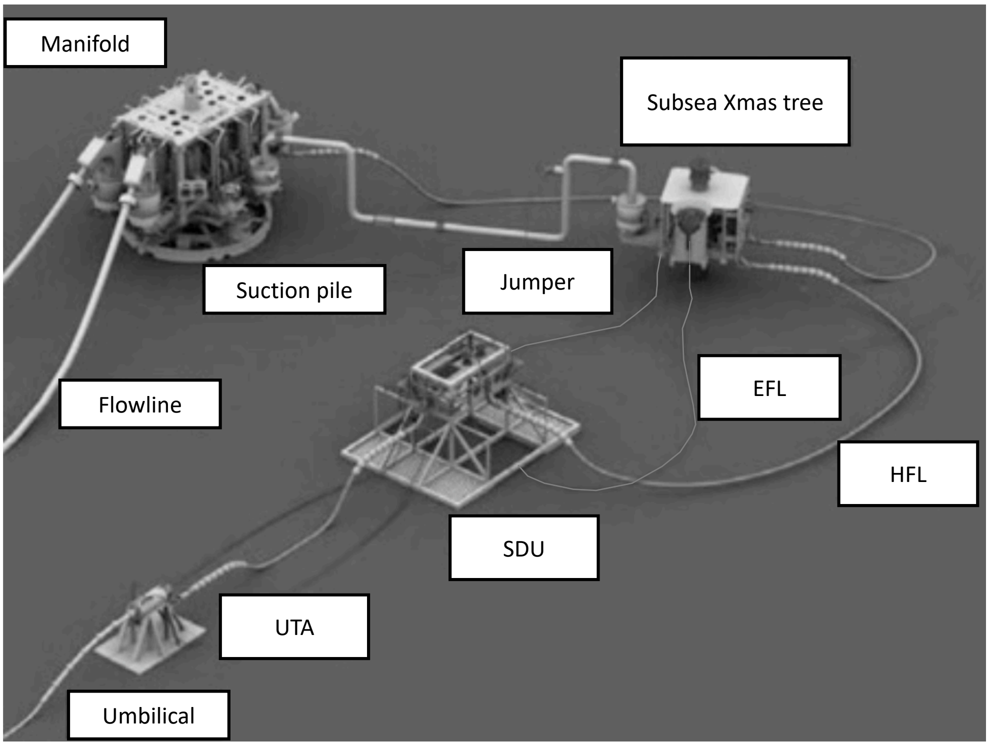

Figure 2.10: Typical subsea production system, adapted from Bai and Bai (2018)

individual wellhead and then to the manifold as HFLs and EFLs. It is the main medium for power and signal transmission between topside and subsea systems (Bai and Bai, 2018).

(5) **Umbilical Termination Assembly (UTA)** – Subsea structure that secures the umbilical in place on the seabed.
(6) **Riser** – Risers connect the flowlines to the topside platform.
(7) **Flowline** – Provides transportation of the production fluids, injection fluids, control fluids and gas between the subsea system and the topside platform.
(8) **Suction Pile** – Foundational structure supporting subsea equipment on the seabed.
(9) **Jumper** – A connector between subsea structures.
(10) **Electrical Flying Leads (EFL) & Hydraulic Flying Leads (HFL)** – Cables running from the UTA to the wellheads and then to the manifold. EFLs and HFLs supply electrical and hydraulic power for wellhead and manifold control functions.
(11) **Subsea Distribution Unit (SDU)** – Equipment distributing hydraulic supplies, electrical power supplies, signals and injection chemicals coming from topside through the umbilical to the subsea equipment.

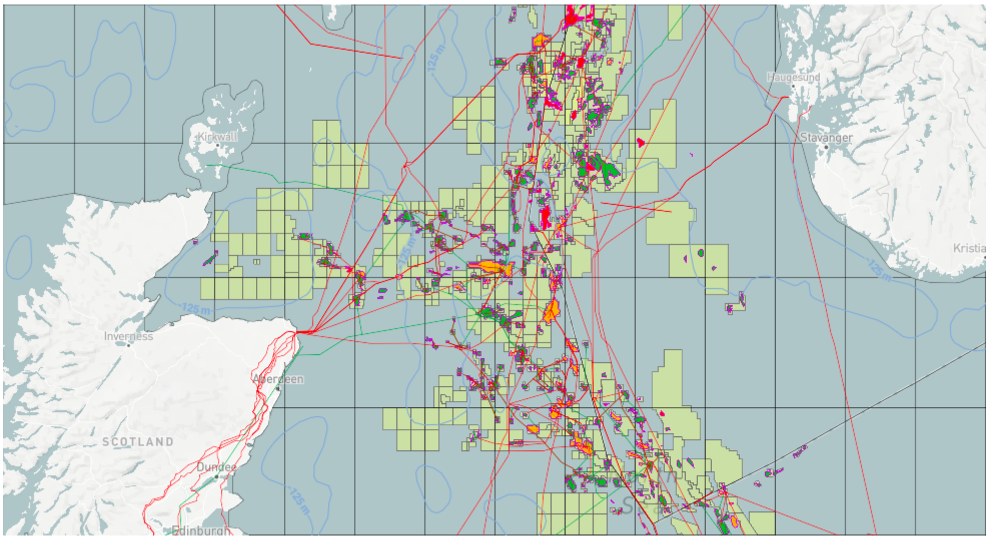

Figure 2.11: Pipeline network in the North Sea (Rystad Energy UCube, 2020)

Oil and gas flow from the well through the Xmas tree, which controls the rate of flow, to the manifold via a jumper. The crude oil and natural gas then flows from the manifold, which commingles all the oil and gas coming from the surrounding wells, through flowlines to the risers which pipe it to the topside platform for processing. Often, a single production platform is supplied by multiple subsea production systems, allowing a platform to produce crude oil and natural gas from multiple fields. Conventional risers used in fixed production platforms are subject to less structural demands and flexing when compared to risers used for floating production facilities.

2.2.2.4 Transport infrastructure

Once crude oil and natural gas have been produced, they need to be transported to onshore terminals. Pipelines are an efficient means of transporting the oil and gas over long distances back to land. Figure 2.11 illustrates a section of the current pipeline network in the North Sea.

In addition to pipelines, crude oil and natural gas can be transported to onshore processing facilities and refineries by means of shuttle tankers. Oil tankers are normally used if the production platform facilitates the storage of oil and natural gas, e.g. FPSOs and concrete gravity base platforms.

2.2.3 Capital Projects

As the name suggests, a capital project in the upstream O&G industry refers to a E&P project to extract hydrocarbons. In addition, a Major Capital Project (MCP) refers to a long-term, capital-intensive E&P project. A project consists of phases, collectively referred to as the field life cycle, which ranges from initial conceptualization to final decommissioning. The field life cycle is described in the next section.

The scale of onshore production projects is dwarfed by its offshore counterpart. Interaction with the industry has suggested that offshore production has significantly greater Major Capital Projects (MCPs) than onshore production, both in frequency and scale. This is mainly due to the complexity of offshore projects and the large hydrocarbon reserves these projects are able to exploit. Offshore projects are much more complex due to additional infrastructure and technology required to operate in the offshore environment. Thus, offshore projects are much more capital intensive and as a result there are also much more of these large scale projects in the offshore environment compared to onshore.

2.2.4 Field Life Cycle

The principal steps in the E&P process are shown in Figure 2.12, alternatively referred to as the field life cycle or stage-gate process. Interaction with the industry suggests that the field life cycle stages vary from company to company, but the general principles employed remain constant. This section will describe the stage-gate process of executing and operating an offshore E&P project. The stage-gate process referred to in ISO 29010 will be used for this study. Onshore production principles provide a basis for offshore production. Due to the many similarities between onshore and offshore practices, the field life cycle described in this section refers to both onshore and offshore projects, however, major differences between onshore and offshore projects will be highlighted. The descriptions of each phase of the field life cycle is developed from the comparison of various peer-reviewed articles such as those of Shukla and Karki (2016*b*), Borthwick *et al.* (1997) and Jahn *et al.* (2008).

2.2.4.1 Conceptualization

The first step is to identify opportunities or regions of interest which involves evaluating the technical, political, economic, social and environmental aspects of regions under consideration (Jahn *et al.*, 2008). Technical and environmental aspects include reviewing geographical maps to identify major sedimentary basins and to determine the potential amount of hydrocarbons to be found (Borthwick *et al.*, 1997). Concepts are developed for exploration and production.

2.2.4.2 Definition

The definition stage involves concept selection by evaluating and comparing suboptions. A major part of concept evaluation involves performing commercial risk analyses. The technical definition of the selected options are then

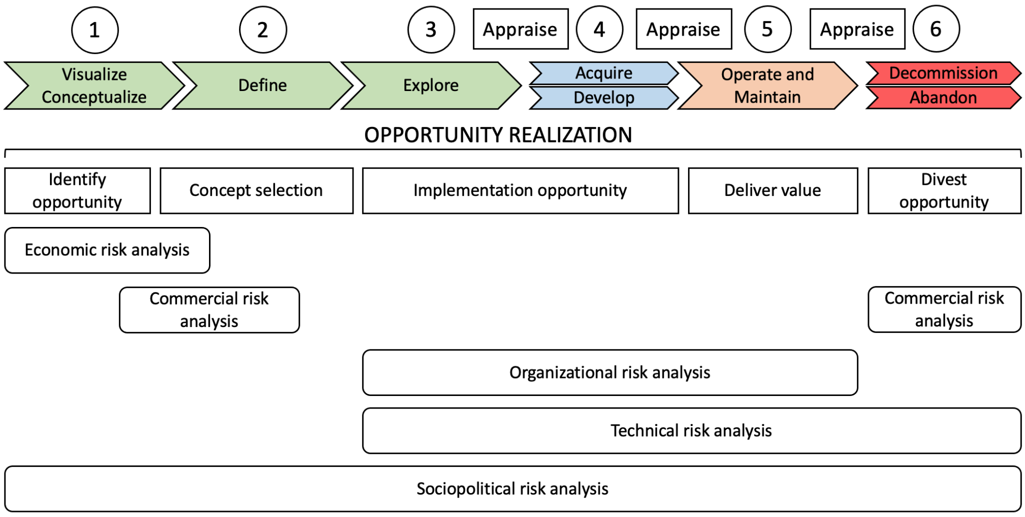

Figure 2.12: Upstream field life cycle, adapted from ISO (2016).

improved through identifying and clearly defining the detailed requirments of the project.

2.2.4.3 Exploration

The exploration process for onshore and offshore oil and natural gas are similar. Exploration activities are carried out to locate hydrocarbon-bearing rock formations. Once regions of interest are identified, aerial surveys and geophysical surveys are generally conducted to create a picture of the various rock layers underneath the surface or seabed, and to identify promising landscape formations such as faults and anticlines. Geophysical surveying methods respond to variations in physical properties of the earth's subsurface such as rocks, fluids and voids (Jahn *et al.*, 2008). These methods include magnetic surveys, gravity surveys and seismic surveys, which is the most common assessment method and is often the first field activity performed (Borthwick *et al.*, 1997). Seismic surveys develop an acoustic image of geological structures below the earth's surface (Shukla and Karki, 2016*b*). The data obtained from the seismic survey is used to identify geological structures that may contain hydrocarbons. If the data shows that formations containing oil and gas exist, exploratory drilling locations are determined. Before commencing with exploratory drilling, the O&G company will conduct environmental and social impact assessments to understand and evaluate the environmental and social implications of drilling operations (Western Sahara Oil, 2020). Exploratory wells are then drilled to confirm the presence of hydrocarbons and the thickness and internal pressure of the reservoir (Borthwick *et al.*, 1997).

Drilling offshore wells requires a modified drilling procedure when compared with onshore drilling. Offshore wells are drilled by lowering a drill string (consisting of a drill bit, drill collar, and drill pipe) through a conduit (riser) that extends from the drilling rig to the sea floor (Speight, 2014). Mobile exploratory drilling rigs, or drill ships, are used to drill wells to determine the presence or absence (dry hole) of oil and natural gas at the predetermined offshore location. To drill a well, a surface hole is drilled a few hundred meters into the seafloor, depending on the depth of the hydrocarbon bearing formation. A continuous steel pipe, referred to as a casing, is lowered into the hole and cemented into place. A Blowout Preventer (BOP), which allows the well to be sealed off, is installed at the well origin to prevent water or hydrocarbons from escaping into the surrounding environment in the unlikely event of an emergency. The next section of the well is drilled by lowering the drill string through the BOP into the well origin. Once a section is completed, the drill string is removed and all the sections are joined, lowered into the well and cemented into place (Atlantic Canada Offshore, 2020). Once the final depth is reached, the well is completed to allow oil and natural gas to flow into the casing and up to the production platform. If economically feasible quantities are present, the well is plugged until a permanent production platform is installed (Speight, 2014).

It is common for a company to work on a prospective location for several years before the first exploratory well is drilled. If the exploratory well has successfully confirmed the presence of hydrocarbons, a wellhead valve assembly may be installed, otherwise the well is sealed off and the site is decommissioned to a safe and stable condition (Borthwick *et al.*, 1997).

Appraisal

Once an exploratory well has confirmed the presence of hydrocarbons, more effort is required to determine the size, quality and extent of the discovered hydrocarbon reservoir (Shukla and Karki, 2016*b*). This phase is necessary to obtain data needed for technical and economic feasibility decisions. This entails drilling additional appraisal wells at predetermined locations to collect more data. Up to this point the data acquired has not been sufficient to create a precise image of the size, shape and extractability of the hydrocarbon-containing structure.

The goal of appraisal is to reduce the uncertainties in the description of the hydrocarbon reserve, particularly relating to producible volumes. This will provide crucial, cost-effective information by means of which a decision can subsequently be made: to either continue on to execution and development, or to stop activities and sell the discovery. Seismic surveys may once again be conducted in addition to other activities carried out in the exploration phase (Borthwick *et al.*, 1997). The information provided by the appraisal stage should generate greater value than the cost of the appraisal activities, thus appraisal should be cost-effective. The information provided by appraisal activities includes estimates for Stock-Tank Oil Initially In Place (STOIIP), Gas Initially In Place (GIIP) and Ultimate Recovery (UR) (Jahn *et al.*, 2008). These are measures E&P companies will use to evaluate the feasibility of a reservoir. Appraisal can be performed at various stages in the asset's field life cycle, as can be seen from Figure 2.12.

2.2.4.4 Development and execution

Production well development and construction of the required infrastructure for final production commences once the project is deemed to be safe and economically feasible as output of the appraisal stage. First, the Field Development Plan (FDP) is formulated. The goal of the FDP is to provide the conceptual project specifications for surface and subsurface facilities (Jahn *et al.*, 2008), as well as serving as the project proposal, including operation maintenance principles. The FDP should provide management and stakeholders with the confidence that all aspects of the production project have been identified and successfully planned for. The FDP should generally contain, but is not limited to, aspects such as objectives of the development, petroleum engineering data, operating and maintenance principles, description of engineering facilities, cost and labour estimates, project planning, summary of project economics, and project budget (Jahn *et al.*, 2008).

Once the FDP has been approved by management and stakeholders, there is a series of actions that are performed to enable production, including the following activities: (Jahn *et al.*, 2008; Atlantic Canada Offshore, 2020)

- Detailed design of facilities;
- Procurement of construction materials;
- Construction and installation of facility infrastructure and equipment required for extraction, storage and transportation of oil and natural gas; and
- Commissioning of the production plant and equipment.

Oil and natural gas may be extracted from small reservoirs using one or more of the appraisal wells. Larger reservoirs require drilling of additional production wells (Borthwick *et al.*, 1997). The process of drilling production wells is similar to drilling exploratory wells.

2.2.4.5 Operation

Once all facilities are installed, the development team, or project team, hands over to operations. The operation phase of the field life cycle involves extraction and production of oil and natural gas from subsurface reservoirs. At this point, the production of crude oil and natural gas begins. This phase is the transition point where revenues are being generated, in contrast to previous phases requiring only significant capital expenditures (Jahn *et al.*, 2008). Operations deals with the day-to-day running of the production facilities and equipment, ensuring that production commences as planned. This includes monitoring equipment status, performing preventative maintenance on equipment and facilities, and any other tasks which allow efficient and effective extraction of hydrocarbons.

Most new oil and gas wells are initially free-flowing (i.e. underground pressures force the oil and gas up through the well to the surface). However, when this is not possible, some form of artificial lift is required, such as pumping mechanisms and/or injection of water or gas through additional wells called injection wells to maintain reservoir pressures (Borthwick *et al.*, 1997). In order to increase production rate and the ultimate recovery yield, water and gas are injected at the start of the field's life. Once the hydrocarbon fluids reach the surface, the water, oil and gas must be separated before being transported and moving on to the midstream segment. The oil must be free of dissolved gas, the gas must be stabilized and free of liquids and other components such as CO_2 and H_2S. The extracted water is treated before being disposed of.

2.2.4.6 Decommissioning

Production installations are decommissioned at the end of their commercial life, which is usually between 20–40 years. Production decreases after passing the peak of maximum production, and after a while production levels make it economically infeasible to continue operations. Thus, once this point is reached where production levels are no longer feasible, or decommissioning is required due to unforeseen circumstances, operations are stopped and the production site is decommissioned. All infrastructure is removed. For offshore production, platforms are either disassembled at site, or towed or shipped back to the coast. The wells are plugged and abandoned and any debris is removed. Lastly, test trawling is carried out to verify that the area is free of any potential obstacles and/or hazards (Atlantic Canada Offshore, 2020).

Decommissioning generally involves the following: (Shukla and Karki, 2016*b*)

- Removal of buildings, equipment and other infrastructure;
- Restoration of the site to environmentally acceptable conditions;
- Site revegetation and implementation of supporting measures; and
- Continued monitoring of site after closure.

2.3 Dynamics of the Oil and Gas Industry

The dynamics of the oil and gas industry refer to factors that greatly influence the industry. This section will discuss oil and gas prices, supply and demand, exogenous shocks, the cost of producing a barrel of oil, and how these factors affect the O&G industry.

2.3.1 Oil and Gas Prices

Oil and gas prices have a strong tendency to fluctuate greatly. In the last decade, crude oil prices were subject to strong upward trends and crash-like downward spirals with high volatility, driven by global and supply changes, economic crises, and military and political conflicts (Klein, 2018). According to the U.S. Energy Information Administration (2020*b*) the prices of oil and gas are mainly affected by supply and demand, economic growth/decline, and geopolitical and economic events.

Different oil varieties have different benchmark prices, however they all seem to follow a similar fluctuating pattern. For the purpose of this study West Texas Intermediate crude oil (WTI), Brent crude oil and Henry Hub natural gas (HH) prices are observed. WTI crude oil is sourced from U.S. oil fields and serves as a benchmark for U.S. oil prices, while Brent crude oil originates from oil fields in the North Sea and serves as the international benchmark for oil prices. The oil and gas prices at the time of writing this paragraph (24 December 2020) are shown in Table 2.1. The price of crude oil is expressed in U.S. dollars ($) per barrel of oil (Bbl), and natural gas is expressed in U.S. dollars per million British Thermal Units (BTU).

	Price
WTI crude oil ($\$/Bbl$)	48.23
Brent crude oil ($\$/Bbl$)	51.29
HH natural gas ($\$/$Mil. BTU)	2.52

Table 2.1: Oil and gas prices Mathur (2020)

Figure 2.13 depicts the 10-year price histories of WTI crude oil, Brent crude oil and natural gas.

The WTI crude oil, Brent crude oil and natural gas prices were $35.79, $37.46 and $3.35 respectively less than two months earlier on 30 October 2020. It can be seen from Figure 2.14 that WTI crude and Brent crude prices follow the same fluctuating pattern. However, the price of crude oil went up, while the price of natural gas decreased during this two-month period. In theory,

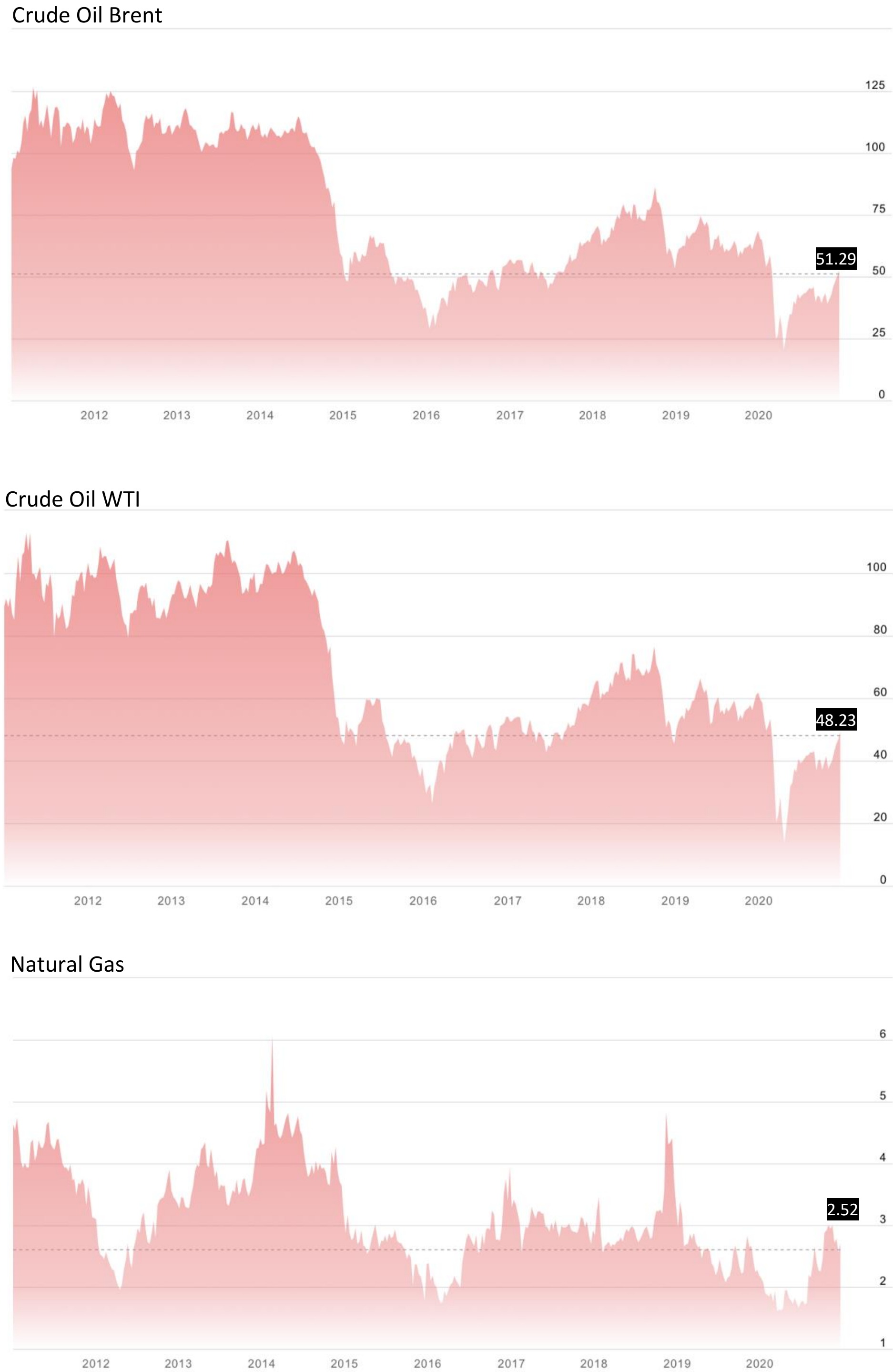

Figure 2.13: Historical 10-year prices of crude oil (Brent) (Nasdaq, 2020*a*), crude oil (WTI) (Nasdaq, 2020*b*) and natural gas (Nasdaq, 2020*c*)

crude oil and natural gas prices should be related since they are substitutes in consumption, and both complements and competitors in production. However, in the past there have been periods where the crude oil and natural gas prices moved independently of one another. Oil prices have been found to influence the long-term prices of natural gas, but the opposite is not found (Villar and Joutz, 2006). The scale and speed of development and exploitation of oil and gas discoveries in deep water depends on sustainable contemporary international oil price levels (Speight, 2014). An increase in the price volatility is likely to increase the cash flow volatility of oil and gas E&P projects, making it more difficult to fund these projects (Choi and Kim, 2018).

2.3.2 Supply and Demand

Supply and demand are an interdependent system and one of the fundamental principles of economics. As with any product, supply and demand of petroleum greatly influences the price of oil and natural gas. Oversupply puts negative pressure on prices, while price increases are observed during periods of high demand and limited supply. The supply of oil and natural gas can be classified as originating either from OPEC, a group of the most powerful oil exporting countries, or non-OPEC countries. This is important considering the different influences these two groups have on oil prices. The Organization of the Petroleum Exporting Countries (OPEC) is an intergovernmental organization whose stated objective is to "coordinate and unify the petroleum policies of member countries and ensure the stabilization of oil markets in order to secure an efficient, economic and regular supply of petroleum to consumers, a steady income to producers and a fair return on capital for those investing in the petroleum industry" (Organization of the Petroleum Exporting Countries, 2020). The current sixteen OPEC member countries include much of the Middle East, South America, Africa and others, Saudi Arabia being the largest producer of oil and natural gas. These countries produce roughly 40% of global supply, while OPEC's oil exports account for approximately 60% of total petroleum traded annually (U.S. Energy Information Administration, 2020*b*). Due to this high market share, OPEC's actions have great influence on international oil prices. Historically, crude oil prices have increased in times when OPEC production targets were reduced. Lack of production cuts and oversupply by OPEC nations, despite the steady increase in non-OPEC production, has been cited as one of the main reasons behind a near 60% drop in the price of Brent crude oil between June 2014 and January 2015 (Khan, 2017).

In contrast to OPEC production, which is subject to central coordination and mostly controlled by National Oil Companies (NOCs), non-OPEC producers make independent decisions regarding oil production while most production activities are performed by International or Investor-owned Oil

Companies (IOCs) (U.S. Energy Information Administration, 2020*a*). Production from non-OPEC countries currently represents approximately 60% of global oil supply. Key locations of non-OPEC oil production include North America, regions of the former Soviet Union, and the North Sea. Non-OPEC production generally occurs in areas that have high finding and production costs, as most of the lower-cost conventional oil resources are located in OPEC member countries. As a result non-OPEC producers are leading the way in unconventional methods such as hydraulic fracturing, oil sands and deep water offshore. While increases in non-OPEC supply contribute to lower oil prices, disruptions to non-OPEC production reduce global oil supply and can result in higher oil prices. These unplanned disruptions to production can persist for long periods of time creating uncertainty which further adds to price volatility (U.S. Energy Information Administration, 2020*a*).

Similar to global supply categorized according to originating from countries belonging to two different groups, the consumption of oil (demand) can be separated according to countries belonging to OECD and non-OECD countries. The Organization for Economic Co-operation and Development (OECD) is an organization that works with governments, policymakers and citizens on establishing evidence-based international standards as well as finding solutions to a range of social, economic and environmental challenges (Organization for Economic Cooperation and Development, 2020). OECD members include countries with some of the most developed economies. Global energy demand is on the rise due to growing populations and GDP increase in developing nations (non-OECD). It is expected that some of the oil and gas demand will shift from OECD member countries to developing nations, while other renewable energies are expected to take some of the market share of oil and gas in OECD countries (Amundrud, 2017).

2.3.3 Exogenous Shocks

Exogenous shocks are defined as events that move market prices and cannot be explained by economics. These are typically sudden and unpredictable occurrences such as natural events, geopolitical events, terrorist activity, etc. These occurances have great influence on oil and gas prices and contribute significantly towards the price fluctuations.

2.3.4 Cost of Producing a Barrel of Oil

The profitability of any E&P major capital project depends on the cost of producing a barrel of oil. The profitability of a project is the most critical factor that drives investment decisions (Arabi *et al.*, 2016). In 2014, when the crude oil prices were above $100, the profits of oil and gas companies were great, providing substantial ROI. However, current prices barely cover the cost of extracting the oil from the ground in areas such as the U.K. Figure 2.12 represents the cost of producing a barrel of oil (which is approximately 159 liters or 42 U.S. gallons) for some of the major oil-producing countries. The Rystad Energy UCube (2016), which is a database that provides a consistent and integrated micro and macro reconciliation of all historic and future E&P activity, establishes the Total Cost (TC) of production as the sum of the following main components, namely; capital investment, production costs, admin/transport costs and oil taxes as shown in Formula 2.1. The capital investment, otherwise referred to as Capital Expenditure (CAPEX), refers to major purchases or acquisitions which will be used in the future (i.e. development/acquisition of production facilities and equipment, and acquisition of land). The other three components can be classified as Operating Expenditure (OPEX) which represents day-to-day costs involved in operations, such as labour costs, supplies and maintenance (Maverick, 2020).

$$\begin{aligned} TC &= CAPEX + OPEX \\ &= Capital\ investments \\ &+ (Production\ costs + Admin/Transport\ costs + Gross\ taxes) \end{aligned} \tag{2.1}$$

The cost of producing a barrel of oil, or Unit Technical Cost (UTC) is shown in Formula 2.2, and consists of the total cost divided by the total number of barrels of oil which can be technically recovered, from now on referred to as the ‘reserve’.

$$UTC = \frac{(CAPEX + OPEX)}{Reserve} \tag{2.2}$$

Ogolo (2020) has argued that the current UTC is not accurate as it does not factor in government deductions before calculating the taxable income. Thus, a modified UTC is proposed by Ogolo as shown in Formula 2.3. The Modified Unit Technical Cost (MUTC) subtracts royalty oil and bonus oil from the reserve before taxable income is calculated.

$$MUTC = \frac{(CAPEX + OPEX)}{(Reserve - Royalty\ Oil - Bonus\ Oil)} \tag{2.3}$$

It can be seen from Figure 2.14 that when the oil price is low, countries with the least expensive oil production will have a greater competitive advantage over other nations. When the oil price is high, they will be more similar (Amundrud, 2017). This difference in UTC is due to several factors, such

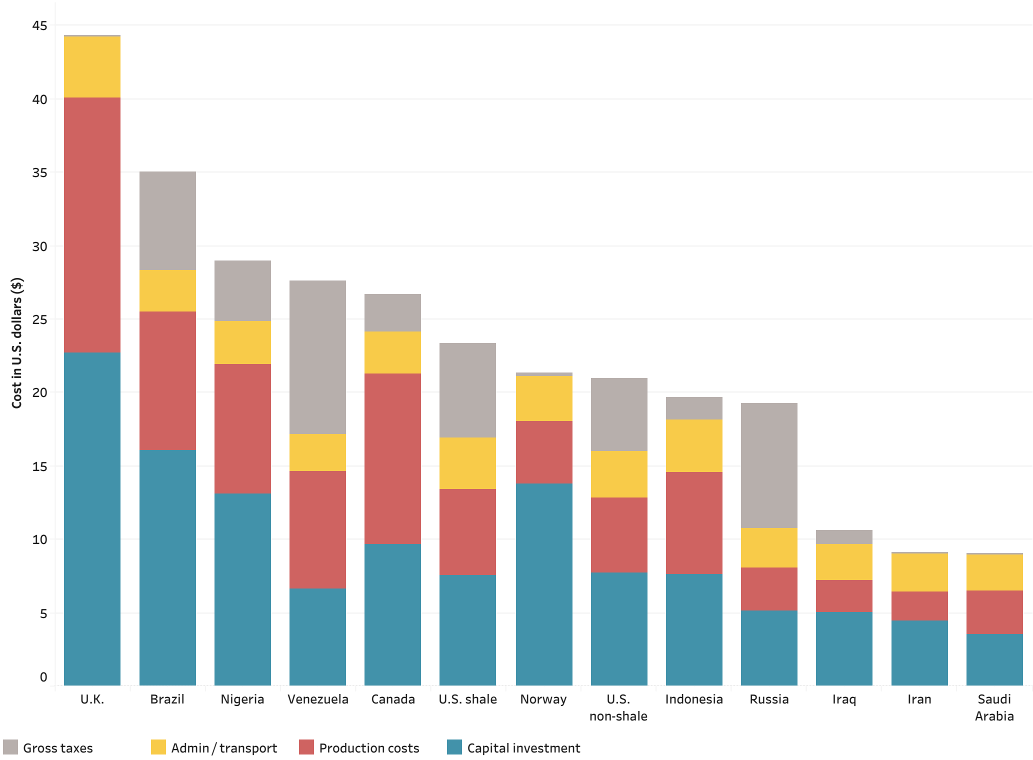

Figure 2.14: Cost of producing a barrel of oil, based on data from March 2016 (Rystad Energy UCube, 2016)

as the production method and infrastructure used and geographical location which impacts transport requirements. In countries where the UTC is low, such as Saudi Arabia, Iran and Iraq, the oil production is mostly onshore in oil fields near the surface of the desert or shallow offshore, allowing lower production costs. In countries where the UTC is high, such as the U.K., oil fields are mostly located offshore which requires complex and expensive extraction methods (Rystad Energy UCube, 2016). This difference in oil price flexibility among countries and regions has strong implications for competition between oil and gas exporters (Amundrud, 2017).

The Unit Technical Cost is important since it is used in the oil and gas industry as a benchmark to determine profitability of any E&P project (Ogolo, 2020). The opportunities for increasing value and profitability lie in reducing production costs, both CAPEX and OPEX, to increase the margin between the current oil price and the cost to produce the oil. An extensive peer-reviewed literature search has shown that digitalization has great potential in reducing costs for offshore oil and gas production (World Economic Forum, 2017; Grange *et al.*, 2018; Sylthe *et al.*, 2018; Devold *et al.*, 2017; Yoder *et al.*, 2019). Digital capabilities can greatly reduce the operational expenditures, especially in countries such as Canada and the U.K. where production costs account for 43.3% and 39.2% of the UTC respectively.

2.4 Chapter Conclusion

Chapter 2 is an extensive literature review of the fundamentals of the upstream oil and gas industry. The first three research objectives established in Chapter 1, are addressed in this chapter. A general understanding of the oil and gas industry value chain is established by briefly discussing each of the three oil and gas segments. The upstream segment is the focus area of this study; accordingly, it is discussed in detail. Onshore and offshore infrastructure, capital projects and asset life cycles are discussed. These three topics are identified as the most relevant points of discussion to explain the upstream segment of the oil and gas industry. Dynamics of the oil and gas industry and the impacts of these on the industry are discussed. Chapter 2 provides the necessary context on the oil and gas industry to aid in the development and understanding of the Digital Transformation Roadmap (DTR) which is presented in Chapter 5.

Chapter 3

Overview of Digital Transformation

Many industries are entering the fourth industrial revolution (Industry 4.0) through digital transformation, which is revolutionizing the way they operate and changing how business is conducted in industrial value-chains (Parida *et al.*, 2019). The rapid pace of technological innovation, together with the proliferation of digital tools is forcing organizations to fundamentally change the way they do business and restructure to survive in a digital world. Digital transformation (DT) has been described as one of the major trends changing society and business in the short- and long-term future (Tihinen and Kaariainen, 2016). This section does not provide a digital transformation roadmap for the upstream O&G industry; however, this section together with Chapter 4 will provide the necessary knowledge to develop a digital transformation approach which is specifically tailored to the upstream segment. This section provides a general overview of digital transformation which includes: (1) definition of the term *digital transformation*, (2) drivers and objectives, (3) building blocks, (4) implementation activities and approaches, (5) success factors, (6) implications, and (7) implementation of new technology.

3.1 Defining Digital Transformation

As part of defining digital transformation, it is important to distinguish between the term *digital transformation* and related concepts – *digitization*, *digitalization* and *digital innovation*. These terms are often confused and used interchangeably, especially the terms *digital transformation* and *digitalization*. The term *digitization* refers to the encoding of analogue information into digital format so that computers can store, process and transmit such information (Dougherty and Dunne, 2012; Loebbecke and Picot, 2015; Yoo *et al.*, 2010). Examples concern the replacement of paper and other conventional, manual

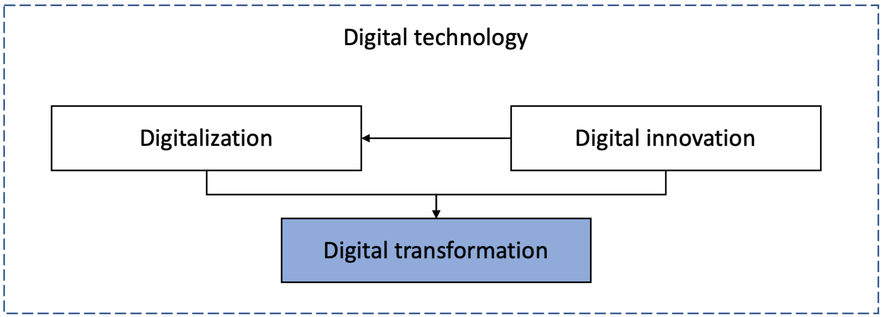

Figure 3.1: Conceptual model of digital transformation and related concepts, adapted from Osmundsen *et al.* (2018)

processes with software which allows more efficient data collection and an improved work process.

A great proportion of literature uses the terms *digital transformation* and *digitalization* interchangeably, and although these terms are closely related there are differences between them. *Digitalization* describes how IT and digital technologies (e.g. AI, cloud, big data, robotics, etc.) can be used to alter existing business processes (Li *et al.*, 2016). It is about leveraging digital technology to alter sociotechnical structures (Osmundsen *et al.*, 2018). According to Brennen and Kreiss (2014), digitalization refers to "the adoption or increase in use of digital or computer technology by an organization, industry, country, etc." Similarly, Gartner (2020*c*) defines digitalization as "leveraging digital technologies to change business models and provide new revenue and value-producing opportunities; it is the process of moving to a digital business." However, Iansiti and Lakhani (2014), Kane *et al.* (2015) and Pagani and Pardo (2017) argue that the definition given by Gartner refers to digital transformation, which highlights the confusion between these two terms in literature. They describe *digital transformation* as the most pervasive phase encompassing a company-wide transformation that leads to the development of new business models. In other words, digital transformation involves implementing digital capabilities to support the transformation of business models which impacts entire organizations, especially operational processes, resources, internal and external users (Henriette *et al.*, 2015). *Digital innovation* is about combining digital technology in new ways or with physical components that enable sociotechnical changes and create new value for adopters (Osmundsen *et al.*, 2018).

These concepts are all closely related (see Figure 3.1). First, these concepts build on digital technology. Secondly, the outcome of digital innovation can lead to digitalization through individuals' adoption of the innovation process. Lastly, digitalization and digital innovation can enable major changes in how business in conducted, leading to digital transformation of organizations or entire industries (Osmundsen *et al.*, 2018). In addition, Verhoef *et al.* (2021) suggest that there are three phases of digital transformation, namely (1) digitization, (2) digitalization, and ultimately (3) digital transformation. Referring back to Figure 3.1, digitization would be the step before digitalization – being placed on top of digitalization in the figure.

Following the explanation on the differences between digital transformation and related concepts, a formal definition of digital transformation can now be formulated. This is done by evaluating and comparing formal definitions found in literature and then constructing a definition from that. Table 3.1 shows formal definitions of digital transformation found in literature.

Table 3.1: Literature definitions of digital transformation

Author(s)	**Definition**
Mazzone (2014)	Digital transformation is the deliberate and ongoing digital evolution of a company, business model, idea process, or methodology, both strategically and tactically.
Osmundsen *et al.* (2018)	When digitalization or digital innovation over time is applied to enable major changes to how business is conducted, leading to a significant transformation of an organization or an entire industry.
Zaoui and Souissi (2020)	A new development model that calls for redefining relationships between companies, their stakeholders, and clients and reviewing previous approaches to offering services and products as companies undergo multidimensional transformation.
Vial (2019)	A process that aims to improve an entity by triggering significant changes to its properties through combinations of information, computing, communication, and connectivity technologies.
Verhoef *et al.* (2021)	A change in how a firm employs digital technologies, to develop a new digital business model that helps to create and appropriate more value for the firm.

Table 3.1: Literature definitions of digital transformation

Author(s)	**Definition**
Mergel *et al.* (2019)	Digital transformation is a holistic effort to revise core processes and services of government beyond the traditional digitization efforts. It evolves along a continuum of transition from analogue to digital to a full stack review of policies, current processes, and user needs and results in a complete revision of the existing and the creation of new digital services.
Schwertner (2017)	Digital (business) transformation is the application of technology to build new business models, processes, software and systems that result in more profitable revenues, greater competitive advantage, and higher efficiency. It is the integration of new digital technologies into all business areas, leading to a fundamental change in the way the organization works.
Kiron *et al.* (2016)	Digital transformation comprises not only the use of digital technologies (e.g. advanced analytics, machine learning, AI applications, the IoT), but also the changes of the key business elements, including strategy, business model, business processes, organizational structures and organizational culture.
Kotarba (2018)	The modification (or adaptation) of business models, resulting from the dynamic pace of technological progress and innovation that trigger changes in consumer and social behaviours.
Bowersox *et al.* (2005)	Digital (business) transformation is a process of reinventing a business to digitize operations and formulate extended supply chain relationships.

Based on the definitions in literature, the following definition of digital transformation is formulated and proposed for this research:

> *Digital transformation is a managed holistic process of change which an organization or industry undergoes in order to create and appropriate more value and to adapt to the requirements of the emerging digital world. It encompasses the application and integration of new digital technologies, as well as changes to key busi-*

ness elements such as the revision of core processes and policies, redefinition of relationships, modification (or adaptation) of business models, and changes to organizational strategy, structure and culture – leading to fundamental changes in how an organization functions.

3.2 Drivers and Objectives

The drivers and objectives refer to the attributes and goals that initiate and influence digital transformation (Morakanyane *et al.*, 2017). Berghaus and Back (2017) examined the motivations behind organizations' digital transformation initiatives, and found many common drivers and objectives irrespective of industry and company size.

3.2.1 Drivers

Digital transformation is found to often be initiated by changing digital customer behaviours and expectations (Haffke *et al.*, 2017; Schmidt *et al.*, 2017; Verhoef *et al.*, 2021), digital technology, digital shifts in the industry, changing competitive landscape and regulatory changes (Berghaus and Back, 2017). Digital competition with an expanding range of rivals and new market entrants (including non-industry entrants) are posing significant challenges and risk to organizations (Verhoef *et al.*, 2021). It is also important to emphasize that digital transformation should not be pursued just because everyone is doing it. Digital transformation should be pursued to solve a business problem, adapt the company/industry position in a competitive environment, generate value, foster collaboration and to drive innovation. The need for digital transformation is also largely found to be driven by limiting existing infrastructure, which in this case refers to limiting IT infrastructure and capabilities (Berghaus and Back, 2017). Despite the different factors driving digital transformation in different contexts, ignoring the call to action and neglecting digital transformation could increase the risk of becoming obsolete in highly competitive markets.

3.2.2 Objectives

According to Berghaus and Back (2017), one of the main objectives of digital transformation is related to organizations wanting to ensure digital readiness – being alert to changing conditions and being able to react quickly when necessary. Other objectives include digitally enhancing products (Mocker and Fonstad, 2017), embracing product innovation Berghaus and Back (2017), improving digital channels, and "exploring and developing new, potentially disruptive, business models in order to stay competitive and generate new revenue" Berghaus and Back (2017).

3.3 Building Blocks

The building blocks of digital transformation refer to essential organizational elements for accomplishing digital transformation. Research has shown that technology itself is only part of the complex transformation process required for organizations to remain competitive in a digital world. Culture, people, strategy, capabilities and alignment are some of the other elements which are essential for successful digital transformation. Digital transformation is a complex process involving all aspects of a business. There is much debate in literature regarding the classification of elements and the business aspects affected by digital transformation.

There are many sources in literature referring to the building blocks of digital transformation; however, Vial (2019) provides the best understanding of the building blocks in accordance with the definition of digital transformation formulated in Section 3.1. He proposes several building blocks of digital transformation (see Figure 3.2). First, *digital technologies* play a central role in the creation, as well as the reinforcement, of *disruptions* taking place at societal and industrial levels. These disruptions trigger *strategic responses* on the part of organizations, which occupy a central place in digital transformation literature. Organizations use digital technologies to alter the *value creation paths* they have previously relied upon to remain competitive. To that end, they must implement *structural changes* and overcome *barriers* that hinder their efforts at transformation. These changes lead to *positive impacts* for organizations, although they can also be associated with *undesirable outcomes* (Vial, 2019).

3.3.1 Digital Technologies

Digital technologies refer to technologies such as artificial intelligence, big data and advanced analytics, cloud and the Internet of Things. Some digital technologies relevant to upstream O&G are described in Section 3.7. Organizations rely on digital technologies to generate, capture, store, analyse and share data, as well as altering value creation paths.

3.3.2 Data

For any organization to remain competitive, it needs the ability to make accurate and timely decisions. Poor quality data resulting in wrong decisions can have severe safety and environmental implications, such as the BP Deepwater

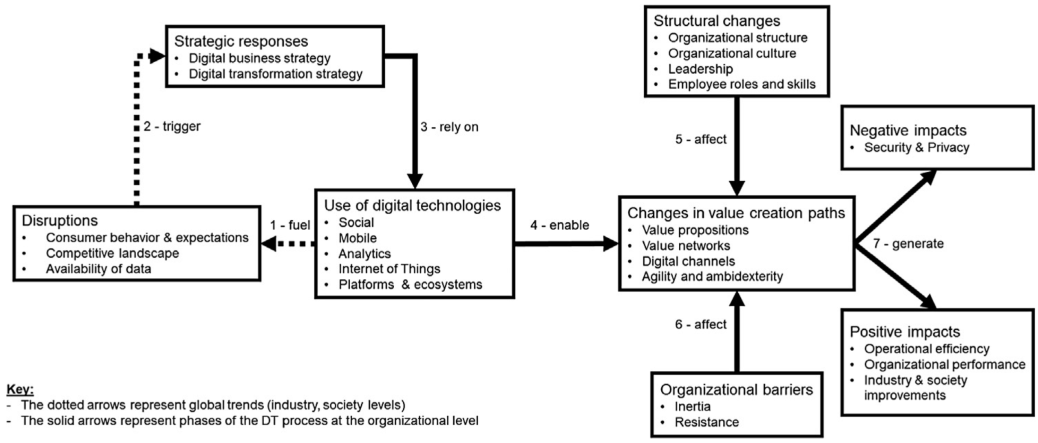

Figure 3.2: Building blocks of digital transformation Vial (2019)

Horizon incident in 2010. Given the volatility of today's economy and the uncertainties of the future, most major O&G companies seek to optimize and balance their business models in the most effective manner, either by reducing the required investment for E&P of new oil or maximizing production through a tailored Well, Reservoir and Facilities Management (WRFM) plan. All these efforts to increase the bottom line and deliver business value can only happen when decisions are based on quality data. For data to be qualified as being of good quality, it must conform to some essential characteristics; namely, it must be accurate, complete, consistent and timely. The heavy dependence on quality data will increase as companies proceed along their digital transformation journeys, thus generating, capturing, analyzing and distributing quality data should become a core capability for companies to realize the full potential of digital transformation.

3.3.3 Disruptions

Digital transformation can be a radical and disruptive process, affecting many aspects of organizations, such as strategy and business models, products and services, work processes, organizational structure and culture, and the implementation of new technologies and information technology (IT) (Parviainen *et al.*, 2017). The term *disruption* is mostly used to "describe the ground-breaking impact of innovations as opposed to sustaining and incremental changes, in order to highlight the urgency of taking action" (Berghaus and Back, 2017). Digital technologies disrupt the competitive landscape by bringing about radical change to the markets where organizations operate. As stated earlier, digital technologies increase the availability of data which is another source of disruption (Vial, 2019).

3.3.4 Strategic Responses

Considering the disruptive nature of digital transformation, it triggers organizations to find ways to respond to the disruptions and remain competitive as digital technologies provide both ground-breaking opportunities and threats to them (Sebastian *et al.*, 2020). The general term *strategy* is often called on to explain and address these responses; however, two concepts are found in literature on digital transformation strategies, namely Digital Business Strategy (DBS) and Digital Transformation and Sustainability (DTS). Bharadwaj *et al.* (2013) define DBS as an "organizational strategy formulated and executed by leveraging digital resources to create differential value." On the other hand, Matt *et al.* (2015) describe the role of DTS as to "focus on the transformation of products, processes and organizational aspects owing to new technologies."

3.3.5 Value Creation Process

The disruptive innovations brought about by digital technologies have the potential to significantly alter existing value propositions, enable the redefinition of value networks, allow changes to distribution and sales channels, and help firms to rapidly adapt to changes in environmental conditions by contributing to organizational agility (Vial, 2019).

3.3.6 Structural Changes

Structural changes, which include changes to elements such as organization structure, organizational culture, leadership and employees, will affect the value creation process mentioned above.

An organization as a whole must adopt a supportive and agile culture in which business and IT initiatives can thrive (Haffke *et al.*, 2017). Openness to change, customer-centricity, innovativeness, willingness to learn, tolerance of failure, risk affinity, an entrepreneurial mindset, trust, participation, cooperation, and communication are important organizational values (Hartl and Hess, 2017). An organization that values openness to change fosters a willingness to accept, implement, promote, and establish a change-orientated mindset, which is crucial for successful digital transformation (Hartl and Hess, 2017). Thus, an organizational culture striving towards agility, rather than control, is better equipped to support digital transformation. It becomes evident from literature that organizational culture and effective change management are absolutely essential to the success of a digital transformation, and should receive the same level of attention as technology and IT.

When it comes to leadership, much literature points to the introduction of a new role, that of the Chief Digital Officer (CDO) to lead the digital transformation. The CDO is a "business executive responsible for creating and executing strategies for digital solutions across their enterprise." The CDO is responsible for coordinating and managing an organization's digital transformation while working closely with the CEO. If a CDO is appointed, this role is dependent on building and achieving sufficient influence in the organization to pursue the intended transformational activities and achieve responses (Horlacher *et al.*, 2016). Strong leadership abilities are an essential skill for achieving a successful digital transformation. In the process of coordinating the transformation process, managing and guiding employees through this process is of the highest importance, since the success of digital transformation depends on the overall transformation of an organization, including all the employees.

Employees play a crucial role in the digital transformation process, and should be incorporated in all aspects of the transformation. Education and training programs for employees will assist in altering employees' mindset towards disruption and provide the required skills to effectively incorporate the changes associated with digital transformation into their everyday work processes.

3.3.7 Barriers

Barriers will also affect the value creation process. Vial (2019) refers to two major barriers to digital transformation, namely inertia and resistance to change. Inertia refers to existing resources and capabilities which can act as barriers to disruption. In this sense, the existing resources, infrastructure and capabilities can impose restrictive and path dependent constraints on the innovation process. The other barrier relates to the resistance to change employees and management can have to the introduction of disruptive technologies in the organization. Changing organizational culture and fostering an continuous learning mindset is crucial to overcoming this obstacle.

In addition to the two barriers mentioned by Vial (2019), many other barriers to digital transformation have been mentioned in literature. In a 2015 study, Kane *et al.* (2015) identified frequently occurring barriers to digital transformation which could be grouped according to the companies' digital maturity stages (see Table 3.2).

	Early	**Developing**	**Maturing**
1	Lack of strategy	Too many priorities	Too many priorities
2	Too many priorities	Lack of strategy	Security concerns
3	Lack of management understanding	Insufficient tech skills	Insufficient tech skills

Table 3.2: Top barriers by digital maturity stage, adapted from Kane *et al.* (2015)

3.4 Implementation

This section aims to discuss implementation activities and approaches of digital transformation found in literature. This is by no means an exhaustive list as each organization or industry will be dependent on its unique contextual requirements. As stated previously, this section does not provide an implementation approach for the upstream O&G industry, however it provides the knowledge base of activities and approaches found in literature on digital transformation.

3.4.1 Initiation

Evidence from literature shows that managers often struggle to understand the impacts of digital transformation, and how to initiate their own organizational digital transformation process (Berghaus and Back, 2017). Digital transformation is initiated by different factors and drivers depending on the organizational context and industry (refer to Section 3.2). Since digital transformation represents an organizational innovation process, the initial phase of digital transformation is a phase of experimenting, assessing opportunities, and collaborating to define the direction, actors, and approach before the start of a digital transformation program (Berghaus and Back, 2017). This phase is often referred to as the "fuzzy front end" of digital transformation since the outcome of any innovation process is usually not yet clear at the beginning stages (Rhea, 2003).

Previous research conducted by Bharadwaj *et al.* (2013) and Hess *et al.* (2016) has concluded that organizations need to approach their digital transformations by designing and developing a digital transformation strategy. Berghaus and Back (2017) support the research on digital strategy, however they argue that due to the ill-defined nature of the initial stages of digital transformation, the formulation of a holistic strategy is not always a suitable first step. Rather, they suggest broadening the scope from just a digital strategy to a system of activities to be undertaken during the initial stages of digital transformation. These activities have no particular order and are subject to the contextual situation of the organization or industry being digitally transformed: (1) Define processes and IT-infrastructure, (2) adapt work processes, (3) create innovative digital business models, (4) develop digital strategies, (5) align transformation initiatives, (6) define governance, (7) change organizational culture, and (8) strengthen collaboration.

Despite the fact that there are contradictions in literature regarding the prioritization of activities at the beginning of digital transformation, creating innovative digital business models and digital strategy formulation are often listed in digital transformation literature, which emphasises their importance. For this reason business models and digital strategies are discussed next. In addition, many of the activities listed in the previous paragraph are addressed in the business model discussed in the next section.

3.4.2 Creating Innovative Digital Business Models

The notion of a business model has been used to refer to “the logic of an organization, the way it operates and how it creates value for its stakeholders" (Casadesus-Masanell and Ricart, 2010). Alex Osterwalder, a Swiss business theorist, created the ‘business model canvas’ (see Figure 3.3) as a strategic management template for developing new business models and documenting existing ones. The business model canvas describes the nine basic dimensions of a business model. These are the *customer segments*, the *value proposition* for each segment, the *channels* to reach customers, *customer relationships* which are established, the *revenue streams* which are generated, *key resources* and *key activities* required to create value, *key partners* and the *cost structure* of the business model (Osterwalder and Pigneur, 2010).

As described in the definition in Section 3.1, digital transformation encompasses the adaptation of existing business models or the creation of new innovative digital business models to create and appropriate more value. In the O&G industry, this can include companies transitioning from being oil and gas companies to being integrated energy companies. Thus, business model innovation is a crucial part of digital transformation. In order to adapt the business model, each of the nine business model dimensions needs to be re-examined and/or redefined. Schallmo and Williams (2016) developed a roadmap for the digital transformation of business models as shown in Figure 3.4. The roadmap is broken down into five phases as shown:

(1) **Digital reality** – The organization’s existing business model is sketched

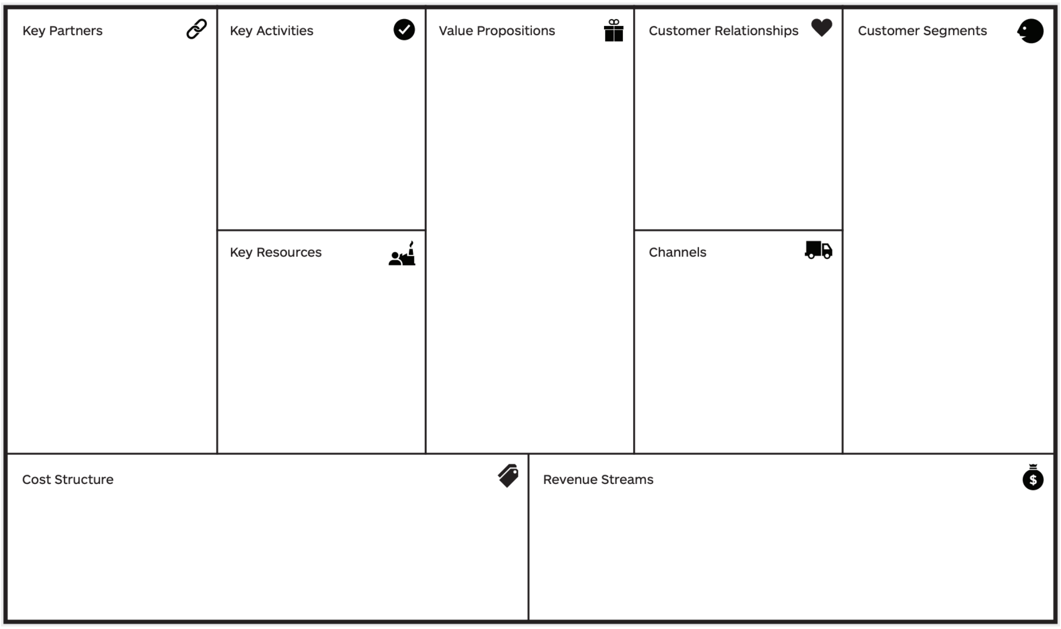

Figure 3.3: The Business Model Canvas (Osterwalder and Pigneur, 2010)

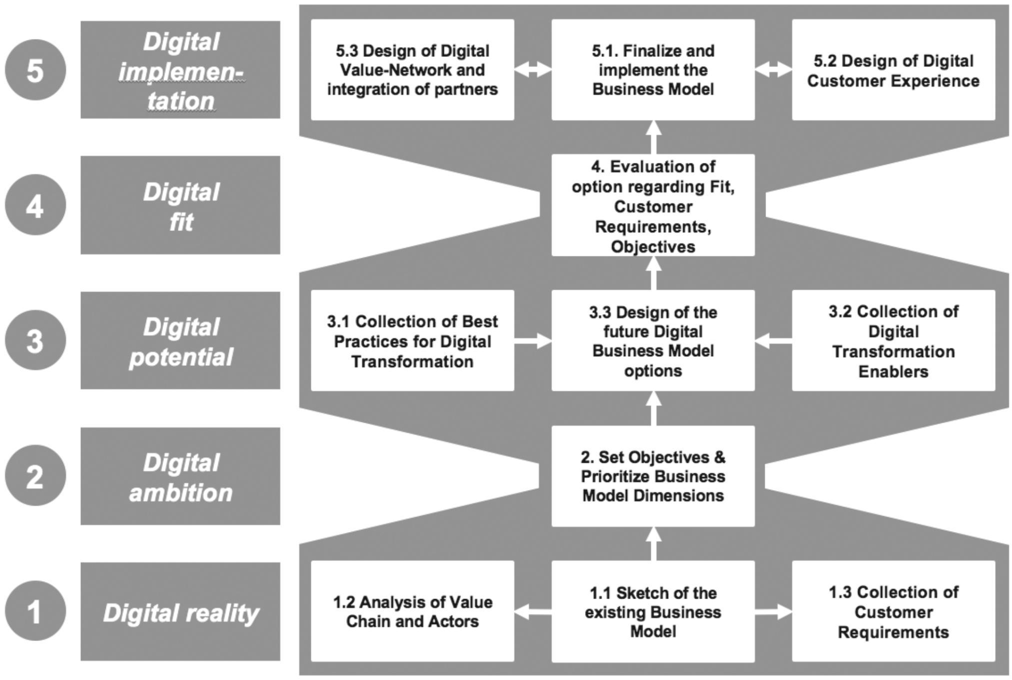

Figure 3.4: Roadmap for digital transformation of business models Schallmo and Williams (2016)

along with a value-added analysis related to stakeholders and a survey of customer requirements. This provides an understanding of the digital reality of the organization in different areas.

(2) **Digital ambition** – Based on the organization's digital reality, objectives of digital transformation are defined. These objectives include factors such as time, finances, space and quality. During the second phase it is determined which objectives should be considered for the business model and its elements. The objectives and business model dimensions are then prioritised.

(3) **Digital potential** – The best practices and enablers for digital transformation are established. This serves as a starting point in terms of the digital potential and the design of a future digital business model. Different options are derived for each business model element and combined logically.

(4) **Digital fit** – Evaluates options for the design of the digital business model, which are then compared with the existing business model to determine the digital fit. This ensures that business objectives are accomplished and that customer requirements are fulfilled.

(5) **Digital implementation** – The finalization and implementation of the digital business model. The various combinations of options are further evaluated within a digital implementation framework. This phase also includes the design of a digital customer experience and value-chain network that describe integration with partners. Resources and capabilities are also identified in this phase.

Business models often generate virtuous cycles; feedback loops that strengthen the dimensions of the model in every iteration. Thus, the virtuous cycles associated with business model innovation contribute to the iterative nature of digital transformation. Business models are often confused with business stra-tegy, and thus digital business models can be confused with digital strategy. Digital strategies are discussed next to separate the two notions and to explain the importance of formulating a digital strategy in order to digitally transform.

3.4.3 Digital Strategies

Developing a proper strategy for effectively leveraging digital technologies is crucial for the success of digital transformation projects. A major output of the strategy formulation process is the definition of strategic goals.

Strategy is often defined as a "contingent plan of action designed to achieve a particular goal", or in respect to business models, strategy refers to the contingent plan as to what business model to use (Casadesus-Masanell and

Ricart, 2010). Defined in the digital strategy is a plan of action as to how to transform the business model by implementing changes to the business model's dimensions, and managing and integrating those changes. Therefore, a business model is the direct result of strategy, but it is not the strategy itself.

Formulating digital strategies is crucial to undergoing a digital transformation, because they "reflect the pervasiveness of changes induced by digital technologies throughout an organization" and "they focus on measures to govern an organization's journey to achieve the desired future state of being digitally transformed" (Chanias and Hess, 2016). Business models are reflections of the realized strategy (Casadesus-Masanell and Ricart, 2010).

As mentioned earlier, digital strategies can refer to DBS and DTS. According to Osmundsen *et al.* (2018), an organization must align transformational changes with its strategy in order to achieve a successful digital transformation. They have found that several organizations have acknowledged the need for a fusion of the Information Systems (IS) strategy and business strategy to form a Digital Business Strategy (DBS). A DBS can guide an organization in transforming and accomplishing the predetermined objectives of digital transformation, by emphasizing emerging digital innovations, digital leadership abilities, digitally enabled customer experiences, and agile and scalable digital operations (Leischnig *et al.*, 2017). As organizations move toward a DBS, it is essential to develop resource configurations which are better aligned to the DBS, since misalignment between the emergent strategy and resources can result in internal tensions (Yeow *et al.*, 2018).

The Digital Transformation Strategy (DTS) serves as a central framework to integrate the entire coordination, prioritization and implementation of digital transformation (Matt *et al.*, 2015). While the DBS often describes the desired future states for organizations that are partially or fully based upon digital technologies, it does usually not include transformational activities and insights as to how to reach those desired future states (Matt *et al.*, 2015). In contrast to the DBS, the DTS serves as a "blueprint that supports companies in governing the transformation that arise owing to the integration of digital technologies, as well as in their operations after a transformation" (Matt *et al.*, 2015). In other words, the DBS states the desired future outcomes as to how digital technologies can be used to create and appropriate value, while the DTS guides the transformation to reach that desired future outcome.

3.5 Success Factors

Similar to the building blocks of digital transformation, the success factors refer to approaches and elements which have been observed to have a deep impact on the successful digital transformation of organizations. Included in this section are approaches and elements found in literature which are not directly related to the building blocks discussed in Section 3.3, but which, together with these building blocks, contribute towards successful digital transformation.

3.5.1 Leadership

Leadership is generally accepted as one of the most critical factors for a digital transformation (Andersson *et al.*, 2018). Effective leadership is crucial to coordinate the digital transformation activities and drive innovation.

3.5.2 Dynamic capabilities

Digital transformation is a disruptive process, which describes the radical impact of digital innovations, as opposed to sustaining and incremental changes. In a study on the digital disruption in the newspaper industry, Karimi and Walter (2015) found that organizations need to develop dynamic capabilities in order to respond to such disruptions. Dynamic capabilities allow an organization to identify and respond to opportunities by transforming the organization, reconfiguring resources, and building digital platform capabilities, and thus respond to industry changes and digital disruption (Karimi and Walter, 2015; Leischnig *et al.*, 2017). Leischnig *et al.* (2017) further points to the importance of market intelligence capabilities in order to foresee environmental changes, identify opportunities and threats, and react to them appropriately.

3.5.3 Transformation Activities

Berghaus and Back (2017) identified transformation activities that organizations typically engage in before, or during, digital transformation. Research shows that there is no generic approach to digital transformation, rather the situational context of an organization determines the appropriate approach. One activity which attracted a lot of attention in case studies was improving an organization's digital channels – in doing so, moving towards a multi-/omni-channel strategy for reaching customers (Berghaus and Back, 2017). In addition, organizations were also found to engage in innovation activities and the development of digital strategies. These activities often involve designated teams in collaboration with external partners. Lastly, change management presents a crucial aspect for successful digital transformation. As stated earlier, digital transformation is a disruptive process as it encompasses a complete restructuring of many business dimensions, which is going to affect how companies and its employees operate. Effective change management can mitigate the disruption, ensure complete adaptation and integration, and manage the transition towards a digital enterprise.

3.5.4 Knowledge

Research has shown the importance of leveraging internal and external knowledge for digital transformation. Hildebrandt *et al.* (2015) found that organizations which are engaging in Merger and Acquisitions (M&A) with digital technology companies became better prepared for digitally transforming their business through acquiring, integrating and commercializing complementary and varying knowledge of digital technologies. Other studies show that collaborating with start-ups to develop more agile project methodologies and implement start-up mentalities can reduce resistance to innovation (Bilgeri *et al.*, 2017; Piccinini *et al.*, 2015). On the other hand, internal knowledge is also found to be essential for digital transformation. Apart from identifying and implementing innovative digital technologies, digital transformation also depends on helping employees to leverage these technologies to be more innovative in their work and become digital transformers themselves (Mueller and Renken, 2017). Mueller and Renken (2017) made four recommendations to ensure that digital technologies are leveraged in people's work and contribute to digital transformation:

(1) Organizations should establish a hybrid project structure (combination of formal and agile methodologies), which emphasizes roles from Information Systems (IS) functions and non-IS functions to ensure that technology reaches employees;
(2) Build collectives for transformation success – providing specific and localized input for requirements and for customizing communication;
(3) Ensure effective communication with employees to teach them about the technology and how they can leverage it;
(4) Foster an organizational culture that supports transformation.

3.5.5 IS Capability

Information Systems (IS) capability refers to an organization's ability to deploy IS-based resources in combination with other resources (Osmundsen *et al.*, 2018). Nwankpa and Roumani (2016) found that IS capability positively influences digital transformation. They also found that firms with superior IS capabilities are better equipped to undergo digital transformation by redesigning and reimagining existing business processes, and transforming traditional offerings into digital offerings.

3.6 Implications

Implications refer to the effects organizations experience as a result of digital transformation (Morakanyane *et al.*, 2017).

3.6.1 Reformed IS Organization

As stated in Section 3.5.4, digital transformation has led many organizations to appoint a new executive role, a CDO, for managing digital activities and overseeing the establishment of digital capabilities in the organization (Haffke *et al.*, 2016). However, this was found to be subject to factors such as company size, digital maturity, degree of fragmentation, organizational culture, and level of cross-industry collaboration. IS is becoming increasingly interconnected with business through digital transformation, which signifies the importance of a tighter alignment between the CDO (business side) and the Chief Information Officer (CIO) through a mutual understanding of the roles and responsibilities of the two positions (Haffke *et al.*, 2016). It was also found that digital transformation, with or without the introduction of a CDO role, has significant implications for the CIO. With the introduction of a CDO, they can enhance the CIO's role in the organization, or while taking over some responsibilities of the CIO, lead to tensions between the CDO and the CIO. Even without the introduction of a CDO, the CIO usually takes on some of the typical CDO responsibilities such as identifying opportunities and threats, increasing executives' digital literacy, coordinating internal digital initiatives, and setting up digital innovation units (Haffke *et al.*, 2016).

3.6.2 New Business Models

As mentioned before, digital transformation has implications for an organization's business model. Digital transformation leads to the adaptation of existing business models or the creation of completely new business models. This is one of the intended outcomes of digital transformation; to create and appropriate more value.

3.6.3 Effects on Outcome and Performance

Digital transformation may have direct and/or indirect implications for an organizations' outcome and performance (Osmundsen *et al.*, 2018). Nwankpa and Roumani (2016) collected data from U.S. CIOs and found that digital transformation positively influences an organization's degree of innovation and organizational performance, which was measured against direct competitors in the areas of (1) profitability, (2) customer retention, (3) ROI, and (4) sales growth. They further suggested that as digital transformation of an organization evolves, the organization is able to achieve reduced costs (through collaboration and integration efforts), increased customization and customer satisfaction. Organizations that have undergone a digital transformation are more digitally mature and better suited to take advantage of new digital technologies, and leverage them to enhance organizational performance (Nwankpa and Roumani, 2016). In addition, digital transformation enables organizations to nurture their digital strategies leading to process improvements and modularization, and introduce new practices and innovative initiatives in their organizations (Nwankpa and Roumani, 2016). Thus, organizations which have undergone digital transformation are inherently also more innovative.

3.7 Implementation of New Digital Technology

The implementation of new digital technology plays a major role in digital transformation. Reviewing literature on digital transformation has identified different technologies that are frequently referred to for reshaping industries across the globe.

- Artificial Intelligence (AI)
- Augmented Reality (AR) and Virtual Reality (VR)
- Big data analytics
- Blockchain
- Cloud
- Custom manufacturing and 3D printing
- Digital Twins
- Industrial Internet of Things (IIoT) and Connected Devices
- Robots and Unmanned Aerial Vehicles (UAVs)

As stated in the definition of digital transformation, ultimately it involves the implementation and complete integration of digital technologies to alter work processes to become more effective and efficient. Thus, technology, the data it generates and consumes, and the individuals utilizing the technologies are crucial components in the digital transformation process. Initially, much of the literature on digital transformation focussed on technology alone, however, as the study proceeded it became evident that technology and culture should be treated with the same level of importance. The benefits that digital technologies provide can only be fully exploited if the organizational culture fosters complete technological integration and utilization of by all employees.

The list of identified technologies is not an exhaustive list for implementation in the upstream oil and gas industry. These technologies have shown great potential in other industries, even in the upstream O&G industry already, and the possibilities these technologies can enable are constantly increasing. For the purpose of this dissertation, literature on specific technologies is reviewed in Appendix A.

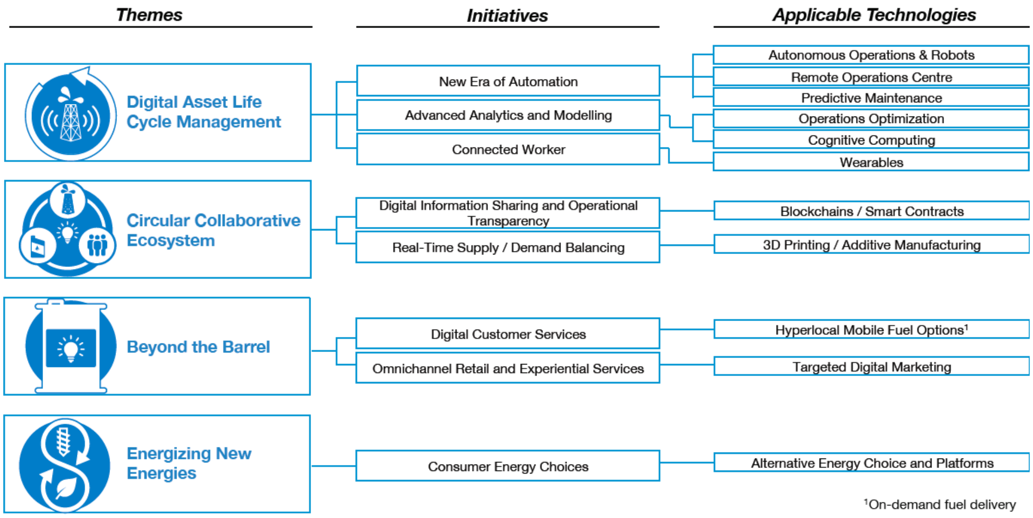

Figure 3.5: Digital transformation initiatives (World Economic Forum, 2017).

3.8 Digital Transformation Initiative of the Oil and Gas Industry

According to the World Economic Forum's (WEF) Digital Transformation Initiative, there are four central themes to the digital transformation of the oil and gas industry (see Figure 3.5), namely digital asset life cycle management, circular collaboration ecosystems, innovative customer engagement models (beyond the barrel customer services), and understanding the impact of new energy sources (energizing new energies) (World Economic Forum, 2017).

In contrast to past digital transformation efforts in industries with evolutionary, incremental performance improvements by selectively implementing digital technologies, the World Economic Forum (2017) argues that digital transformation may be more beneficial if a revolutionary agenda is pursued with digital at the core.

Other current trends and technologies which have been identified to be influencing the industry are as follows:

- **Virtualizing the ecosystem** – Create digital twins of offshore assets to increase structural integrity and prototype new and lean structural designs.
- **Enabling cross-functional workflows** – Enable cross-functional, cross-disciplinary workflows to connect traditionally siloed processes and provide an integration view of an asset throughout its lifecycle.
- **Integrating operations data** – Combine data from different sources in one unified view. Establish a control tower to serve as a central database

throughout the life cycle of an asset.

- **Robotizing and automating equipment and platforms** – Improve the safety of operations by automating and robotizing dangerous and complex tasks on assets.
- **Constructing complex parts** – 3D printing technology and other additive manufacturing methods allow more complex part geometries as well as reduced lead times on spare parts through implementation of such capabilities on assets.
- **Energizing new energies** – Broaden the business scope by developing new business models and value propositions (developing new products and forms of harnessing new energies) to transition from an O&G company to integrated energy company (World Economic Forum, 2017).
- **Fostering collaborative ecosystem** – Build data-sharing capabilities and integration throughout industry to enable a collaborative innovation ecosystem in which the industry as a whole can progress through faster innovation cycles (World Economic Forum, 2017).

3.9 Chapter Conclusion

Chapter 3 discusses the fundamentals of digital transformation as identified from literature. The fourth, fifth and sixth research objectives are addressed in this chapter. A definition of digital transformation is formulated and proposed for the study. The following elements of digital transformation are discussed: drivers and objectives, building blocks or elements, implementation components, success factors and implications of digital transformation. The implementation of technology and the World Economic Forum's (WEF) digital transformation initiative of the oil and gas industry conclude the chapter. Chapter 3 provides valuable context on digital transformation, which is crucial towards gaining a thorough understanding of the term, as well as aid in the development of the DTR in Chapter 5.

Chapter 4

Learning from Other Industries

The O&G industry can learn from the experience of digital transformation initiatives in other industries. This chapter studies the procedures employed in other industries on their digital transformation journeys. Through the analysis of literature on industries and companies that digitally transformed their business – trends and similarities in elements, business dimensions, barriers to adoption and implementation procedures are identified which can be applied to aid in the implementation of a digital transformation strategy in the O&G industry.

General overviews of digital transformation initiatives and current observed trends in the banking, automotive, chemical and mining industries are discussed in Section 4.1. The digital transformation of these industries are analysed and procedural trends and common elements identified in Section 4.2. Although the nature of these industries differ greatly, it is the purpose of this chapter to determine whether the process of digital transformation has components in common irrespective of the industry being digitalized. Establishing similarities in digital transformation practices among industries in different sectors can provide a basis for developing an effective digital transformation strategy and implementation roadmap for the upstream offshore O&G industry. Additional case studies are included in Section 4.3 to compare the observed trends and similarities to company-specific digital transformation initiatives. The three companies included in the case studies are ABB, CNH Industrial, and Vodafone.

It is the purpose of this chapter to identify commonalities in the digitalization approach employed in these industries and to assess the relevance of approaches followed to those which can be applied in the oil and gas industry. This chapter forms a basis for the implementation roadmap to be developed for upstream oil and gas.

4.1 Overview of Digital Transformation in Other Industries

The banking, automotive, chemical, and mining industries have been chosen for the analysis due to the differences that exist between them. These industries differ in terms of product and/or service offerings, technology, business sector and business structure. There have been numerous advances, successes and failures in digital transformation of these industries, which results in lessons having been learnt. The banking industry is amongst the most digitalized industries. It is second only to the telecommunications sector in terms of its digital maturity (Schepinin and Bataev, 2019). The automotive industry is well suited for analysis since it finds itself in the process of a digital transformation and faces huge opportunities and risks owing to digitalization, with various industry-specific trends such as electric mobility, multichannel sales, car connectivity and autonomous driving (Chanias and Hess, 2016). Finally the chemical industry and mining industry are investigated so as to include examples of processing industries (similar to O&G industry) in the investigation.

This section provides an overview of digital transformation in the identified industries. There is a general lack of detail in literature regarding specific digital transformation implementation procedures within industries, including the industries discussed in this chapter. This shortage in public knowledge can most probably be attributed to the need to keep implementation procedures confidential in order to retain competitive advantage. In addition, digital transformation is still an ongoing process in the majority, if not all, of the industries. Thus, in order to obtain valuable insights from this analysis, the common elements and enablers of digital transformation and barriers to it are identified across multiple industries.

4.1.1 Banking Industry

The digital transformation in banking is progressing at an ever-increasing pace (Diener and Špaček, 2021). This transformation looks at ways to ease the management of funds, increase customer experience and remain competitive in an industry under threat by financial technology companies (FinTech). For this analysis, a qualitative literature search was conducted and 13 sources were deemed relevant for this analysis of digital transformation in the banking sector. Of these 13 sources, 8 are peer-reviewed articles while the other 5 are online sources from the WEF, Accenture, Deloitte, Forbes and Deutsche Bank. Figure 4.1 shows the frequency of keywords observed throughout this literature analysis.

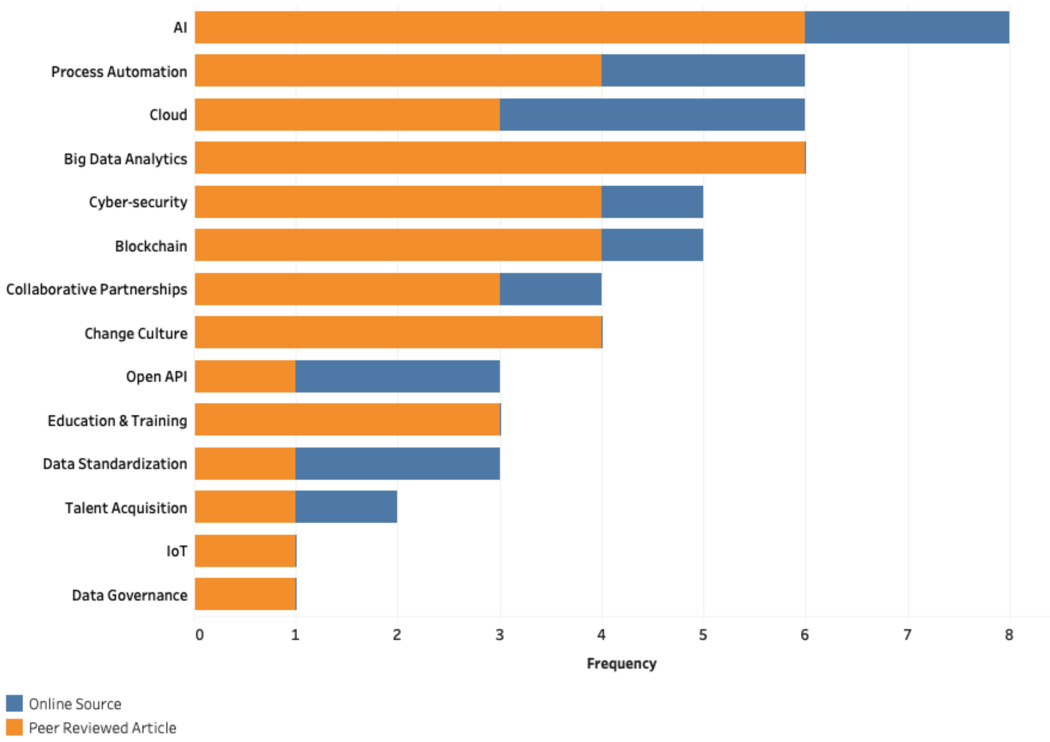

Figure 4.1: Keywords obtained from literature search on Digital Transformation in the Banking Industry

4.1.1.1 Trends, elements and business dimensions

Common advantages of digital transformation in banking include increased productivity, reduced costs and improved interaction with both customers and employees. Findings by Diener and Špaček (2021) reveal that elements of strategy, management, technology, regulation, customers and employees receive a high level of attention within digital transformation. The digital transformation in banking is driven by technological advancements, new digital trends, new business models, and changes in expectations from customers (Schmidt *et al.*, 2017; Khanboubi *et al.*, 2019). It is also found that companies achieved sustainability during the transformation processes when effectively mastering customers, data processing and innovation. The transformation affects many dimensions, including strategic direction, competitiveness, business model, decision-making, innovation, entrepreneurship, productivity, and customers. It was mentioned previously that there are many elements involved in digital transformation, however, up to this point how these elements and process changes are implemented remains unclear.

Data standardization is a crucial building block of digital transformation. The standardization of data adds consistency and quality to the data. Data governance is related to the aggregate data obtained from traditional banking

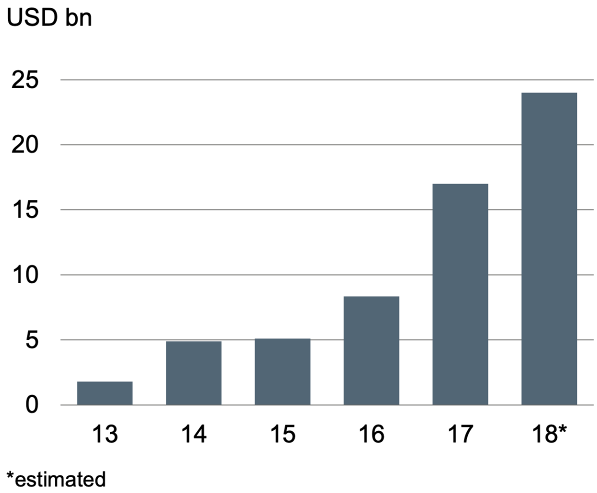

Figure 4.2: Growth in venture capital investments in AI start-ups globally from 2013 to 2018 (Kaya *et al.*, 2019)

systems and the need for more granular data.

Artificial Intelligence (AI) is definitely the most widely discussed topic of digital transformation in banking. The popularity of AI in general has increased significantly over the past several years (see Figure 4.2). However, to date, AI implementation in banking has been modest. In their quest to become more efficient, banks mostly seem to be exploring AI applications to automate activities and processes which are costly, laborious and repetitive (Kaya *et al.*, 2019). It is also used to improve scoring, make automated and customized product proposals or to provide advisory services.

Other new technological advances such as cloud, blockchain big data analytics, biometric technology and their use in cybersecurity, blockchain and IoT, are prevalent topics found in literature. However, it is mostly found that the way these technologies are implemented and utilized in this case are predominantly specifically suited to the banking industry.

It is emphasised that the integration of employees into the thinking process of change is fundamental and that this should be secured and promoted by the necessary freedom of thought and continuous exchange between employees and management. It is essential that employees are informed regarding technological applications and know how to apply them properly and safely. Specific education and training programs and events for customers and employees are being introduced in banks to facilitate the implementation of digital approaches and ultimately, enable digital transformation, as well as to enhance the acceptance and integration of employees and customers.

The most advanced financial institutions in the digital transformation process try to make large technology investments profitable by pursuing digital strategies that imply profound organizational change (Cuesta *et al.*, 2015). A recurring theme observed in literature is organizational culture. The respective corporate "change culture" is crucial, as employees also have to be prepared to be led by specialists and managers and should not be completely opposed to new methods and change. Only companies with a high innovation affinity and a culture which embraces change can actively undergo digital transformation (Schepinin and Bataev, 2019; Diener and Špaček, 2021). Top management has to show a real risk tolerance regarding innovation. Communicating change is the only way that you can manage resistance to change. One way to accelerate this culture shift is to establish collaborative partnerships with technology start-ups backed up by investment or even acquisition by the financial industry. Apart from receiving first-hand familiarity with the most innovative ideas, these small enterprises are a source of new skills and talent required for digital transformation (Cuesta *et al.*, 2015). It has also been proposed to flatten the hierarchical organizational structure.

It has been common for banks to establish digital transformation units, and create and appoint a Chief Digital Officer (CDO) to head the digital transformation and align the top management strategy with the overall organizational activities.

4.1.1.2 Implementation procedures

Cuesta *et al.* (2015) identified three successive stages in a bank's digital transformation process: (1) developing new channels and products, (2) adaptation of technological infrastructure, and (3) achieving strategic positioning in the digital environment through far-reaching changes in the organization.

In the first phase banks react to changes in supply and demand for financial services by developing new digital channels and products with which to position themselves in the new competitive market. The new channels are mainly focused on mobile devices while the digital products are focused on retail payments (Cuesta *et al.*, 2015).

The second phase involves carrying out a redesign of the technology platform, to convert it into a more modular and flexible infrastructure which enables new technologies to be integrated, as well as quicker product development. It is during this phase where technology is integrated and processes are automated to replace manual and repetitive tasks (Cuesta *et al.*, 2015).

The final phase involves pursuing digital strategies that imply far-reaching organizational changes. It is during this phase that banks establish metrics to quantify the effect of digital investments, build loyalty and marketing products, implement a shift in corporate culture, and establish collaborative partnerships and acquisitions (Cuesta *et al.*, 2015).

4.1.1.3 Barriers and challenges

The barriers and challenges to digital transformation in the banking industry that have been referred to in literature are presented below (Diener and Špaček, 2021; Abbot, 2021):

- Implementation and maintenance costs;
- Lack of knowledge and skills;
- Lack of sense of urgency;
- Ambiguity of modern banking;
- Lack of qualified consultants;
- Lack of motivation and professional advice;
- Conflicting guidance;
- Outcome uncertainty;
- Inconsistent support;
- Security and compliance risks;
- Misalignment between IT and business;
- Regulation and government;
- Customer demand;
- Level of competition; and
- Resistance to change.

4.1.2 Automotive Industry

For this analysis, a qualitative literature search was conducted and eleven sources were deemed relevant for the analysis of digital transformation in the banking sector. Of these eleven sources, seven are peer reviewed articles while the other four are online sources from the WEF, IBM, McKinsey, and Kearney (an Indian management consultancy firm). Figure 4.3 shows the frequency of keywords observed throughout this literature analysis.

4.1.2.1 Trends, elements and business dimensions

Digital technologies are transforming the automotive industry and disrupting traditional business models by delivering opportunities for new services (Riasanow *et al.*, 2017). Recent digital initiatives like autonomous driving, connectivity and big data are revolutionizing the industry, forcing companies to adjust their business models and change their organizations to deal with the disruptive nature of these digital initiatives. Automotive companies with a cohesive strategy for integrating digital and physical elements have been able to transform their business models successfully. According to IBM (2011), successful companies move forward by focusing on two strategies: reshaping

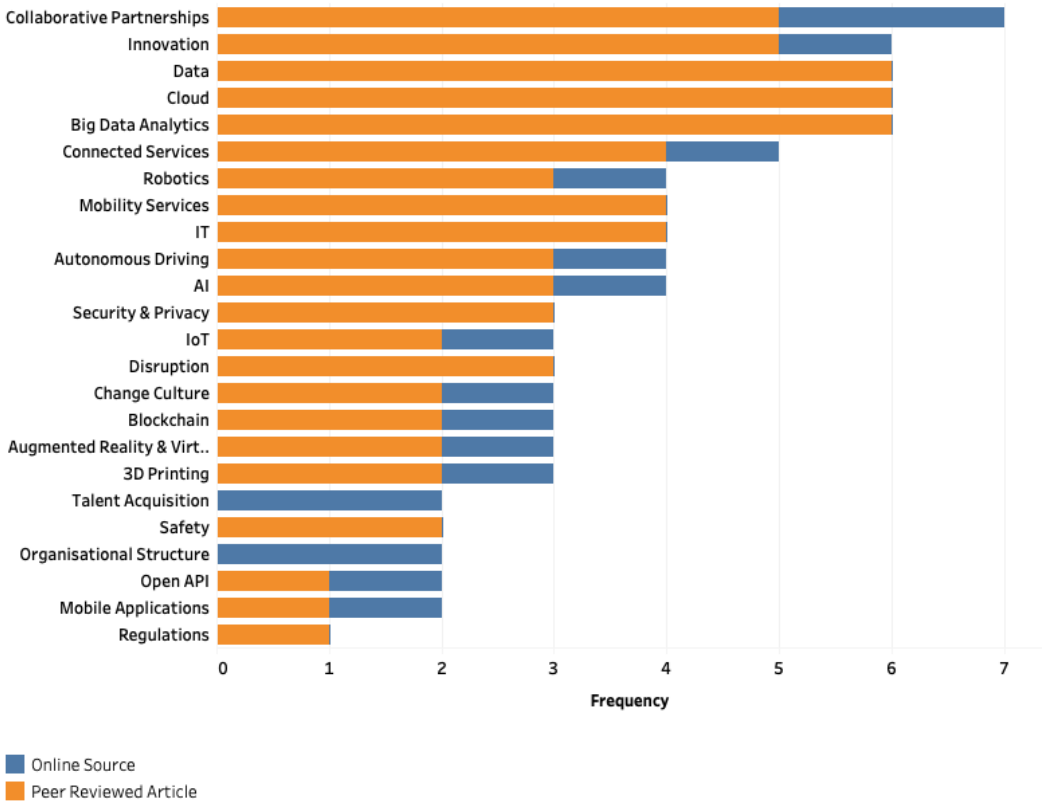

Figure 4.3: Keywords obtained from literature search on Digital Transformation in Automotive Industry

the customer value proposition and reshaping the operating model (see Figure 4.4).

Similar to observations in the banking industry, significant emphasis is placed on the digital strategy, alternatively referred to as the 'digital transformation strategy'. In most cases organizational sub-communities and departments started their own digital transformation initiatives prior to the company-wide digital transformation strategy initiated by top management.

Original Equipment Manufacturers (OEM) of passenger vehicles in particular are increasingly transforming their business models from a business-to-business (B2B) focus based on a multistage distribution model, which depends on independent dealerships, to a business-to-customer (B2C) focus through the use of digital technologies (Chanias and Hess, 2016). This is done in an effort to compete with new market entrants, which provide customer-centric mobility for customers. Thus, customer-centricity – placing the customer at the center of all activities – has become a prevalent topic among companies within the automotive industry.

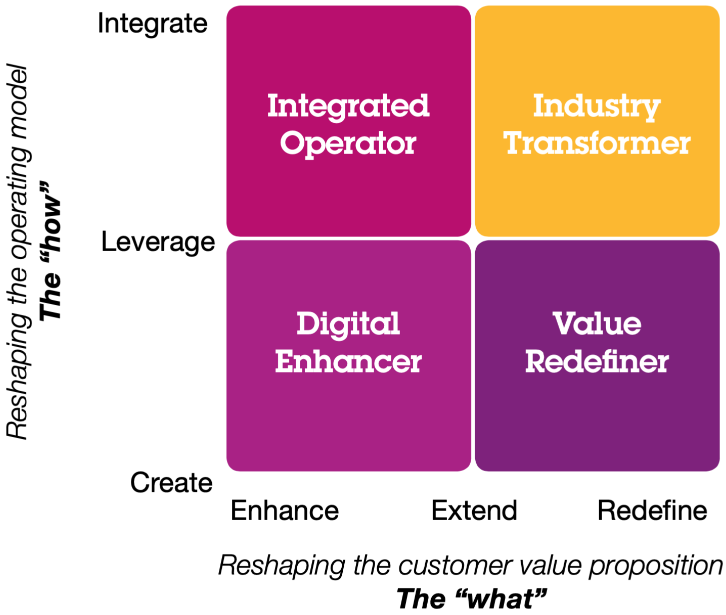

Figure 4.4: Digital transformation framework (IBM, 2011)

The establishment of dedicated and cross-functional digital transformation units to drive the digital transformation and mediate the involvement and strategy of top management throughout the organization has been found to confirm and emphasise the trend observed in the banking industry.

The use of new technologies such as AI, cloud, big data analytics, robotics, IoT, blockchain, AR & VR, and 3D printing are discussed in literature concerning the automotive industry, with similar utilization to that discussed in Section 3.5. However, the procedure followed for implementing these new technologies could not be found in literature. The frequency with which these new technological advancements are listed in literature emphasises their importance in the digital transformation of the automotive industry.

Hildebrandt *et al.* (2015) found that digital technology-related mergers and acquisitions have a positive impact on digital business model innovations. It allows OEMs to acquire external knowledge and capture the potential of digital innovations (Henfridsson and Lind, 2014). Openness towards external market players and knowledge will support digital innovations, increasing business performance and resulting in better user experience (Keller and Hüsig, 2009). In addition, organizations must collaborate with partners, suppliers and customers, including with external market players such as telecommunications, software providers and electronic manufacturers (IBM, 2011). Elevating alliance management as a critical organizational competency may be required to effectively manage new partnerships and extensions of the value chain (IBM, 2011).

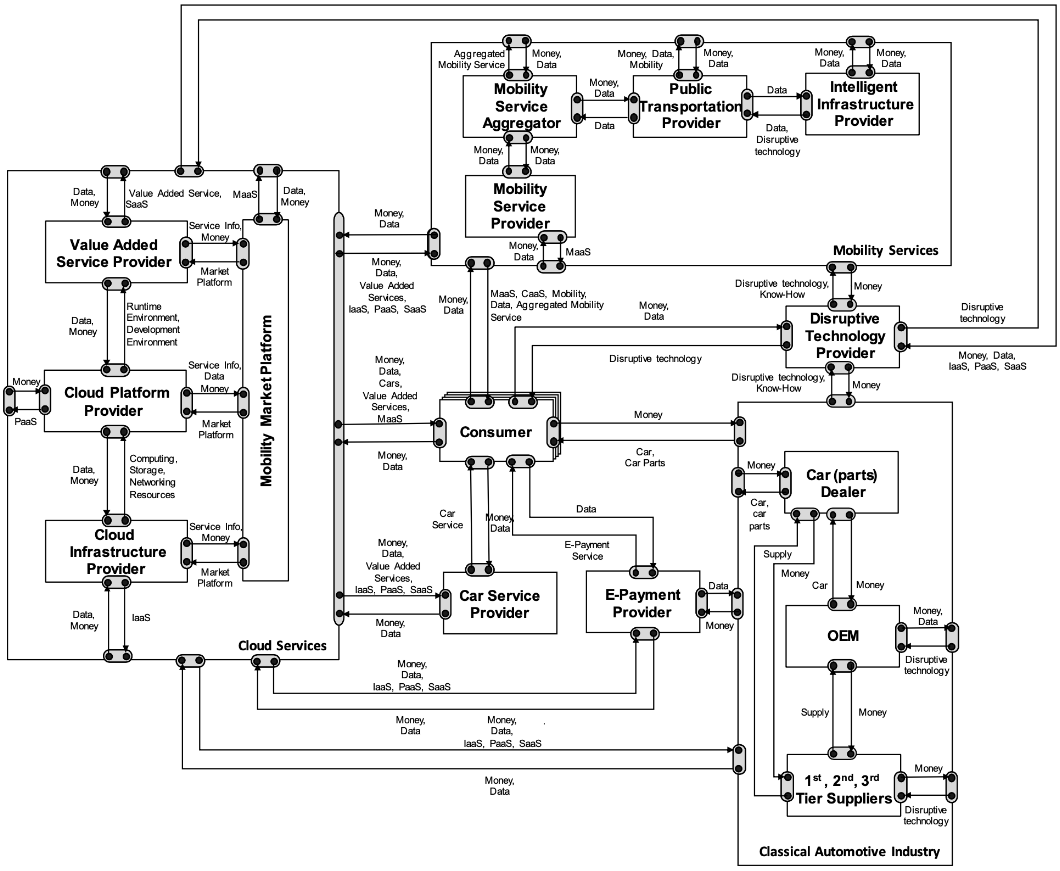

Figure 4.5: Proposed Generic Value Network for the Automotive Industry (Riasanow *et al.*, 2017)

Digital transformation is changing value networks and affecting physical products. As with many other industries, the automotive industry is moving from a well-defined and structured ecosystem, with OEMs as the central actor, to a "flexible networked ecosystem with open boundaries" (Athanasopoulou *et al.*, 2016). Riasanow *et al.* (2017) visualised a generic value network for the automotive industry based on identified roles, new market entrants and value streams (see Figure 4.5). Different roles create value within the value network by providing data, services and physical products. Such a visualization enables companies to analyze their position in the automotive industry and their relationship to competitors and partners. According to Llopis-Albert *et al.* (2021), digital transformation brings about significant improvements to the value network by boosting efficiencies, reducing costs, and generating greater collaboration and innovation. Furthermore, it will aid in the transformation of business models from a business-to-business focus to business-to-customer focus, with new methods of interacting with customers and partnerships through data.

4.1.2.2 Implementation procedures

Research is still missing a holistic chronological analysis of the current and ongoing transformation of the automotive industry, as existing studies focus solely on organizations' business models. Chanias and Hess (2016) conducted a study for the formulation of a digital transformation strategy in the automotive industry. Their findings show that digital transformation primarily begins through a multitude of emergent strategizing activities of organizational sub-communities through a bottom-up perspective, even before top management initiates a holistic strategy. Further, there existed a triggering event which set the formulation of a digital transformation strategy in motion. In the case of the automotive industry, some of these events included a desire to change company culture, desired efficiency gains, possibility of new business models, and risk posed by new market entrants.

When formulating a digital transformation strategy, management representatives require a clear overview of the ongoing digital transformation efforts and an understanding of the intentions behind the actions that led to the initiation of such efforts. In doing so, the desired future state (or "to-be state") for a digital transformation strategy should balance top management intentions and the intentions of the overall organizational community.

It is of great value to identify roles and value streams to visualize the new value network in its future state in the same way as what Riasanow *et al.* (2017) has proposed in Figure 4.5. As stated previously, this will enable companies to analyze their position in the industry and adapt their business models.

From the literature analyzed, Winkelhake (2019) has provided the most useful insights into digital transformation strategy formulation and implementation; however, this too does not provide a holistic analysis of the ongoing transformation. In Figure 4.6, he proposes a framework for the development of a digital transformation strategy in terms of corporate culture and IT solutions. Winkelhake (2019) further argues that digital transformation initiatives should be designed to address a company's business model as a cross-cutting issue and influence all key business processes. Therefore, a digital transformation strategy that covers all areas should not be treated in isolation, but should be developed as an integral component of a long-term, strategic corporate planning process.

In the first step, an understanding of the market situation and customer requirements form the basis for the subsequent strategic decision on which products and solutions would best fit which markets and customers. In order to implement the strategy, the business model, together with its corresponding processes, should then be designed to be as lean and efficient as possible (Lean enterprise). Building on this optimized structure, a vision for the future

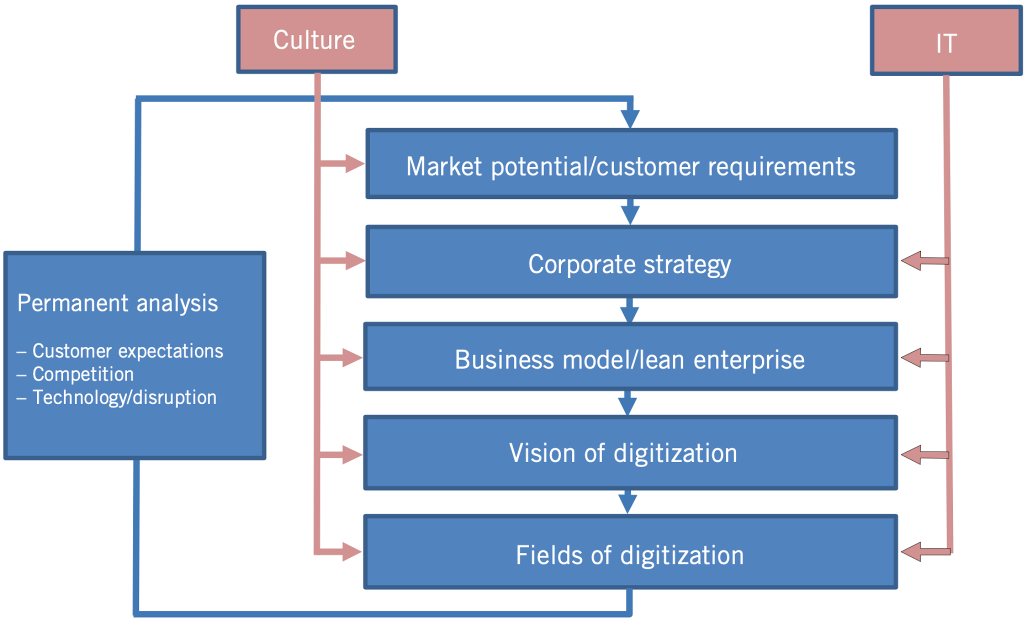

Figure 4.6: Development of a digital transformation strategy in the interface between corporate culture and IT solution (Winkelhake, 2019)

direction and purpose of digital transformation must be developed. For implementation, the final planning step will define fields of digitization and the procedures involved. During this process, corporate culture and IT are not to be seen only as a part of the individual planning steps, but are overarching topics whose involvement is a basic prerequisite for a successful transformation.

Building on Figure 4.6, (Winkelhake, 2019) further proposes an overarching framework of action to be taken (see Figure 4.7). Based on the strategic objectives defined in the corporate strategy, the cross-cutting business model with efficient business processes is established in the sense of a lean enterprise. Embedded in this are four digitization fields in which the initiatives are to be implemented:

- connected services and digital products, a field which also includes new digital products and new revenue opportunities, based on data;
- mobility services as a new field of business due to massive incentives from technologies for autonomous driving;
- improvements in efficiency due to the automation and digitization of business processes; and
- the areas of customer experience in sales and aftersales.

All four fields of action use the digital technologies relevant for the automotive

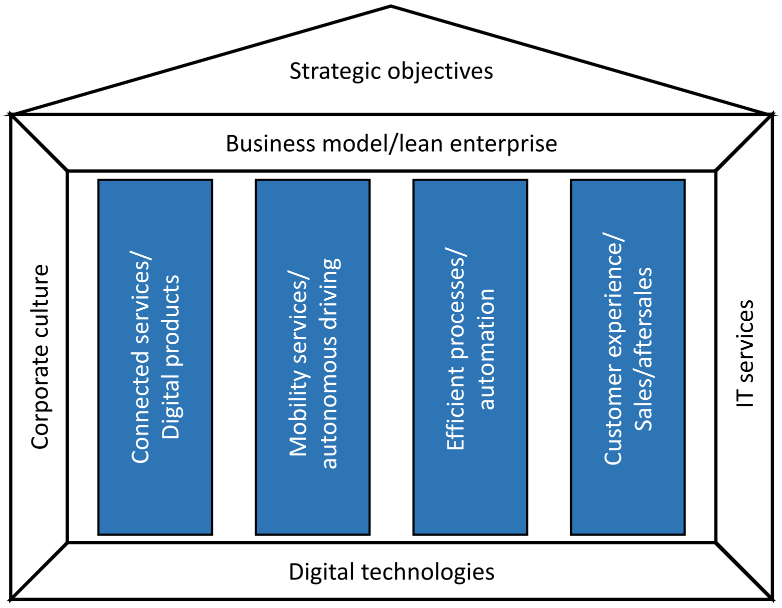

Figure 4.7: Overarching framework of action with four pillars for the digital transformation of a company in the automotive industry, adapted from (Winkelhake, 2019)

industry in interdisciplinary projects. These are chronologically arranged in manufacturer-specific, integrated strategies.

4.1.2.3 Barriers and challenges

Piccinini *et al.* (2015) identified emerging barriers and challenges to digital transformation in the automotive industry:

- Competing with an expanding range of new rivals and non-industry rivals and entrants;
- Building complementary partnerships among different ecosystem players (business and IT) to design new business models;
- Bridging gaps between previously separated business units and ecosystem players to create new digital value; and
- Improving information flows and exchange between business ecosystem partners to enable a seamless customer experience.

4.1.3 Chemical Industry

The literature search on on digital transformation in the chemicals industry include all sub-industries. The outcome of the literature search reveals that there is almost no published material on the subject. This may suggest that

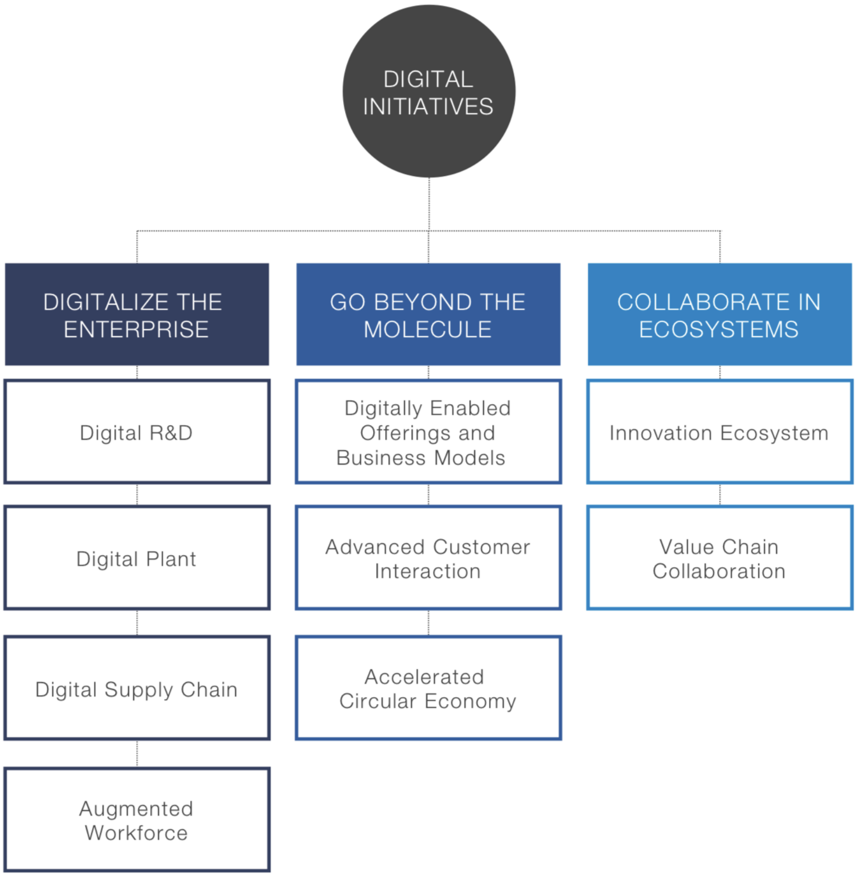

Figure 4.8: Digital Initiatives in the Chemicals Industry (WEF, 2017*a*)

industry knowledge on the subject is being kept from the public knowledge domain to retain competitive advantage.

4.1.3.1 Trends, elements and business dimensions

The industry has begun the digital transformation journey, broadly seeking opportunities to benefit from digital technologies in areas such as operational excellence or extension of traditional product offerings with digital components. Research conducted by the WEF (2017*a*) identified three digital initiatives that are expected to have a serious impact on chemical companies, as the industry is digitally transformed over the coming years (see Figure 4.8). These are general initiatives as every company will have its own agenda.

The Global Digital Chemistry Survey conducted by Deloitte (2017) in 2016 asked respondents to rank capabilities required to monetize digital initiatives according to importance (see Figure 4.9). Big data analytics, organizational agility and new business models ranked the highest among respondents. Organizational agility includes corporate culture of innovation, thus culture is

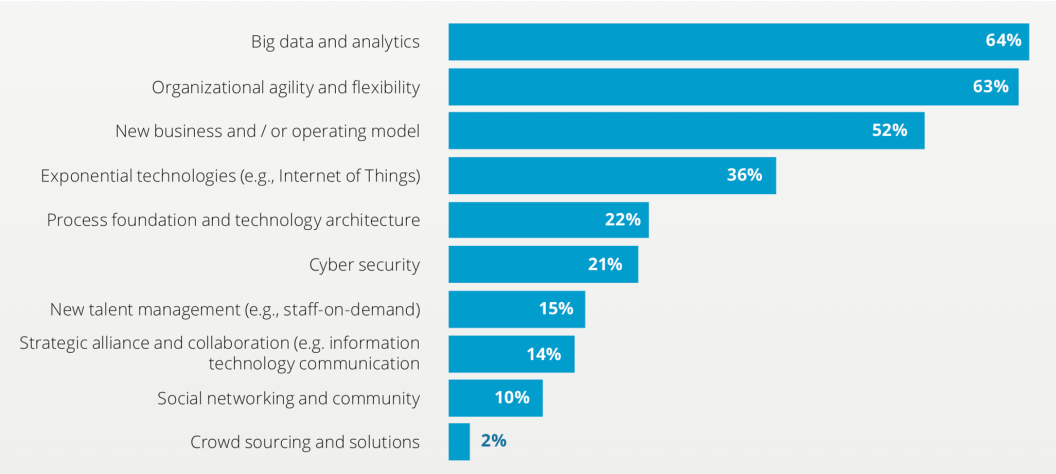

Figure 4.9: Capabilities required to monetize digital initiatives (Deloitte, 2017)

crucial.

In addition, Newman and McClimans (2017) found that leading businesses are implementing big data analytics, blockchain, cloud, IIoT and machine learning, which if implemented together effectively, drive business-wide value. The WEF (2017*a*) suggests a selection of digital technologies relevant to the chemical industry, namely automation and robotics, sensors, big data analytics, AI, 3D printing, IIoT, mobility and devices, IT/OT convergence, and cloud and platform-specific applications. These technologies can be utilized in a number of ways to provide value, for example, IIoT, predictive analytics and machine learning can help companies identify problems before they occur.

Advanced digital technologies, such as IIoT, automation and AI, will improve core operational functions. Digital transformation provides the chemical industry with opportunities to launch new digitally enabled offerings, create outcome-orientated business models and improve customer interaction. Accelerated innovation cycles will drive the industry to build flexible and interconnected innovation ecosystems. Intense collaboration and data sharing along the value chain will help to better address customers' requirements and manage volatility.

According to (Newman and McClimans, 2017) an innovation challenge exists because digital transformation cannot be undertaken with technology alone – it requires the combination of people, technology and massive amounts of data. However, innovation itself is not the entire challenge, rather the real challenge is in being able to innovate at scale across an entire organization, while creating a system for those innovations to be shared, sustained, and used to drive value back into the core of the business. This requires (1) the ability to select, implement and utilize technologies that work together; (2) an innovation culture that fosters the ability to adapt to changes and embrace new processes; and (3) the ability to manage and analyze massive amounts of real-time data to gain valuable insights from it (Newman and McClimans, 2017).

Digital transformation and digital innovation are expected to transform various aspects of how the industry operates, its offerings and its approaches to collaboration (WEF, 2017*a*):

- **Higher levels of efficiency and productivity** – Advancements in digital technology provide opportunities to further increase efficiency, productivity and safety throughout the industry's value chain;
- **Digitally boosted innovation** – Digital innovation can aid in the design of new offerings and solutions, promote Research and Development (R&D) productivity, and decrease time to market;
- **Data management and insight generation** – Insights generated from data and analytics will form the basis of many digitalization benefits and will emerge as key capabilities;
- **Workforce impact** – Technology will play a greater role in the upskilling and training of employees, as well as knowledge management:
- **Digitally enhanced offerings** – Analytics services can enhance product offerings to improve product performance for customers; and
- **Digital ecosystems** – Allow the chemical companies to complement internal capabilities with external capabilities. Various ecosystems already exist (innovation, supply and delivery, and offerings), and digital transformation will enable these ecosystems to interconnect, e.g. through cloud-based collaboration platforms.

The industry might be on the digital transformation path, however the industry still scores low on digital maturity. According to Deloitte (2017) this is due to (1) most chemical companies lacking a digital transformation roadmap or strategy; (2) companies focusing on digital initiatives for operational purposes which can lead to incremental growth instead of radical company-wide transformation; and (3) the current digital responsibility still residing with the IT department in many chemical companies.

While innovations may be unique to individual businesses, there are common building blocks which can be replicated to any business to manage technology, business processes, data and enable effective transformative change (Newman and McClimans, 2017). A culture of innovation is crucial to any digital transformation. This culture of innovation requires (1) the willingness to explore both open and closed lab approaches that involve all employees; (2) adopting a fail-fast mentality that focuses on the rapid testing of ideas; (3)

partnerships and collaborations to share, focus and drive efforts (Newman and McClimans, 2017).

Lastly, a trend which is observed from literature is to follow a customer-centric approach by placing the customer in the center of every decision, applying it to all aspects of the business.

4.1.3.2 Implementation procedures

Literature does not present well-defined implementation procedures; however, the WEF (2017*a*) proposes key considerations for successful digital transformation in the chemicals industry:

(1) **Set the right digital strategy** – Leaders should have a digital strategy or roadmap in place to plan an effective, and company-wide transformation to unlock the full potential of digitalization. This is crucial to adjust and adapt to the disruption associated with digital transformation. This digital strategy should incorporate all aspects of the company.
(2) **Manage cultural change** – Corporate cultures will need to become more open and agile to adapt to constant change. Cultural transformation should be driven by the CEO and top leadership team, alongside external influence to further foster a digital mindset.
(3) **Bring workforce into the digital age** – Companies need to rethink their competency requirements and supplement their workforce with deep digital skills. Chemical companies must have strategies in place to leverage and train employees with digital technologies. Advanced knowledge management tools are required to support changes in working style and to transfer knowledge.
(4) **Ensure cybersecurity** – Digital transformation requires appropriate attention, investment and capabilities to be assigned to managing cybersecurity.
(5) **Successfully collaborate in digital ecosystems and accelerate cross-industry partnerships** – Work on identifying and understanding partners and dynamics in the network, as well as the role to be played in the relevant ecosystems. Leaders should implement appropriate governance for ecosystem collaboration.
(6) **Identify, develop and launch new business models** – Create new business models with improved as well as new additional revenue streams made possible by incorporating digital services to their core business processes.

4.1.3.3 Barriers and challenges

Emerging barriers and challenges to digital transformation in the chemicals industry have been identified as follows (WEF, 2017*a*; Newman and McClimans, 2017; Deloitte, 2017):

- Current digital responsibilities are misplaced;
- Change management to ease workforce adoption of the digital agenda appears absent;
- The critical role of cybersecurity, talent management, and strategic alliances have not been fully recognized;
- Difficulties in attracting new talent and educating existing employees on the opportunities digital offers;
- Finding new revenue streams;
- Deployment of digital technology dramatically increases both the vulnerability to cyberattacks and the complexity of cybersecurity required to defend against them;
- Corporate culture, industry character and investors' short-termism;
- Preparing groundwork for data transparency, quality and integration;
- Integration and interoperability of enterprise systems;
- Concerns about intellectual property, protection, data ownership and privacy for effective collaboration;
- Regulations and data standardization.

4.1.4 Mining Industry

The outcome of the literature search on digital transformation in the mining industry reveals that there is almost no published material on the subject. According to Gandhi *et al.* (2016) and Young and Rogers (2019), the mining industry lags behind most other industries in terms of its relative digitization (see Figure 4.10), and thus lacks published material on the subject (even more so than the chemical industry).

4.1.4.1 Trends, elements and business dimensions

It has been found that some mining companies rely on Enterprise Resource Planning (ERP) systems instead of adopting a digital transformation strategy (Gren *et al.*, 2019; Ganesh *et al.*, 2014). ERP systems are crucial for creating process standards, however, they do not provide operational insight or a competitive advantage (Ganesh *et al.*, 2014).

Figure 4.11 shows the number of companies which mentioned specific terms in their annual reports as well as the frequency of mentions considering all reports (Young and Rogers, 2019). The terms *data* and *technology* received the most mentions in annual reports, however these terms where used out of context of digital transformation, a term which in itself was not frequently observed.

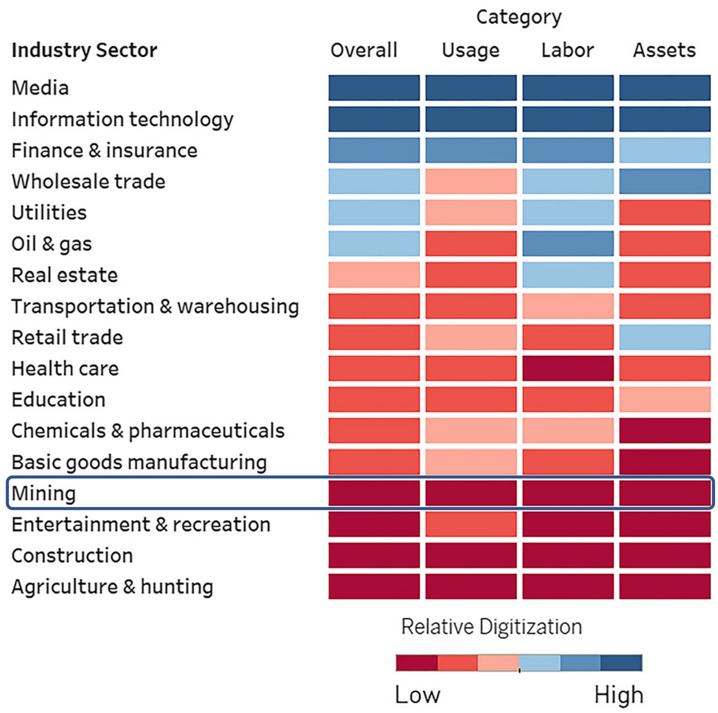

Figure 4.10: Relative digitization by industry (Young and Rogers, 2019; Gandhi *et al.*, 2016)

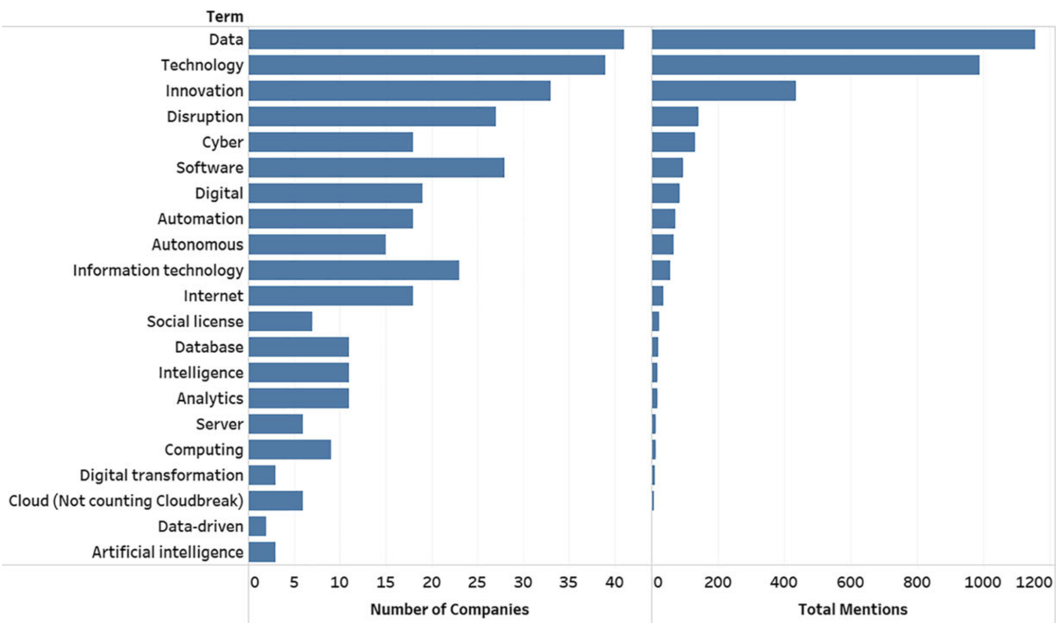

Figure 4.11: Keywords obtained from literature search on Digital Transformation in Mining Industry (Young and Rogers, 2019)

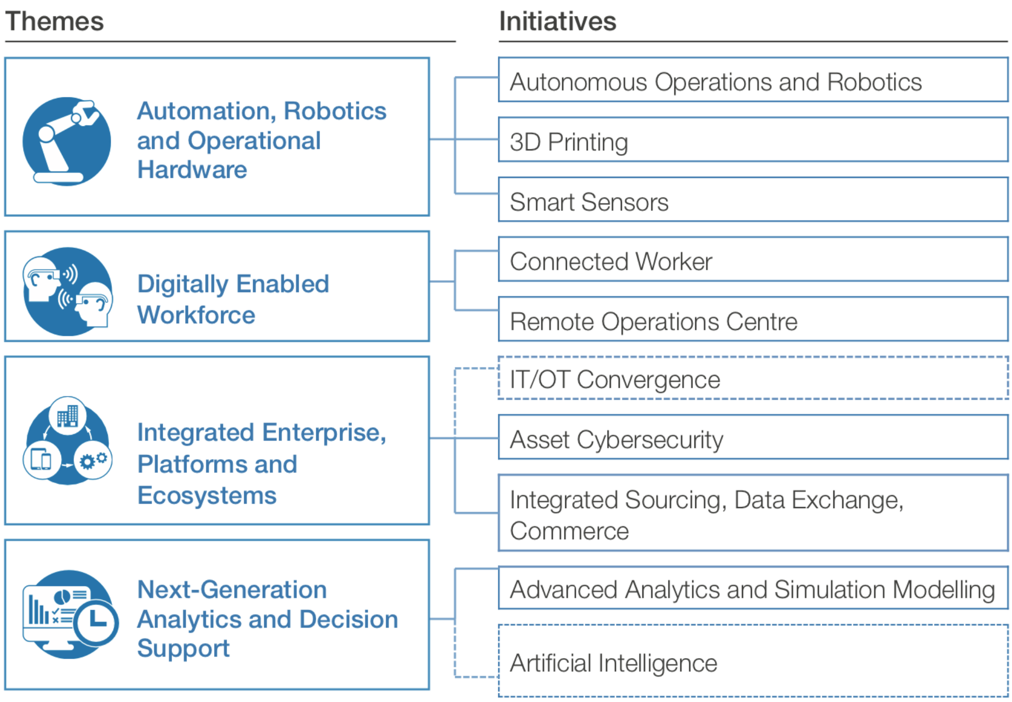

Figure 4.12: Digital themes and initiatives in the mining industry (WEF, 2017*b*)

Research conducted by the WEF (2017*a*) identified three digital initiatives that are expected to have a serious impact on chemical companies, as the industry is digitally transformed over the coming years (see Figure 4.12). These are general initiatives as every company will have its own agenda. First, the implementation of automation, robotics and operational hardware to perform and improve activities that have traditionally been carried out manually or with human-controlled equipment. Secondly, empowering the workforce with connected mobility, virtual and augmented reality. Thirdly, integrating enterprise, platforms and ecosystems by linking operations, IT layers and devices or systems which are currently separate. Lastly, next generation analytics and decision support capabilities by implementing algorithms and AI to process data from both within and external to the traditional value network.

Digital transformation creates value in many other industries through the development of customer-facing applications that engage and enhance customer experience (Vial, 2019; Setia *et al.*, 2013). However, in the mining industry, most companies have very few customers and mining products must undergo many value-adding processes before they reach the consumer. As a result, improving customer engagement creates little economic incentive for mining companies (Young and Rogers, 2019).

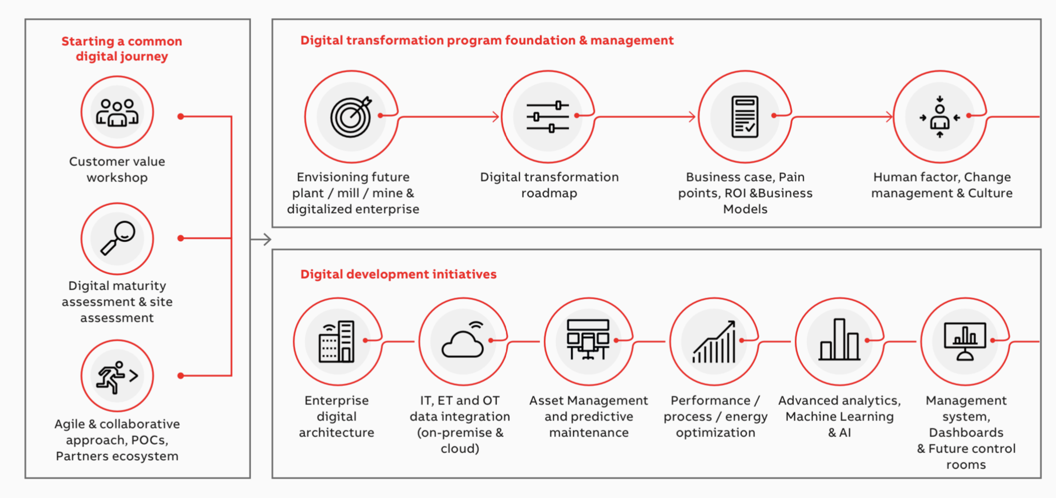

Figure 4.13: ABB's Digital Framework for the mining industry (ABB, 2019)

4.1.4.2 Implementation procedures

The WEF (2017*b*) proposes key considerations for successful digital transformation in the mining industry:

(1) **Align strategy and operations towards innovation** – Build a focused strategy that incorporates digital technologies, and align it to the business model, processes and organization as a whole. This will encourage digital usage and experimentation.
(2) **Look externally** – Connecting outside current value network can extract further value, i.e. connecting in new ways with buyers, suppliers and customers.
(3) **Improve data access and relevance** – Obtain real, applicable insights from data, and share these effectively with the right levels in the organization.
(4) **Engage and train digital workforce** – Establish a culture of adopting digital technology and embracing change.
(5) **Forge new partnerships and strengthen existing partnerships**.

ABB (2019) created a general high-level framework for digital transformation, in this case tailored to the mining industry (see Figure 4.13). The framework consists of three stages; namely, (1) starting a common digital journey with agile quick wins, (2) building digital culture and programme management, and (3) implementing digital initiatives, delivering results, and scaling up to enterprise-wide rollout.

4.1.4.3 Barriers and challenges

Barriers and challenges to digital transformation are not certain within the mining industry; however, a few challenges specific to the current state of the mining industry are identified:

- High number of retirements, staff reductions and loss of talent;
- Cybersecurity;
- Digital transformation presented at high-level to mining companies, without explaining the low-level complexities;
- Achieving performance improvements at scale;
- Unclear vision and KPIs;
- Old infrastructure with legacy systems and lack of sensors;
- Inadequate data readiness, cyber-security status and measures;
- Lack of skills necessary for implementation.

4.2 Common Approaches, Trends and Similarities

This section identifies and summarizes the common elements, business cases and implementation approaches presented in the previous section.

4.2.1 Common Elements

The elements discussed in this section are classified according to: (1) affected business dimensions, (2) data, (3) technology, (4) people, and (5) organizational change (see Table 4.1).

	BANKING	AUTOMOTIVE	CHEMICALS	MINING
Affected Business Dimensions	Strategic direction; competitiveness; business model; decision-making; innovation; productivity; entrepreneurship; customers and interaction; services; employees; organizational structure.	Strategic direction; business and operating model (B2B to B2C focus); innovation; customers and interaction; value networks, products and services; employees; organizational structure.	Strategic direction; customers and interaction; business model; innovation; products; employees; supply chain; value network.	Strategic direction; business and operating model; employees; decision-making; productivity.
Data	Data standardization and governance; cyber-security.	Data sharing (collaboration); cyber-security; privacy.	Data ownership; privacy; data sharing; cyber-security; data standardization.	Data accessibility; data sharing; cyber-security.
Technology	AI; cloud; big data analytics; cyber-security; blockchain; IoT.	AI; cloud; big data analytics; robotics; IoT; blockchain; AR and VR; 3D printing; autonomous driving; connectivity.	AI; cloud; big data analytics; blockchain; IIoT; automation and robotics; smart sensors; 3D printing; mobility and devices; IT/OT convergence.	AI; automation and robotics; 3D printing; smart sensors; connected workers; IT/OT convergence; big data analytics; remote operations centre.
People	Employee integration; education and training; talent acquisition.	Talent acquisition; education and training.	Talent acquisition; talent management.	Education and training; talent and skills acquisition.
Organizational Change	Culture change (high innovation affinity and embracing change); risk tolerance; collaborative partnerships; flatten hierarchical structure; establish digital transformation unit and appoint CDO to lead digital transformation.	Culture change; collaborative partnerships; digital-technology related merger and acquisitions. Establish cross-functional digital transformation units. Value network moving to a flexible networked ecosystem with open boundaries. Customer-centricity. Elevate alliance management as a critical organizational competency.	Culture change (high innovation affinity, organizational agility and flexibility); customer-centricity; strategic alliance management and collaboration.	Culture change (adopting digital technology and embracing change); establish collaborative partnerships

Table 4.1: Identified elements of digital transformation in industries

Affected business dimensions
There are significant similarities with respect to the affected business dimensions of digital transformation in the four industries analyzed. The following are business dimensions which is observed:

- Organizational structure;
- Customers;
- Partners and suppliers;
- Business models and value creation;
- Communication channels;
- Governance.

Data
The emphasis which is placed on the importance of data and data architecture as an enabler and driver of digital transformation is a common theme observed in the analyzed industries. Data is at the center of this transformation process and should not just be treated in conjunction with other business dimensions, but as an overarching capability that will determine the success of the digital transformation.

Technology
Great similarities exist in new technological advancements among the industries investigated in the previous section. AI, cloud, big data analytics, IoT, AR & VR, 3D printing, autonomous vehicles, robotics and blockchain are prevalent themes attracting much attention among industries. Thus, this trend reaffirms the decision to investigate and discuss the technologies in Section 3.5 as identified by the WEF.

People
Literature highlights the importance of people in the digital transformation process. All four industries regard talent acquisition to gain the necessary skills as a key enabler of digital transformation. Educating and training existing employees regarding the use of new digital technologies and processes, while integrating all employees in the transformation process is another major element crucial for the transformation process.

Organizational change
New trends have also been observed in transformation from product-centric orientations to customer-centric or service-centric orientations. However, the mining industry has been an exception in this regard as a customer-centric approach is of little economic incentive. The upstream O&G industry is similar to the mining industry in terms of the hydrocarbons having to undergo many

value-adding processes before they reach the end consumer. Thus, a customer-centric orientation will most probably not be a valuable focus point. The formation of a dedicated digital transformation unit has been observed in the two industries which are most digitalized, namely banking and automotive.

4.2.2 Business Cases

The business case for digital transformation was described in Chapter 3 according to drivers, benefits, barriers and success factors of undergoing a digital transformation. The identified business case of each industry is presented in Table 4.2.

	BANKING	AUTOMOTIVE	CHEMICALS	MINING
Drivers	Technological advancements; new digital trends; new business models; change in customer expectations; risk posed by new market entrants (FinTech).	Technological advancements; new digital trends; risk posed by new market entrants; desire to change company culture; desired efficiency gains; possibility of new business models.	Technological advancements; new digital trends; opportunities to launch new digitally enabled offerings.	Technological advancements; new digital trends.
Benefits	Increased productivity; reduced costs; improved interaction with both customers and employees.	Improvements to value network by boosting efficiencies, reducing costs, and generating greater collaboration and innovation.	Higher levels of efficiency and productivity; digitally boosted innovation; improved decision-making with better insights from data; enhanced digital offerings; greater collaboration; improved safety; improved core operational functions; better manage volatility; better address customer requirements.	Improving Overall Equipment Effectiveness (OEE); increasing revenue; reducing costs.
Barriers	Implementation and maintenance costs; lack of knowledge and skills; lack of sense of urgency; ambiguity of modern banking; lack of qualified consultants; lack of motivation and professional advice; conflicting guidance; outcome uncertainty; inconsistent support; security and compliance risks; misalignment between IT and business; regulations and government; customer demand; level of competition; resistance to change; cyber-security.	Cyber-security and privacy; competing with new market entrants; building complementary partnerships to design new business models; bridging gaps between separated business units and ecosystem players to create new digital value; improving information flows and exchange between business ecosystem partners.	Current digital responsibilities misplaced; change management absent; critical role of cyber-security, talent management, and strategic alliances not fully recognized; attracting talent and educating existing employees; finding new revenue streams; cyber-attacks and complexity of required cyber-security; corporate culture, industry character and investors' short-termism; data transparency, quality and integration; integration and interoperability; IP, data ownership and privacy; regulations and data standardization.	Retirements, staff reductions and loss of talent; cyber-security; digital transformation presented at high-level to mining companies, without explaining the low-level complexities; achieving performance improvements at scale; unclear vision and KPIs; old infrastructure with legacy systems and lack of sensors; inadequate data readiness, cyber-security status and measures; lack of skills necessary for implementation.
Success Factors	Achieved sustainability during transformation when effectively mastering customers, data processing and innovations.	Cohesive strategy for integrating digital and physical elements. Successful companies focused on two strategies: reshaping customer value propositions and reshaping operating model.	Ability to select, implement and utilize technologies that work together. An innovation culture that fosters ability to adapt to changes and embrace new processes. Ability to manage and analyze massive amounts of real time data to gain valuable insights.	Align strategy and operations towards innovation; connect outside current value network to extract value; improve data access and relevance; engage and train digital workforce; forge new partnerships and strengthen existing partnerships.

Table 4.2: Identified business case of digital transformation in industries

4.2.3 Implementation Approaches

As stated previously, there is minimal information in literature regarding detailed implementation procedures. The few literature sources that discussed strategizing and implementation activities were inconsistent in approaches (see Table 4.3). However, this section can compare the different points of each industry to the generic implementation procedures discussed in Chapter 3.

BANKING	AUTOMOTIVE	CHEMICALS	MINING
No detailed literature available on implementation approaches, however one case identified phases of a bank's digital transformation. **1. Developing new digital channels and products** – Focus on mobile devices for new channels; – Focus on retail payments for new digital products **2. Adaptation of new technological infrastructure** – New technology integration and architectural redesign; – Automation of processes. **3. Achieving strategic positioning in the digital environment through far-reaching changes to the organization.** – Pursue digital strategies that imply far-reaching organizational changes; – Establish metrics to quantify the effect of digital investments in terms of winning customers. building loyalty and marketing products; – Implement a shift in corporate culture – Establish collaborative partnerships and acquisitions.	*Digital transformation primarily begins through multitude of emergent strategizing activities of organizational sub-communities in bottom-up perspective.* **1. Formulating a digital transformation strategy:** – Understand market situation and customer requirements; – Assess digital maturity; – Management requires clear overview and understanding of reason for initiating actions (with regard to bottom-up approach); – Develop vision of desired future state and set strategic objectives; – Desired future state should balance top management and overall organization intentions; – Identify roles and value streams; – Visualize new value network in future state; **2. Implementing digital transformation strategy:** – Business model and corresponding processes should be lean and efficient (lean enterprise); – Define fields of digitalization and procedures involved; – Align IT, corporate culture, digital technologies and business model.	*No detailed literature available on implementation approaches in chemical industry, however key considerations to implementing digital transformation follows:* – Set the right digital strategy; – Manage cultural change; – Bring workforce into the digital age; – Ensure cyber-security; – Successfully collaborate in digital ecosystems and accelerate cross-industry partnerships; – Identify, develop and launch new business models.	**1. Starting a common digital journey with agile quick wins** – Digital maturity assessment and site assessment; – Establish agile and collaborative approach. **2. Building a digital culture and program management *** – Envision future digitalized enterprise and set objectives; – Digital transformation roadmap; – Business case and business models; – Digitally enabled workforce, change management and culture. **3. Implementing digital initiatives, delivering results, and scaling up to enterprise-wide rollout *** – Enterprise digital architecture; – Information Technology (IT), Engineering Technology (ET) and Operational Technology (OT) data integration; – Asset management and predictive maintenance; – Performance, process and energy optimization; – Advanced analytics and AI; – Management system, dashboards and future control rooms. **Focus areas 2 and 3 are interconnected and occur simultaneously*

Table 4.3: Common implementation approaches.

The most consistent approach found in this literature search revealed that the digital transformation process is comprised of two separate stages (which confirms the findings in Chapter 3) which can be referred to as: (1) digital strategy formulation, and (2) digital strategy implementation. The first stage, digital transformation strategy formulation, involves assessing digital technologies on processes, identifying digital opportunities and prioritising initiatives. During this stage, a digital transformation roadmap is developed, incorporating all the elements and business dimensions to undergo transformation, to transform the enterprise from the current state to the desired future state, a digital enterprise. During the second phase, as the name suggests, the digital transformation strategy is implemented. This involves executing the strategy and implementing the change procedures through updated/new business models, technology, processes, people, organizational structures, etc. The method with which this is done is dependent on the company size and structure.

Since the literature analyses on digital transformation of the banking, automotive, chemical and mining industries did not provide adequate information on implementation approaches, digital strategy implementation is still an uncertain subject. For this reason, a further literature search was conducted on digital startegy implementation approaches and frameworks. It was found that Correani *et al.* (2020) developed a digital strategy implementation framework based on case studies of successful digital transformation projects in three companies, namely ABB, CNH Industrial and Vodafone (see Figure 4.14). These cases are illustrative examples of successful alignment between digital strategy formulation and implementation in different contexts, and provide a basis for identifying correlations in digital strategy implementation approaches across different industries. The first case, ABB, is a Swiss/Swedish multinational technology company that operates in electrification, robotics, automation and motion technology. The second case, CNH Industrial, is an Italian/American multinational corporation that specializes in the design and production of agricultural and construction equipment, commercial vehicles, and powertrains. Lastly, the final case study, Vodafone, is a British multinational telecommunications company.

Correani *et al.* (2020) identified specific elements which were common among the cases investigated. From these elements they constructed a framework which companies can use to implement their digital transformation strategies effectively. This findings and framework of Conrreani et al. will contribute to the development of a digital transformation roadmap in Chapter 5. The analysis conducted by Conrreani et al. seeks to identify common elements and approaches to implement a digital transformation strategy effectively, and thus excludes the formulation of a digital transformation strategy itself. The process of formulating a digital strategy was already discussed in Chapter 3.

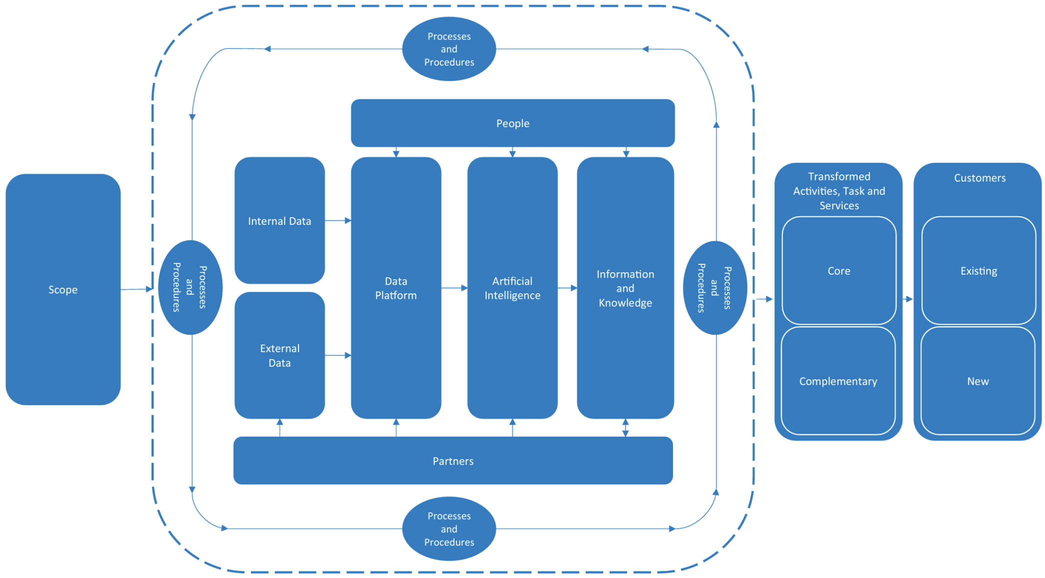

Figure 4.14: Digital strategy implementation framework Correani *et al.* (2020)

Studies have shown that effective strategy implementation is more critical for avoiding failure as compared with good strategy formulation (Lee and Puranam, 2016). Analysis of the cases suggests that the starting point of effectively implementing a digital transformation strategy is to focus on the **scope** of the transformation. In Chapter 3, it is observed that the scope should be defined during the formulation stage. **Data** is a crucial element of a digital transformation strategy. It has a central role in a digital economy and is a key enabler of digital transformation (Correani *et al.*, 2020). Data must be collected continuously to support the analytics and data models in a feedback loop. Upon collecting, cleaning and securely storing the data, **AI** techniques can be applied to extract **information** that feeds the organizational **knowledge** base. Companies must define the relevant job roles, strategic **partners**, and the processes and procedures needed to support the information extraction and knowledge generation process. Then, the information and knowledge generated is used to drive decision-making and support the **transformed activities, tasks, and services** that create value for **customers**.

Scope

The scope is defined during the strategy formulation process. The scope of the strategy is important to be effective and avoid inefficiencies throughout the digital transformation, acting as a connection between the strategy formulation and strategy implementation. The scope of digital transformation is thus the starting point for the implementation process. It is the foundation for defining how the company intends on creating value. In the three cases analysed, the scope of the digital transformation of each case was clearly defined:

- **Case 1 – ABB**: Create continuous value for customers through software- and platform-enabled services.
- **Case 2 – CNH Industrial**: Develop new services around predictive maintenance and intelligent logistics through the digitalization of its fleet.
- **Case 3 – Vodafone**: Automate and improve customer care services as well as offering personalized products and services based on customer preferences.

Both ABB and CNH Industrial set out to change their business by creating new business models which incorporate new, high added-value services to customers through the creation of digital platforms that collect and using data. Vodafone set out to enhance existing services through the use of digital technologies.

Data source

Since data plays a central role in any digital transformation, the proper management of data is critical to effectively support digital transformation. All three of the cases analyzed depend on internal and external data sources to implement digital transformation strategies. The function of data is to provide information and insights which can be used to drive better decision-making and ultimately increase competitive advantage. Since crucial resources, such as data, allow companies to establish and sustain a competitive advantage (Barney, 1991), companies need to ensure complete control over them. All three cases were very careful in this regard, and managed to ensure their control on their data. In order to ensure access to data sources, companies can internalize them such as through the use of IoT devices and sensors to guarantee a continuous data stream, or set up agreements with external sources, such as formal partnerships (Correani *et al.*, 2020). Companies must ensure that data sources provide timely, accurate and reliable data.

Data platform

Data platforms are software platforms where data is collected from data sources, sorted, enriched, and made available through a structured data library. As a result, data can be accessed by various areas of the business, partners and customers through the use of Software as a Service (SaaS) and Platform as a Service (PaaS) solutions to create value and drive productivity through improved decision-making. Thus, building data platforms is the logical next step to ensure data can be effectively captured, stored and analyzed. Depending on the industry, these platforms often collect end user data, and must hence be accurately governed and protected in compliance with the law. The three companies invested heavily in cyber security solutions to protect data platforms from cyber crimes.

People

Digital transformation generally involves changes to a company's operations and business models; however, new professional roles may be required as a result of revised activities and processes. The acquisition of new talent as well as equipping existing employees with additional skiils and capabilities have been shown to be crucial to exploit the benefits and unlock the full potential of digital transformation (Davenport and Harris, 2017). On the other hand, digital transformation requires strong leadership to drive the digital transformation. This may require an new managing role such as a Chief Digital Officer (Singh *et al.*, 2020). The three cases have highlighted the importance of people in the transformation; both management and employees.

Partners

Digital transformation may entail a radical change of a company's core capabilities. Establishing partnerships can assist the company in obtaining new knowledge, data, capabilities and competencies that are critical for the implementation of the digital strategy. More partnerships can be pursued over time to support the digital transformation as it progresses and adapts. All three cases established partnerships with Microsoft to develop IT infrastructure required to sustain the digital transformation, as well as other partnerships to obtain new capabilities and knowledge. Previous studies conducted by Andal-Ancion *et al.* (2003) have also shown the important role of partnerships in assiting with the adaptation and implementation of companies' digital strategies. The role of partners in the framework constructed by Correani *et al.* (2020) illustrates their relation with other elements supporting the implementation of the digital strategy.

Artificial intelligence

A common occurance in the three cases is that data is collected and used to develop and test machine-learning models deployed for various purposes. Partnerships can assist in deploying AI solutions. In these cases, Microsoft AI technologies were employed within a rapid insight and data exploration framework to establish an agile approach to data discovery and value creation (Correani *et al.*, 2020). The revision of the business model and organizational activities requires lean analytics and an AI operations framework. In fact, a "learn fast and fail fast" philosophy is at the center of every approach to data and machine-learning model design and experimentation. This approach is a key success factor that allows for developing better solutions to existing problems, identifying new patterns in data, obtain new insights, promote specific actions, gathering relevant knowledge, promote better decision-making, and enable improvements in products and services (Vam der Meulen, 2018). Therefore, according to Correani *et al.* (2020), a digital business model should define the specific AI strategies and capabilities needed to transform data into information and, eventually, generate knowledge that can be used to drive decision-making, and create and appropriate more value. Typical examples of AI usage are described in Appendix A.1. In the case of the three companies, machine learning is the most relevant and proven technique to obtain the most from data.

Information and knowledge

The information and knowledge involves the output of the data analysis and may be processed to increase organizational knowledge. Increasing the organizational knowledge base and obtaining quality information on all business activities is crucial for elevating decision-making capabilities.

Processes and procedures

The implementation of a digital transformation strategy could be radical, forcing companies to revise the processes and procedures they use to create value. Processes and procedures should be designed and configured to be agile and lean when undergoing a digital transformation in order to allow the company to adapt to rapid change and incorporate emerging opportunities, thus imitating the behaviour of start-ups rather than that of consolidated companies. In addition, this can also involve the revision of the formal relationships among employees and the formulation of dedicated business units (Correani *et al.*, 2020).

Transformed activities, tasks, and services

Digital companies use information and knowledge obtained from data analyses to gain insights to directly influence the core activities, tasks, and services in such a way that it allows companies to take action and create and appropriate value. In addition, the incorporation of new digital technologies alters the way activities and tasks are performed.

Customers

Transfomed activities leads to more value created for customers. New business models can lead to the capture of a new customer base as well as provide better services and products to existing customers.

Technology

Albeit technology is not included as a stand alone element in the framework of Correani et al., it is implied that technology is part of every element in the framework, from acting as data sources to automating processes and activities, etc.

4.3 Chapter Conclusion

Chapter 4 investigates digital transformation projects in other industries. The eighth and ninth research objectives are addressed in this chapter. Overviews of digital transformation in the banking, automotive, chemical and mining industries are presented. Common elements, business cases and implementation procedures are identified and discussed. Chapter 4 provides best practices and common approaches to digital transformation which jointly deliver structure to knowledge obtained from Chapter 3 and provides a starting point for the development of the DTR in the next chapter.

Chapter 5

Digital Transformation of Upstream O&G

The digital transformation process is company-specific – each approach is dependent on the company's current state, planned outcome and scale of operations. It is thus up to the company to develop a tailored solution to meet their unique requirements.

This research has examined the upstream oil and gas industry, digital transformation literature and examples of digital transformation projects in other industries. This was done for the purpose of identifying important elements and successful approaches and solutions to undergoing digital transformation. Together this forms the knowledge backbone for constructing a digital transformation roadmap for upstream companies, to guide them in developing tailored solutions for digitally transforming their projects.

First it is important to define a roadmap and distinguish it from a framework. Merriam-Webster dictionary defined a roadmap as "a detailed plan to guide progress towards a goal." It also defines a framework as "a basic conceptual structure (as of ideas)." From these definitions it is evident that a roadmap is a more structured, chronological set of activities to guide a specific endeavour. Thus, the purpose of this study is to develop a roadmap rather than a framework. The Digital Transformation Roadmap (DTR) aims to guide upstream O&G companies to answer the following three strategic questions in terms of delivering projects:

(1) How digital is the enterprise today?
(2) How digital should the enterprise become?
(3) How does it become more digital?

The proposed DTR is a phased, iterative process. It was stated earlier that

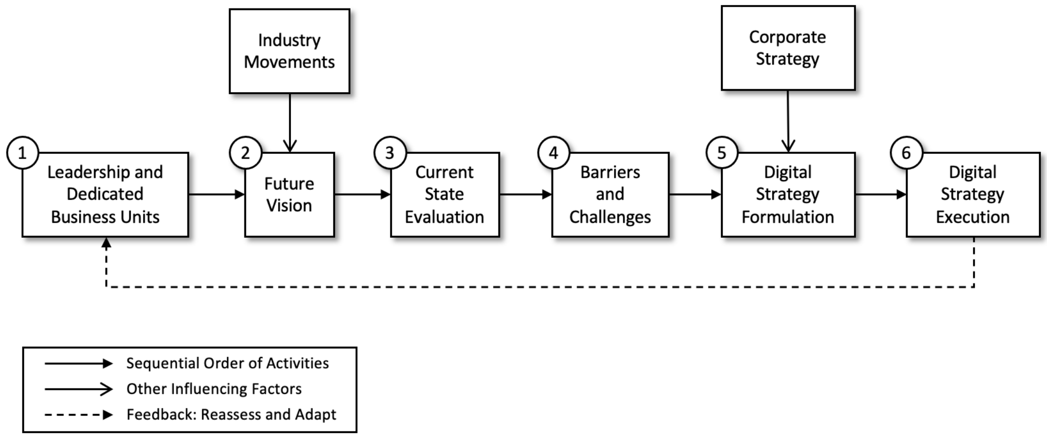

Figure 5.1: High-level Digital Transformation Roadmap (DTR)

digital transformation is a continuous process with a fast changing landscape. Thus, the process of implementing digital transformation needs be constantly evolving and adapting to changing conditions as technology advancements allow ever greater possibilities. The proposed DTR is thus formulated in that it is an iterative process requiring continuous reassessment and adaptation. This digital transformation roadmap was initially aimed at the digital transformation of MCPs; however, in reality the O&G organization needs to undergo digital transformation as a whole since it is a holistic process affecting all aspects of the organization. Digital transformation must be implemented on an organizational level to create the correct context for MCPs. Thus, the proposed roadmap is a high-level digital transformation roadmap addressing the holistic digital transformation of an upstream O&G company in an effort to digitally transform the company's projects.

For the most part, the DTR focuses on implementing digital transformation at a company level but certain steps will need to be taken at an industry level to enable the digital transformation of all O&G companies. These industry-level enablers need to be addressed before commencing with the DTR (see Section 5.1).

The high-level roadmap is shown in Figure 5.1. This is a condensed version of the DTR which is presented in Section 5.8 (see Figure 5.7). The DTR offers upstream O&G companies a framework providing insights with which they can develop their own tailored approach to digitally transforming their organization. Assuming a complete starting point, digital transformation is initiated by establishing a digital transformation *leadership team* to head the transformation and ensure all subsequent tasks are performed. This is followed by constructing a *future vision*, or desired future digital state, as outcome of the digital transformation. Performing a *current state evaluation* to assess digital maturity and transformational readiness succeeds the future vision. Comparing the future vision with the current state of the organization will identify gaps and highlight specific areas on which to focus. This is a valuable starting point for formulating a digital strategy. *Barriers and challenges* to undergoing digital transformation are identified. The next step is to *formulate a digital strategy* and to align it with the *corporate strategy*. This strategy will guide the organization in its digital transformation efforts. Next, the digital strategy is executed by building and improving skills and capabilities throughout the organization. Lastly, the whole process is reassessed step-by-step and adapted to any changing conditions (such as technology advancements, industry movements, regulations, internal and external conflicts).

5.1 Enablers of the DTR

The DTR is based on the premise that executives and senior management are aware of the purpose and impacts of digital transformation and are initiating the digital transformation through adopting this roadmap. If this is not the case, digital transformation has to be prioritized in the company to start initiating the transformation process. Digital transformation, as with any other transformation, needs to be led from the top. In addition, there are other enablers on an industry level for implementing digital transformation, as discussed in Chapter 3. These issues need to be addressed before starting the digital transformation with the proposed DTR. All companies will benefit by collaborating to ensure these issues are resolved. Digital transformation on an industry level is not a prerequisite but rather an enabler. However, the purpose of this study is to develop a digital transformation roadmap for the upstream O&G industry, and organizational digital transformation is an enabler for the digital transformation of the entire industry. Each organization needs to build their own capabilities in order to drive the digital transformation of the entire industry through collaborative efforts. According to research, the following elements need to be addressed on an industry level:

- **Make digital a priority** – Prioritizing digital transformation on an industry level enables building a collaborative ecosystem in the industry where competitors can share innovation to ensure the industry as a whole can progress. Making digital transformation an industry priority is also necessary to facilitate the following two points.
- **Develop global data standards** – Data standardization is crucial as data plays a central role in a digital enterprise – the outcome of digital transformation. Data standards should include policies related to data sharing and security.
- **Create clear regulatory frameworks** – This will promote the shift towards the low-carbon economy and support a more inclusive society.

These issues are also listed as barriers in Section 5.5 since data standardization and regulatory frameworks will need to be updated as the industry progresses along its digital transformation. Thus, it will remain a barrier since innovation in the O&G industry will always be dependent on standardized data and updated regulatory frameworks.

5.2 Phase 1 – Establish Leadership

The first step of the proposed DTR is to implement changes to the organizational structure to accommodate the establishment of a strong leadership team to drive and lead the digital transformation of the company. Many additional structural changes will be required in a later phase (see Section 5.6.1) as a company progresses with its digital transformation. It was observed in Chapter 3 that leadership is one of the most critical factors for a digital transformation. In addition, from observing trends in other industries (Chapter 4), it was found that there is a direct correlation between leadership and a company's success with digital transformation. Thus, creating a role to lead the digital transformation is key to initiating a successful digital transformation. It is proposed that such a role should be filled by appointing a Chief Digital Officer (CDO), if that role does not yet exist within the company. The CDO should also be provided with a dedicated digital transformation team in the form of a cross-functional business unit to aid the integration of digital into all aspects of the company. It is a common trend in the digital transformation of other industries to establish dedicated cross-functional digital transformation units to drive the digital transformation and mediate the involvement and strategy of the CDO and the rest of top management throughout the organization. This is a transition from the typical occurrence of the digital responsibility still residing with the IT department as was observed in industries still scoring low on digital maturity.

The CDO is effectively in charge of the digital transformation; however, the CDO should work closely with the CEO, Chief Information Officer (CIO), Chief Financial Officer (CFO) and business unit leaders. In this setting, the CDO has to be an active participant in and shaper of the digital strategy, communicate the digital strategy and value proposals effectively throughout all levels of the organization, and ensure the strategy is successfully executed. There is still much confusion regarding the different responsibilities between the CDO and CIO. It is proposed that the CDO is responsible for the Information System (IS) which incorporates the technology, people, and processes involved with information. On the other hand the CIO should be responsible for Information Technology (IT) which is the design and implementation of information, or data, withing the information system. Some of the major responsibilities of the CDO will be at least to:

- **Define digital strategy** – Translate the future vision into a digital strategy while integrating it with the corporate strategy (see Section 5.5).
- **Build a business case for the digital strategy** – Document the justification for initiating the digital strategy to gain understanding and support throughout the company.
- **Develop a change management plan to support digital initiatives** – Avoid disrupting workflows and help support all aspects of organization throughout transformation.
- **Advance structural and cultural change for digital adoption** – Foster an innovation company culture which embraces change, as well as implementing structural changes to enable digital transformation.
- **Obtain and manage the budget for the digital programme** – Work closely with the CFO to secure budget and manage the financial aspect of the transformation.
- **Measure performance** – Monitor performance and measure digital transformation progress against predetermined criteria and objectives.
- **Build collaborative ecosystem** – Be familiar with trends inside and outside the industry, identifying possible acquisitions and partners that can provide complementary capabilities, thus building external networks of people, technologies and ideas.
- **Coordinate digital transformation** – Coordinate people, technology, processes and other transformation activities to enable complete digital transformation.

5.3 Phase 2 – Define Future Vision

One of the top barriers to successful digital transformation observed in Chapter 4 was lack of clear future vision. The future vision is critical for undergoing a digital transformation as it allows the company to cement and communicate what they wish to achieve through the transformation and where they aspire to be in the future. Thus, defining a future vision is proposed as the next phase. The future vision (Phase 2) aims to provide answers to the question: "How digital should you become?"

It is proposed that rather than analyzing current capabilities and then plotting an organization's next steps, organizations should work backwards from a future vision (see Figure 5.2). The future vision might not be attainable with current technology, but as technologies progress, they are implemented systematically to enable the organization to get closer to the future vision of a digital enterprise. New capabilities make new solutions possible, thus starting with the future vision and working backwards to the current state identifies gaps in capabilities and skills. Implementing these capabilities and

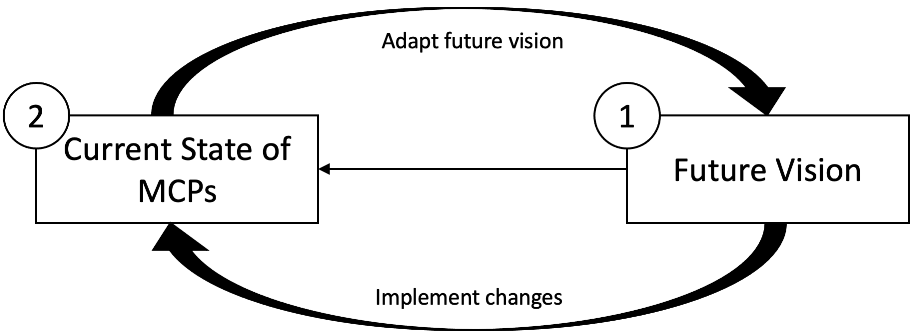

Figure 5.2: Transition process from current state to desired future state

skills provides new possibilities for the future vision which is then adapted. This is a continuous cycle as technology and capabilities progress. It is crucial to be agile and keep adapting to changing conditions while building skills and capabilities for attaining the future vision. Thus, less emphasis should be placed on technology itself, but rather on how technology can enable digital transformation of an organization, i.e. placing the emphasis on the digital strategy.

When constructing the future vision, it is proposed to start with observing industry movements. In digitally maturing organizations, as discussed in Chapter 4, most strategies focus on improving decisions and innovation. The 2015 study by Kane *et al.* (2015) found a similar result with nearly 90% of digitally maturing organizations' strategies focusing on improving decisions and innovation. Focusing on the importance of improving decisions as an outcome of digital transformation – a proposed follow-up point for constructing the future vision, or alternatively referred to as the desired future digital state, is to focus on the following points:

(1) Decisions you want to make;
(2) Information you need to visualize to make those decisions;
(3) Data and technology you need to acquire; and
(4) Supporting elements.

These points will aid in establishing a clear future vision for the digital transformation of the organization. Innovation enables generating insights to make timely and accurate decisions. Using MCPs an example, first, these points need to be mapped onto the MCP stage-gate process to address each stage separately. Next, the company must find ways to integrate the stages to create a streamlined flow of information throughout the entire stage-gate process from conceptualizing to decommissioning of an MCP (see Figure 5.3).

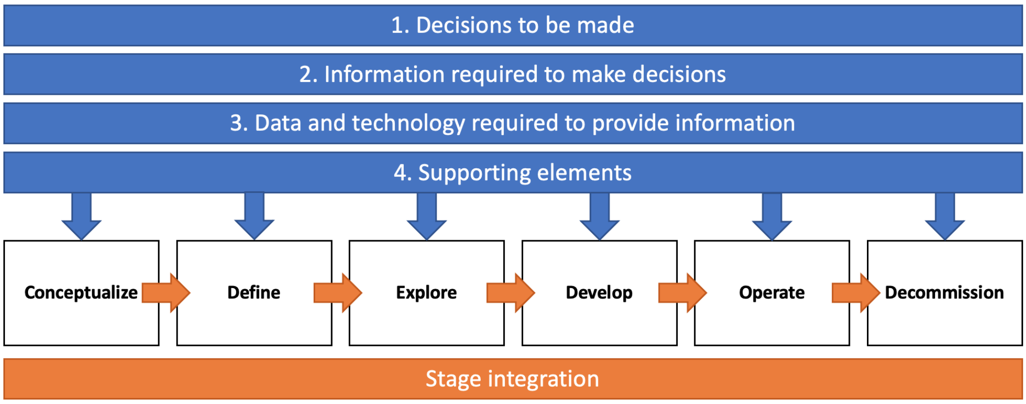

Figure 5.3: Mapping future decision requirements on MCP stage-gate process

Thus, the decisions made possible from information obtained in one phase (outcomes) can be used as direct inputs to the following stage.

In addition to focusing on the previously mentioned points, it is of great value to identify roles and value streams to visualize a new value network in its future state as was illustrated in Figure 4.5. This will enable companies to analyze their position in the O&G industry and adapt their business models later in Phase 5 of the DTR. It is fundamental that employees are integrated into the thinking process of change and allowed the necessary freedom of thought to contribute towards building a future vision for the company. The future vision should consist of digital initiatives leading to a radical company-wide transformation, instead of digital initiatives for operational purposes which lead merely to incremental growth.

5.3.1 Industry Movements

It is important to focus on and stay updated on industry movements in terms of technological advancements, regulatory changes and innovations since these factors will influence the competitiveness of O&G companies in the future. These factors are direct inputs to formulating the future vision and will affect the decisions that will be required to produce improvements to the organization and solve business problems through digital transformation. Companies can learn from successes and failures in other O&G companies and strive to foster a collaborative innovative ecosystem to keep the upstream O&G industry moving forward on its digital transformation.

5.3.2 Mapping Future Vision of the MCP Stage-gate Process

The following examples illustrate the process of mapping the future vision in terms of the different stages of the MCP stage-gate process. These examples are intended only to illustrate the process; the actual mapping of the future vision should incorporate all decisions to be made during the stage along with the information required, technology to be implemented, and elements to enable and support the intended changes. Digital transformation cannot be undertaken with technology alone – it requires the combination of people, technology, large volumes of data, and updated work processes. In this sense these other elements are the supporting elements that enable digital transformation alongside the application of digital technologies.

Example: Operation stage

(1) **Desired Decisions** – Determine when to conduct preventative maintenance.
(2) **Required Information** – Information regarding the status of equipment and components.
(3) **Enabling Technology** – Key equipment and components fitted with sensors (IIoT) to relay information on status of equipment to central control tower for remote monitoring.
(4) **Supporting Elements** – Digital skills, big data analytics, cloud, etc.

After mapping the technological requirements, these technologies need to be implemented and integrated to ensure complete interoperability. It has been stated earlier that digital transformation is undergone to solve business problems, therefore mapping the future vision present solutions to problems whereas the digital strategy provides the measures of how these changes are implemented.

5.4 Phase 3 – Evaluate Current State

Lessons learnt from other industries (Chapter 4) highlight the importance of evaluating the current state of the company. The current state evaluation (Phase 3) aims to provide answers to the question: “How digital are you today?” It is proposed that the current state evaluation succeeds the future vision as the future vision will guide the process of evaluating the current state. Keeping the desired future digital state in mind while evaluating the current digital state of the organization will highlight gaps and specific areas on which to focus. The current digital state of an organization can be determined by performing a digital maturity evaluation. The future vision guides the selection of a digital maturity evaluation model that will evaluate the company's current state according to criterea that is aligned with the future vision. It falls outside the scope of this study to formulate a digital maturity evaluation model, therefore a model is selected from literature as an example. It is up to the company to select an existing digital maturity model of their choice, or to formulate their own.

Table 5.1 shows a digital maturity model which was adapted from Rossmann (2018). In this case, the O&G company's digital maturity is measured against eight dimensions, namely; strategic capabilities, leadership capabilities, product capabilities, operational capabilities, people and expertise capabilities, cultural capabilities, governance capabilities and technology capabilities. Each capability consists of four items pertaining to the capability being evaluated. Each item is given a score based on the 7-point Likert scale (1 – strongly disagree to 7 – strongly agree).

Table 5.1: Digital maturity evaluation model, adapted from Rossmann (2018)

#	Capability	Items	Score
1	**Strategic**	Company has implemented a digital strategy.	
		Digital strategy is documented and communicated.	
		Digital strategy has significant influence on existing business and operating models.	
		Digital strategy is being continuously evaluated and adapted.	
		Strategic Score	/28
2	**Leadership**	Executives support digital strategy implementation.	
		Digital strategy is implemented holistically.	
		Leadership culture is based on transparency, cooperation, and decentralized decision-making processes.	
		Digital strategy has an influence on task and role profiles of executives.	
		Leadership Score	/28
3	**Products**	Digital products and services are embedded in business interfaces and business processes and create a perceptible impact on customer experience.	
		Direct added value is created by the progressive digitalization of products and services.	
		Digital products and services have a large impact on the overall performance of the company.	
		Company is creating significant sales volume via digital channels.	
		Market Score	/28

Table 5.1: Digital maturity evaluation model, adapted from Rossmann (2018)

#	Capability	Items	Score
4	**Operational**	There are sufficient resources (time, people, budget) available to implement the digital strategy.	
		Established a strong cross-functional cooperation and co-creation with stakeholders throughout the value chain.	
		Digital and physical processes are fully integrated by holistic process models.	
		The impetus of the digital strategy is leading to innovations in operations.	
		Operational Score	/28
5	**People and Expertise**	There are sufficient experts on digital core issues within the company.	
		Further education opportunities for digital core topics are available within the company.	
		Comprehensive measures to strengthen digital literacy development are implemented within the company.	
		Within our firm, new job profiles have been created for employees with expertise in digital core topics.	
		People and Expertise Score	/28
6	**Cultural**	Decisions within our firm are transparent to our own employees.	
		Digitization has an impact on the decision-making agility of our firm.	
		In day-to-day business, employees and executives exchange information about the digital transformation of our firm.	
		Continuous change is part of our corporate culture.	
		Cultural Score	/28

Table 5.1: Digital maturity evaluation model, adapted from Rossmann (2018)

#	Capability	Items	Score
7	**Governance**	Guidelines for the use of digital technologies are communicated and used by employees.	
		Our firm implements a holistic management model for the digital strategy and corresponding key metrics	
		The key metrics for the digital strategy are fully integrated into controlling.	
		The corporate strategy and the digital strategy are intensively networked and complement each other.	
		Governance Score	/28
8	**Technology**	Our firm uses large amounts of data to optimize strategies, processes and products	
		Within our firm, we use tools for digital modelling, automation and control of business processes.	
		Our firm has implemented enterprise-wide digital workplace concepts. Digital platforms are used for day-to-day collaboration.	
		Digital technologies are the mainspring for the further development of products and services.	
		Technology Score	/28
DIGITAL MATURITY SCORE			/224

The company's current maturity level is determined by the score obtained from the digital maturity model (see Figure 5.2), 32 being the minimum score and 224 being the highest possible score. The digital maturity levels are split into quintiles (equal 20% parts). Ideally, the company strives to reach the *transformed* maturity level through digital transformation and maintain that level as the desired future state is adapted over time.

It is also recommended that companies visualize their value network (similar to that of Riasanow *et al.* (2017) in Section 4.1.2.1) to determine their position within the industry and their relationship to competitors and partners. This visualization, together with the future vision, will grant the company a better understanding of where they can strengthen capabilities and relationships to boost competitive advantage.

Maturity Level	Unaware	Conceptual	Defined	Integrated	Transformed
Maturity Score	32 – 69	70 – 108	109 – 147	148 – 185	186 – 224

Table 5.2: Digital maturity levels

For O&G companies starting on their digital transformation journeys, this phase will precede the formulation of a digital strategy. As a result, the company will initially score low on digital maturity. However, the proposed DTR represents digital transformation as an iterative process where companies must restart the DTR process upon reaching the end and revisit all phases. Thus, a company's digital maturity score will increase each time the current state is reassessed, and each time new focus areas are identified. This is also a way the company can track its digital transformation. Finally, the company's digital maturity evaluation will identify the capabilities which need to be improved (observing capabilities with lower scores) to advance its digital transformation.

5.5 Phase 4 – Identify Barriers and Challenges

It has become clear from literature that many barriers and challenges will need to be overcome in order for the O&G industry to implement a successful digital transformation. Following the formulation of a future vision and evaluating the current state during this phase (Phase 4), organizations should identify barriers and challenges which are anticipated to arise during the digital transformation from current state to desired future state (future vision). Accounting for the barriers and challenges early on could aid organizations in improving their capabilities and other business dimensions to enable and advance their digital transformations. This phase precedes the formulation of the digital strategy since this will lead to additional objectives as part of the digital strategy in order to address and overcome these identified barriers and challenges. Frequently occuring barriers to digital transformation was investigated in Chapter 3. Though these barriers are non-specific to the oil and gas industry, they provide a good starting point for O&G companies to plan ahead as they become more digitally mature. Possible solutions to further barriers and challenges to digital transformation relevant to upstream oil and gas that have been identified throughout this study are briefly discussed in order to guide the digital strategy formulation to address and plan for these barriers and challenges. However, it is up to each O&G company to identify and plan for any additional barriers and challenges specific to its organizational context and digital maturity level.

Leadership

In Chapter 3 it was observed that leadership is generally accepted as one of the most critical factors for successful digital transformation. The leadership of the digital transformation must possess the ability to make quick decisions due to the fast-changing climate that the digital transformation brings. A strong leadership team is crucial for formulating a digital strategy, communicating that digital strategy throughout the organization, implementing the digital strategy, and managing the digital transformation. Thus, phase 1 of the DTR (establishment of leadership) represents a crucial factor in the success of the digital transformation, and can present major challenges if leadership lacks the necessary capabilities. The leadership should be continuously assessed and refined.

Lack of clear vision

Digital transformation requires a future vision to work towards. Chances of succeeding with the transformation initiatives increases significantly if the leadership succeeds in conveying the purpose of the transition throughout the organization, as this creates a general understanding of what is going to happen and why. Thus, articulating a clear future vision during Phase 2 of the DTR is a crucial starting point to overcome this challenge. Next, the future vision will have to be transformed into a set of objectives and value propositions to be communicated throughout the organization. As the future vision is adapted over time, all changes must also be conveyed throughout the organization.

Resistance to change

Currently, the resistance towards change within the O&G company cultures represents a major barrier to unlocking the full potential of adopting digital transformation. When communicating the purpose of the transformation and digital strategy throughout the organization, it should be formulated as an opportunity, to avoid the transformation being perceived as a threat to the employees.

Standarization and regulatory frameworks

There are currently many data standards such as standards from the International Organization for Standards (ISO), American Petroleum Institute (API), Professional Petroleum Data Management (PPDM) and the International Electrical Commission (IEC) which apply to upstream oil and gas. However, there are still a gaps in data standardization which need to be addressed. Data is the foundation of a digital enterprise, thus data standardization becomes a crucial prerequisite for undergoing a digital transformation, as discussed before. Data standardization enables effective data management, data integration and interoperability, thus enabling collaboration and data sharing capabilities. Current efforts such as the development of the Capital Facilities

Information HandOver Specification (CFIHOS) is addressing data standardization, updating legacy formats and improving the ease and integration of data exchange along the data supply chain.

Data quality

Data provides information, and information generates insights and enables better decision-making. Thus, data is at the core of a digital O&G enterprise, the outcome of a digital transformation. In a digitally transformed O&G industry of the future where data is even more heavily relied on, quality and reliable data is essential. As mentioned before, quality data must comply with the following criteria – it must be accurate, complete, consistent and timely. The challenge of obtaining quality data also relies on data standardization and regulatory frameworks.

Lack of collaboration

Industry-wide collaboration is necessary to initiate and enable digital transformation for all companies, and to allow O&G companies to benefit from digital transformation through delivering projects more safely, quicker, more sustainably and at reduced costs. Closed-source software and lack of standardization and interoperability are major barriers to collaboration, leaving organizations with an inability to share information across the ecosystem.

Cyber security

In Chapter 4 it was observed that cyber security is a major concern for many industries undertaking digital transformation. The O&G industry is no different. Technological advancements and innovations bring with them greater risks of digital attacks. Companies will have to invest heavily in securing their organizational data mainframe and IT processes.

Lack of necessary competence

Digital transformation is largely dependent on skills and competencies of organizations. Companies need to acquire talent or consult externally to acquire the necessary skills and competencies to realize digital transformation. Acquiring talent can be a barrier on its own. Apart from obtaining new skills and competencies from outside the company, current employees should be trained and educated to allow easy adaptation to the changes, and ultimately start to drive the digital transformation through adoption.

Measuring success

Apart from performing current state evaluation studies, tracking the progress and performance of a digital transformation and measuring success can be a challenge. Companies need to establish KPIs and other outcome quantification measures to evaluate the performance of the digital transformation initiatives.

5.6 Phase 5 – Formulate a Digital Strategy

During this phase companies must find answers to the question: "How do you become more digital?" To accomplish this, companies have to develop a digital strategy in order to successfully navigate the process of transitioning from their current state to the desired future state, adapting business models, overcoming barriers to digital transformation and eventually becoming a digital enterprise. Build a focused strategy that incorporates digital technologies, and align it to the business model, processes and the organization as a whole. Setting the right digital strategy is also crucial to adjusting and adapting to the disruption associated with digital transformation. To a great extent, digital strategy drives digital maturity. There is no "one-size-fits-all" method of formulating a digital strategy found in the literature study. However, there were common elements which were frequently present in literature on digital transformation, digital strategy and busines models as discussed in Chapter 3 and Chapter 4. Thirteen elements, or dimensions, of digital transformation have been derived from the building blocks, success factors, initiating factors in Chapter 3, and affected business dimensions in Chapter 4. These elements are proposed for the DTR going forward:

(1) Data architecture
(2) Application of technologies
(3) Corporate culture
(4) Business model and value creation
(5) Structural changes
(6) Communication channels
(7) Work processes
(8) Talent and organizational capabilities
(9) Collaboration
(10) Customers
(11) Alignment and integration
(12) Financial aspects
(13) Governance

In literature, some of these elements were sometimes grouped together. However, for the purpose of this study the elements have been separated into simpler forms to showcase each individual element as a separate capability to be addressed during the digital transformation. To a certain degree, these elements can guide a company in formulating a digital strategy by incorporating each element in the digital strategy.

In companies which have already implemented a digital strategy it was found that many approached the formulation of a digital strategy similar to formulating any other strategy. However, external consultations were often

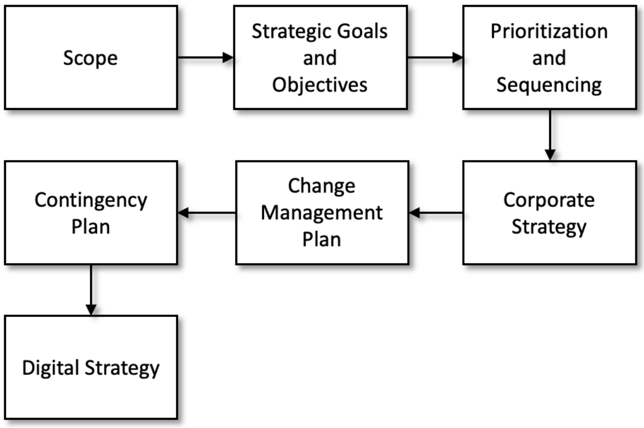

Figure 5.4: Proposed digital strategy formulation process

required to provide the necessary digital transformation knowledge to aid in the formulation process. In addition to the thirteen elements, other important best practices were obtained and lessons were learnt. First, it is important to have a purpose and vision for the digital transformation which can then be translated into a digital strategy. Following the DTR up to this point, Phase 2 already provides the desired future vision for the digital transformation. This future vision must be translated into a set of strategic goals and objectives which can easily be communicated throughout the organization. It is important to keep the digital strategy flexible to ensure that the company is agile and able to implement changes and adapt the digital strategy so that regular adaptations and updates can be made. Literature suggests that implementing the digital strategy is crucial and should not be delayed by perfecting it.

Albeit that literature does not present a formal method of formulating a digital strategy, a process of digital strategy formulation is proposed in Figure 5.4 based on recurring elements found in literature which were described in Chapter 3 and Chapter 4 (in particular Figure 4.6 and Figure 4.7). This proposed digital strategy formulation process is purely for the purpose of contributing towards the digital transformation roadmap, and is not based on actual proven procedures. The power of a digital strategy lies in its scope and objectives. Thus, to start formulating a digital strategy companies must set the scope of the intended digital transformation. This is followed by setting strategic goals and objectives to establish the boundaries for what the company's efforts must be focussed on. These goals and objectives must then prioritized and transcribed into a sequential form derived from cross-functional interdependencies and prerequisites that are identified by the organization.

5.6.1 Scope

The company must first define the scope of the digital strategy. It is important to set boundaries for a transformation and to establish a timeline.

5.6.2 Strategic Goals and Objectives

Set strategic goals and objectives from the future vision, current state and barriers and challenges according to the thirteen identified dimensions. Put a methodical approach in place for developing and/or industrializing new capabilities to enable the transformation from the current state to the future state, a digital enterprise.

5.6.2.1 Data architecture

Set objectives for reforming the company's data architecture. This should include building a framework for how the IT infrastructure will support the digital strategy. As stated in Chapter 4, IT should be overarching topics whose involvement is a basic prerequisite for a successful transformation. There should be easy and quick access to data. Reforming the company's data architecture requires appropriate attention, investment and capabilities to be assigned to managing and ensuring cybersecurity.

5.6.2.2 Application of technologies

Set strategic goals and objectives to guide the establishment of the required technological capabilities for the digital transformation. Develop a methodical approach to implement new digital technologies in the company to facilitate the digital transformation. Based on the required technology identified during Phase 2 (defining the future vision), Figure 5.5 shows an example of the application of new digital technologies in upstream MCPs. These objectives should address when to implement technologies, how they will be implemented and how to build digital capabilities and skills to effectively incorporate the new technologies in the value creation process of the company. Technological capabilities must be built to evolve to allow future improvements and the incorporation of additonal technologies. The objectives must also include staying up to date with new emerging technologies, and how they can be utilized to create value for the company.

5.6.2.3 Corporate culture

Set objectives to guide the cultural change that is required. These objectives should stipulate the procedure for driving an innovation culture and fostering a mindset open to change and technology adoption. The innovation culture requires the willingness to explore both open and closed lab approaches that

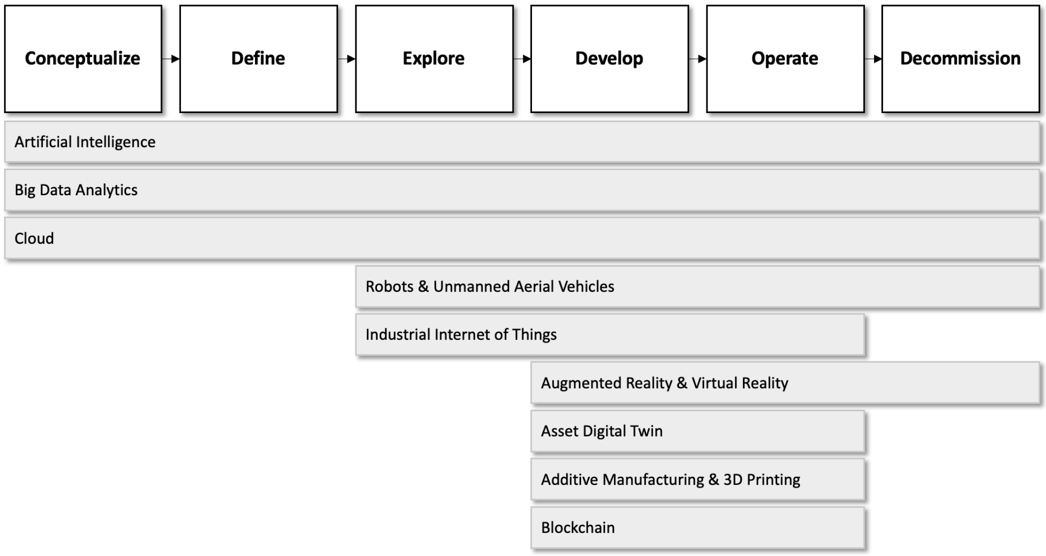

Figure 5.5: Proposed application of key digital technologies in upstream MCPs

involve all employees, adopting a fail-fast mentality that focuses on the rapid testing of ideas and partnerships and collaborations to share, focus and drive efforts. Observations in Chapter 4 showed that only companies with a high innovation affinity and a culture that embraces change can actively undergo digital transformation. Top management has to show a real risk tolerance regarding innovation. Companies should develop approaches for accelerating the cultural shift, such as collaborative partnerships with tech start-ups.

5.6.2.4 Business model and project value chain

This set of objectives serves the purpose of creating business models with improved as well as new additional value streams made possible by incorporating digital services to the core business processes. This includes combining new ways of working with advanced digital solutions and defining improved End-to-End (E2E) value chains. O&G companies must adapt their business models (see Figure 3.4) and redefine their value network to create and appropriate more value. Digital transformation initiatives should be designed to address a company's business model as a cross-cutting issue and influence all key business processes. Thus, adapting the business model will guide the process of setting objectives for all other business dimensions in an effort to realize the new adapted business model. As a result, setting objectives for adapting the business model should precede some of the other objectives, but this will be discussed in more detail in Section 5.6.3. In order to implement the strategy, the business model, together with all corresponding processes, should be designed to be as lean and efficient as possible, striving for a lean enterprise in addition to becoming a digital enterprise. As stated in Chapter 4, digital transformation brings about significant improvements to the value network by boosting efficiencies, reducing costs, and generating greater collaboration and innovation.

5.6.2.5 Structural changes

This set of objectives initiates the digital transformation and serves the purpose of structuring the company to promote the adoption of digital transformation, while minimizing disruption and maximizing engagement. It has been proposed in other industries to flatten the organizational hierarchical structure in an attempt to open up lines of communication and collaboration.

5.6.2.6 Communication channels

Set objectives to establish effective communication channels to enable communication throughout the organization. A digital strategy is only as good as how effectively it can be communicated throughout an organization. Easy and quick communication is crucial to ensure new information is conveyed to and consumed by all relevant parties without the information becoming outdated. This enables a "single source of truth" to be in circulation at any given time. There needs to be infrastructure in place that enables continuous exchange of information between employees and management. The ability to communicate change in the company will have a significant impact on all other elements of digital transformation, thus, effective communication channels are absolutely crucial for successful digital transformation. In addition, communicating the change is the only way to manage the resistance to change.

5.6.2.7 Work processes

These objectives address the required changes and possible improvements to work processes as a result of implementing digital technologies and new business models. The application of technology creates new possibilities for work processes, and in turn work processes need to be adapted to incorporate the technologies.

5.6.2.8 Talent and organizational capabilities

Set objectives to acquire talent and build organizational capabilities and skills. This includes setting approaches for investing in human capital and development programmes that promote new, digital thinking. Also, education and training programmes for employees are required to inform employees on the required changes of digital transformation, build human capabilities and skills, and enhance the acceptance and integration of employees. Companies need to rethink their competency requirements and supplement their workforce with deep digital skills. Advanced knowledge management tools are required to support changes in working style and to transfer knowledge.

5.6.2.9 Partners and suppliers

Identify opportunities and set objectives and approaches to deepen collaboration with partners and suppliers, and understanding of sharing-economy platforms. Organizations must collaborate with partners and suppliers, including external market players. Connecting outside the current value network can extract further value. Intense collaboration and data sharing along the value network will drive innovation for all parties involved and manage volatility. Contributing towards the previous point, collaborative partnerships are sources of new skills and talent required for digital transformation. In addition to collaboration, digital technology-related merger and acquisitions have a positive impact on digital business model innovations. Companies must also elevate alliance management as a critical organizational competency to manage partnerships and collaborations.

5.6.2.10 Customers

Objectives regarding customer relations should stipulate how to effectively use digital technologies to strengthen customer engagement.

5.6.2.11 Alignment and integration

Set objectives to ensure complete alignment and integration of all aspects of the transformation to undergo an integrated business transformation.

5.6.2.12 Financial aspects

Financial aspects refers to how the digital transformation is to be funded. Strategic objectives should include estimating costs and setting up a budget, procuring funds, managing expenses, and tracking ROI.

5.6.2.13 Governance

Develop metrics to measure the performance and track the progress of the digital transformation initiatives (outcome quantification).

5.6.3 Prioritization and Sequencing

A complex web of interdependencies between technologies and other business dimensions often makes it difficult for the industry to enable its digital transformation. It is important to understand the relationship and hierarchical structure of technologies and associated enabling elements. In order to construct the roadmap, digital transformation objectives need to be chronologically arranged by understanding initiating enablers and their effects on subsequent factors. It is also essential to prioritize factors based on their relative importance in enabling digital transformation. By doing this, the fuzzy front end of digital transformation can be ordered into a structured step-by-step approach to achieving digital transformation objectives.

From observing trends in the automotive, banking and processing industries in Chapter 4, it is clear that for a whole industry to benefit from digital transformation, there are certain initiating steps that need to be carried out at industry level before digital transformation can be pursued at company level. Following this approach for the upstream O&G industry, central factors that will influence the entire industry need to be identified and prioritized.

With data being at the center of digital transformation, with all other elements being dependent on it, it is only logical that industry-wide data architecture should be addressed first. This mainly includes data policies, rules and standardization which have to be done at industry level since collaboration, interoperability and data sharing among partners, suppliers and clients are some of the major outcomes of transitioning to a digital industry. Secondly, it is proposed that each organization implement a digital transformation of the business model. Since business models incorporate other business dimensions such as value propositions, customers, suppliers and partners, adapting the business model will lead to identifying the required changes to those business dimensions. Thereafter, organizations should identify the relative relationships among business dimensions to establish a sequential order of activities to be undertaken to build the required capabilities, infrastructure and skills based on the organizational context to enable the digital transformation.

5.6.4 Alignment with Corporate Strategy

The digital strategy cannot work independently from the corporate (business) strategy. A digital strategy that covers all areas should not be treated in isolation, but should be developed as an integral component of a long-term, strategic corporate planning process. Thus, it is critical to the success of the transformation that the digital strategy aligns with the corporate strategy

5.6.5 Develop Change Management Plan

It is crucial to develop a change management plan to help manage the digital transformation process. In addition, it ensures control over the budget, schedule, scope, communication and resources. The change management plan aims to reduce the disruption and impact a transformation can have on a company, employees, customers and other stakeholders. It falls outside the scope of this study to propose a change management plan; however, there are multiple approaches to developing such a plan available in literature.

5.6.6 Develop Contingency Plan

As stated in Chapter 3, the difference between a digital strategy and the business model rests on planning for contingencies. The digital strategy refers to the choice of business model adopted, and it includes a contingency plan. The contingency plan should account for outcomes other than that which is planned. It should contain procedures for when the transformation is not executed as planned and when identified risks become reality.

5.7 Phase 6 – Implement the Digital Strategy

Digital strategy execution entails building and improving skills and capabilities to realize the digital strategy. It is the most important and challenging phase of the digital transformation process. It is a challenge to innovate at scale across an entire organization, while creating a system for those innovations to be shared, sustained, continuously adapted and improved, and to drive value back into the core of the business. In its most basic form, this requires the ability to select, implement and utilize technologies that work together, an innovation culture that fosters the ability to adapt to changes and embrace new processes, and the ability to manage and analyze massive amounts of real time data to gain valuable insights from it. The proposed procedure for implementing the digital strategy, formulated in the previous section, is shown in Figure 5.6. The implementation procedure can be grouped into two stages, namely validation and implementation. The validation stage starts with the development of a Proof of Concept (POC) to test the performance of the digital strategy through simulations, evaluate performance of approaches and minimize implementation challenges. This is followed by scaling up to a pilot project where the digital strategy is implemented in a testing environment to ensure all aspects of the digital strategy can be executed successfully. Following the termination of a successful pilot project and conclusion of the validation stage, implementation of the digital strategy can commence. It is proposed that the digital strategy is initially implemented on all greenfield projects, particularly MCPs. MCPs are chosen for initial implementation since that is the area where the most capital is expended. This is followed by implementation on existing/legacy projects. This leads to company-wide digital transformation once the digital strategy is being implemented on all projects and there exists full integration and interoperability within the company. The last phase is related to digital transformation on an industry level, where collaboration and data sharing creates a collaborative innovation ecosystem for upstream O&G companies, partners, suppliers, and customers. It is important to emphasize that the

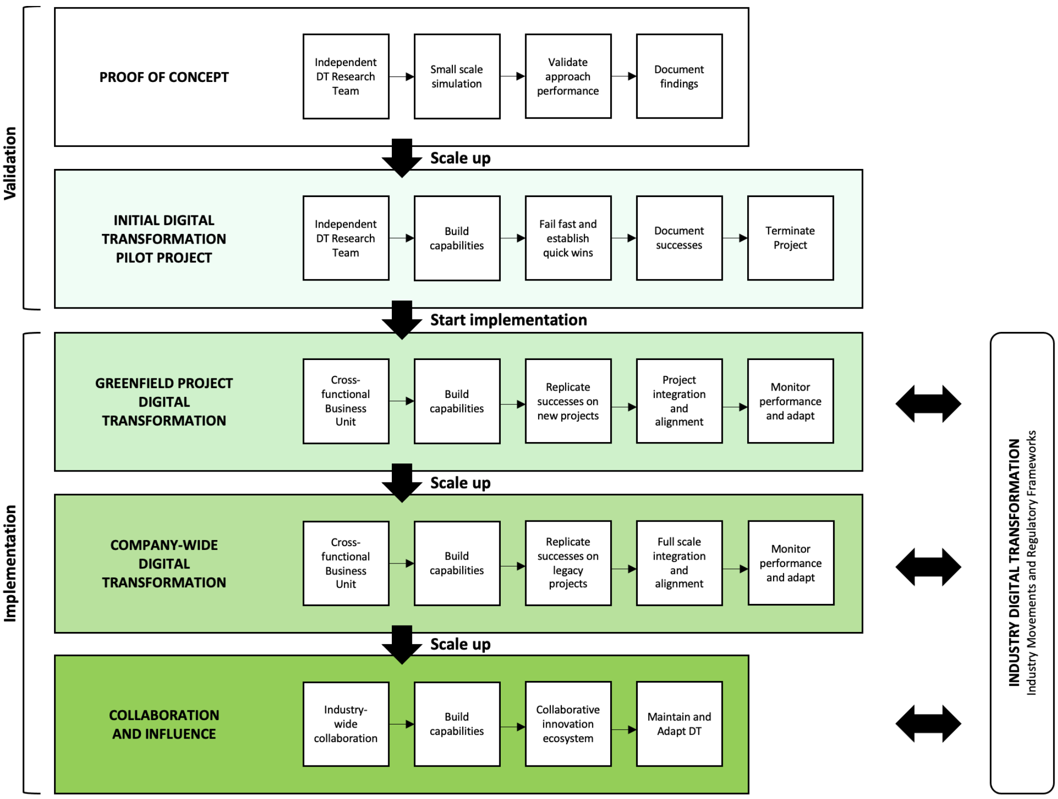

Figure 5.6: Proposed procedure for validating and implementing the digital strategy

implementation on company-level works in parallel with implementation on an industry-level. In order for the industry to be digitally transformed, it is required of each company to build capabilities and align themselves to the future vision of the entire industry to enable the digital transformation of the entire upstream oil and gas industry. Thus, each company will progress with its digital transformation while conforming to the industry regulations regarding digital transformation for future collaboration and integration.

5.7.1 Proof of Concept (POC)

The implementation of digital transformation starts with establishing an independent digital transformation research team which is to become the cross-functional business unit as the digital strategy implementation progresses and the complexity increases. This team is responsible for constructing a Proof of Concept (POC) to test the performance of the digital strategy through simulations, evaluate the performance of the digital strategy and identify challenges to minimize problems in later stages during real-world implementation. The digital strategy implementation approach is to be adapted based on the documented findings of the POC. In conclusion, the main purpose of the POC is to demonstrate and verify the digital strategy to allow initial implementation during the pilot project that follows.

5.7.2 Initial Pilot Project

The pilot project provides the research team with a learning environment to implement the digital strategy without consequences to the company. It is larger in scale than the POC since the pilot project involves iterations of the digital strategy to practise implementing the digital strategy in a real-world scenario. The pilot project serves a different purpose than the POC. During the pilot project the research team aims to optimize the digital strategy implementation procedure by implementing the digital strategy on a "mock-up project". During the pilot project it is crucial to fail fast, learn and adapt, and to establish quick wins in order to scale up to real world implementation on actual projects. It is during this phase where most of the problems with the implementation procedure should be addressed as they are encountered. The digital strategy implementation procedure should be adapted over time as iterations of the implementation reveal optimal approaches, guiding the implementation procedure closer to successful digital strategy implementation. Once the digital strategy can be implemented successfully and the research team is knowledgeable on all facets of the digital strategy implementation procedure, the process should be documented and prepared for scaling up to full-scale implementation of the digital strategy.

5.7.3 Greenfield Projects

Upon finalizing the validation of the digital strategy, implementation of the digital strategy within the company can commence. This is effectively the start of the company's digital transformation. Albeit this phase refers only to greenfield projects, the implementation of the digital strategy is company-wide in terms of all business aspects except implementation on existing project assets. This means that all aspects of the digital strategy will commence; however, the digital strategy will be implemented on existing project assets which are already in operation only in the next phase. This is because digital transformation, being a holistic process, should be implemented in the entire company to enable the transformation. The greenfield projects are prioritized for digital strategy implementation to ensure all projects, and MCPs, which are delivered from that point forward are digitally transformed projects, progressing closer to the future digital enterprise. However, it will not be a complete company-wide digital transformation until existing projects, that are still economically feasible, are digitally transformed and integrated into the new digital state of the company during the next phase. Legacy projects which are still economically feasible and have potential for significant improvements to safety and reliability could be used as pilot projects for more incremental changes compared to radical changes which is possible with developing greenfield projects.

Initially, implementation of the digital strategy in the company is centrally focused around delivering digitally transformed greenfield projects. This is initiated by expanding the task force from a research group to a dedicated cross-functional business unit. The cross-functional business unit is responsible for building the capabilities in accordance with the digital strategy. This includes organizational capabilities and talent, improving communication channels, cultural changes, reforming the company's IT architecture, implementing key digital technologies, structural changes, changes to work processes and value chain, and ensuring integration and alignment between all aspects of the business. The performance of the implemented digital strategy should be monitored continuously. The collective feedback from all projects and all business units should be analysed centrally, appropriate adaptations should be made, and a unified updated digital strategy should be implemented. This is the iterative nature of implementing the digital strategy.

5.7.4 Company-wide Digital Transformation

In parallel with implementing the digital strategy in greenfield projects, the cross-functional business unit should expand the transformation to existing project assets which are still economically feasible for digital transformation as well as all other projects. This is done in a similar manner to the greenfield projects; however, the scale of implementation will likely be lower to allow integration with the legacy system running the asset. During the digital transformation, greenfield projects can be developed and delivered as digitally transformed assets in accordance with the digital strategy from the start. In contrast, existing assets have to be adapted to the digital strategy after already being delivered. Thus, the implementation of the digital strategy will be approached differently than the greenfield projects and dependent on the life cycle of the asset. The general practices will remain constant – building capabilities and replicating successful approaches to ensure the existing assets can be integrated with the transformed operations and systems of the company. Identical to the previous phase, the digital strategy should be continuously monitored and adapted. Company-wide digital transformation leading to a digital enterprise will likely only occur once all greenfield projects are being delivered with full integration of the digital strategy and all existing assets are phased out and decommissioned.

5.7.5 Collaboration and Influence

The last phase of digital transformation entails ensuring full industry alignment. This entails adapting the digital strategy to build a collaborative innovation ecosystem in the upstream offshore O&G industry. This is to be enabled by the prerequisites discussed in Section 5.1. Central regulations and standards will enable companies to adapt their digital strategies by building capabilities to allow data sharing and collaboration. This will create a more inclusive and unified O&G industry. The performance of the digital transformation should be continuously monitored, to maintain and/or improve the digital strategy on both an industry level and company level. Each iteration brings about significant change to companies as innovations create more possibilities.

5.8 Digital Transformation Roadmap for Upstream Oil and Gas

The high-level Digital Transformation Roadmap (DTR) for upstream oil and gas is presented in Figure 5.7. The roadmap is based on an in-depth literature search on digital transformation and upstream oil and gas. The roadmap is chronologically laid out following a sequential order of activities. The DTR is adaptable to allow constant reassessment and evolution of the digital transformation. As describes earlier the digital transformation initiatives of each organization should happen in parallel with the digital transformation of the entire industry, however it is up to each organization to build the required capabilities to undergo the digital transformation and contribute towards building a collaborative innovation ecosystem.

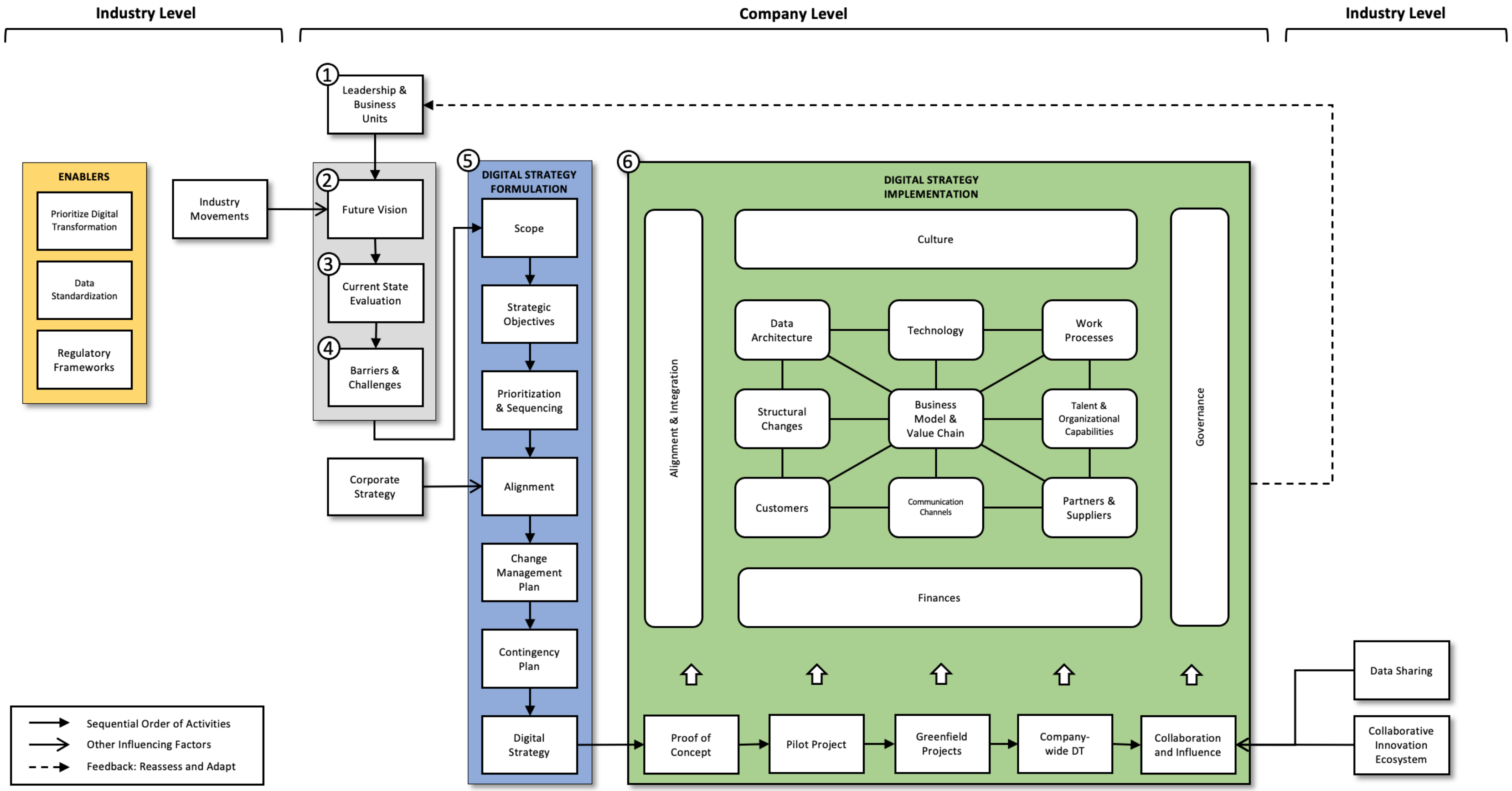

Figure 5.7: Proposed Digital Transformation Roadmap (DTR)

5.9 Chapter Conclusion

Chapter 5 is the salient chapter in this thesis and addresses the tenth research objective. The developed DTR is explored, and the final deliverable of the study is presented in the form of a high-level, holistic roadmap. As established, the DTR is six-stage process is summarized as follows:

- **Stage 1**: Establish leadership and business units
- **Stage 2**: Establish future vision
- **Stage 3**: Perform current state evaluation
- **Stage 4**: Identify barriers and challenges
- **Stage 5**: Formulate digital strategy
- **Stage 6**: Implement digital strategy

The development of the DTR in Chapter 5, has prepared the material for validation, which is discussed in Chapter 6.

Chapter 6

Research Validation

This chapter presents the research validation, addressing the eleventh research objective presented in Chapter 1.

6.1 Validation Approach

The validation approach selected for this work is to interview industry leaders in this field, present them with the work and obtain their feedback. Jette *et al.* (2003) suggest that expertise in the chosen topic can reduce the number of participants or interviewees required. In addition, Dworkin (2012) states in her work that many articles and books suggest anywhere from 5 to 50 participants as adequate (this is dependent on the type of study). Thus, getting feedback from x very knowledgeable professionals rather than $x \times 10$ people with limited knowledge is the chosen approach for validating the research study. It is extremely difficult to gather experts at such a high level within the oil and gas industry, therefore obtaining feedback from five such individuals is already a challenge in itself. The following four points are addressed in the chapter, namely:

(1) Why the particular interviewees were chosen;
(2) How the points of discussion were formulated and what information was needed from them;
(3) The feedback that was received from the industry leaders; and
(4) Interpretation of the feedback and the status of validation.

6.2 Choosing the Interviewees

The interviewees were strategically chosen based on the positions they held in various O&G companies. In this case, the work is validated based on the feedback obtained from the interviews as discussed in Section 6.3. Five very knowledgeable professionals were identified and approached for interviews, all of whom agreed to participate. The interviewees and the companies they represent will remain anonymous for confidentiality reasons. Instead, they will be referred to as Interviewee A, B, C, D and E respectively.

Interviewee A

This individual has more than 30 years of experience in the oil and gas industry. He holds a Bachelor of Science (BS, Mathematics & Natural Sciences) degree, a Master of Science (MS, Mathematics & Natural Sciences) degree, and a Doctor of Philosophy (PhD, Mathematics & Natural Sciences) degree. He is based in the Netherlands and is currently a director at a major international O&G association, but previously held various high-ranking positions at one of the world's largest multinational energy and petrochemicals companies with more than 80,000 employees in more than 70 countries.

Interviewee B

Interviewee B is an engineering professional with 18 years of experience in the oil and gas industry. She holds a Bachelor of Science (BS, Mechanical Engineering) degree as well as a Master of Science (MS, Materials Engineering) degree. She is based in the United States and is currently in a supervisory role in IT at one of the world's largest multinational oil and gas corporations. She is active in industry task forces around data standardization and digital transformation.

Interviewee C

This individual is an experienced technical manager with more than 10 years' experience in the oil and gas industry. He holds a Bachelor of Science (BS, Mechanical Engineering) degree, a Master of Science (MS, Mechanical Engineering) degree, and a Master of Business Administrations (MBA) degree. He was previously employed as a project lead manager at one of the world's largest multinational energy and petrochemicals companies with more than 80,000 employees in more than 70 countries. He is based in the Netherlands and is currently working in collaboration with other oil and gas companies as a project execution director on a major international project.

Interviewee D

This person has more than 30 years of experience in the oil and gas industry. He holds a Bachelor of Science (BS, Chemistry) degree and a Doctor of Philosophy (PhD, Chemistry) degree. He is based in the United Kingdom and is currently working as a Vice President of one of the world's largest multinational oil and gas companies with more than 70,000 employees operating in Europe, North and South America, Australasia, Asia and Africa. He is active in digital projects and the digital transformation of the company.

Interviewee E
He has more than 30 years' experience in the oil and gas industry, with extensive experience in leading technical and commercial functions in the upstream and midstream segments of the global energy industry. He holds a Bachelor of Arts (BA, Computer Science) degree. He is based in the United States where he has held various managerial positions in IT and is currently managing the IT transformation of a major multinational energy corporation which is active in more than 180 countries. He leads the IT function of this corporation's upstream business on one of the continents.

6.3 Formulating the Points of Discussion

Interviewees received a draft copy of the manuscript and guiding questions seven days before the scheduled interview session. The points of discussion were specifically chosen and structured to guide the interviewee into specific areas of focus in the work while also giving them a chance to reflect on the work as a whole. Chapter 1 serves as a valuable starting point to formulate the points of discussion by looking at the problem statement and research objectives. The following are the points or areas of importance on which to focus during the interviews:

Evaluating the problem statement
The problem statement is key to the study as it outlines the problem addressed by the study and provides the main reason for conducting it. Thus, it is crucial that the problem statement is included in the validation to ensure that the problem outlined is indeed valid and that the findings of the study address that problem. The discussion point is formulated as:

- *Do you agree with the problem statement formulation?*

Evaluating the literature review
The literature review is an important aspect to include in the validation as it equips the reader with the necessary knowledge to understand the study. It is important that the literature review is comprehensive and reflects on all elements which will be referred to in the later parts of the study. The literature review is included as a point of discussion to obtain feedback from the interviewees as to its completeness and whether any part is missing that should have been included. The literature review includes literature on the upstream O&G industry, digital transformation and digital transformation in other industries in Chapters 2, 3 and 4 respectively. Research objectives 1 through 9 (see page 6), which are addressed in those chapters, are evaluated by introducing a discussion point on the completeness of the literature. The discussion point is formulated as:

- *Is there anything obviously missing in the literature?*

Evaluating the deliverable
The deliverable is the main focus of the study and therefore it should be the main focus of the validation. The deliverable (DTR) should be evaluated based on completeness, logic, and if it is understandable. The tenth research objective is evaluated by assessing the proposed Digital Transformation Roadmap which is presented in Chapter 5. The discussion points are formulated as:

- *(a) Are there any elements missing?*
- *(b) Is it understandable?*
- *(c) Is the logic structure correct?*

Determining the value of the deliverable
As part of the validation it is crucial to find out if the study has addressed the problem statement correctly and created value; thus a point of discussion should be to determine if the work has immediate value for the industry? The discussion point is formulated as:

- *Does the deliverable have immediate value for the industry?*

Additional comments
Asking the interviewee for any additional comments allows them to reflect on the work as a whole and give feedback on points which fall outside the predetermined points of discussion. This gives the interviewee the necessary freedom to express their thoughts on other matters which are deemed important to consider.

6.4 Feedback Received

The five interviews were conducted virtually due the interviewees' various locations where they are based around the globe. Table 6.1 shows the time duration of each validation discussion. The feedback obtained from the interviews is summarized and paraphrazed in Table 6.2.

Interviewee	A	B	C	D	E
Time duration	55 minutes	49 minutes	40 minutes	51 minutes	47 minutes

Table 6.1: Time duration of validation discussions

Table 6.2: Feedback received from interviews

INTERVIEWEES	**DISCUSSION POINTS AND RESPONSES**
	1. Problem Statement: Do you agree with the formulation?
Interviewee A	Yes, there is no good roadmap in place in the public domain. Currently, the industry is struggling with priority setting, but digital is seen as extremely important.
Interviewee B	Yes, this is assuming management already understands the value of digital transformation. One of the fundamental problems with the industry is that the future vision is effectively lacking.
Interviewee C	Yes, the industry is not a homogenous entity so even if you developed the most logically compelling roadmap, there is no way to direct the industry. You can only influence and facilitate initiatives and hope the uptake will be there. No one has the answers.
Interviewee D	There are no published roadmaps available. Consulting companies have constructed roadmaps but keep them to themselves because that is their business model (source of income). Other companies and other industries also have roadmaps but keep them to retain competitive advantage. Currently in the O&G industry, digital transformation is considered to be of equal importance to the energy transition to new low-carbon forms of energy. The digital transformation will allow some of the low-carbon energy transitions. Therefore, digital transformation has become absolutely crucial for the oil and gas industry.
Interviewee E	Yes it is correct, however the question arises whether there can be a structured and systematic roadmap which would be broadly applicable given the different ways companies choose to structure and organize themselves. Formulating such a digital transformation roadmap is an ambitious task.
	2. Literature Review: Is there anything obviously missing?

Table 6.2: Feedback received from interviews

INTERVIEWEES	**DISCUSSION POINTS AND RESPONSES**
Interviewee A	No, but it could mention the other initiatives being prioritized by the industry, namely the energy transition to integrated energy companies and standardization.
Interviewee B	No, but in terms of evaluating digital maturity, the USPI Orchid Model provides a good measurement model.
Interviewee C	*No comment. Quickly browsed the literature review.* However, in the interviewee's experience the best literature on the topic were publications addressing the following: • Artificial intelligence; • Standardization of data specifications and data liberation i.e. open access to all in open environment; and • Best articles spend as much time on change management as they do on technology.
Interviewee D	No, it is comprehensive. Can mention that OPEC delayed digital transformation of the industry. Agree with literature that biggest problem is not technology but rather culture (mindset), leadership (need top-down push), access to quality data and lack of standardization.
Interviewee E	No, however there is more recent literature on shale gas and composition of production (Figure 2.15). Also a more consistent level of depth in Chapter 2.
	3. Digital Transformation Roadmap: **(a) Are there any elements missing?** **(b) Is it understandable?** **(c) Is the logic structure correct?**

Table 6.2: Feedback received from interviews

INTERVIEWEES	**DISCUSSION POINTS AND RESPONSES**
Interviewee A	(a) No, it is quite a complete picture that covers almost everything. The industry is currently prioritizing digital transformation, standardization and energy transition. The roadmap could incorporate the other initiatives (energy transition and standardization) to gain more leverage instead of working in isolation. It could also incorporate smaller steps in between where people can see value generated over a much shorter time frame. Small gains through small wins is a good approach for implementation. Lastly, an important point could be to highlight what makes this roadmap specific to oil and gas. (b) Yes (c) Yes, an important point could be to consider if value can be generated quicker based on the lessons learned from other industries.
Interviewee B	(a) No, the business dimensions are correct. More discussion might be required on people and process both in terms of how important they are as building blocks as well as how they are barriers to adoption. Corporate strategy is a fundamental aspect of the business and should be considered as the starting point for formulating a digital strategy, as it completely influences what the future vision should be. Therefore it is important to start with the corporate strategy and determine if it is well-defined and future-looking enough. Another important factor to consider is that not all of the use cases that would lead to a company's digital transformation are going to be things that you would want to implement on a project. Therefore, one should consider that implementation will not always be sequential but instead different routes based on the use cases being explored. (b) Yes (c) Yes; however, it is important to state that the continuous improvement of previous phases (Phases 1 through 5) should rather be viewed as revalidation instead of complete retesting which could become an unnecessary timely process.

Table 6.2: Feedback received from interviews

INTERVIEWEES	DISCUSSION POINTS AND RESPONSES
Interviewee C	(a)No, but digital savviness is crucial under talent and organizational capabilities. Another important point to mention is where in a company to start with the digital transformation (Where do most companies start? Where lies the most value for the company?) Perhaps more emphasis could be placed on tangible outcomes. (b) It is complex. (c) The first part (everything up until implementation) is sensible but not unique to digital; however, it is correct that it can be applied to any industry undergoing any transformational process. The difference comes in at the implementation where the problems often arise. Hard-linking to business outcomes is a prerequisite.
Interviewee D	(a) No; however, more emphasis on change management (it should be included as a business dimension under implementation). An important points to consider is to look at how much change can be undergone at a single moment. Digital can be seen as just a cost, therefore it is crucial to be able to measure return. (b) Yes (c) Yes
Interviewee E	(a) No; however, organizations can pursue digital transformation without industry, therefore it is not a prerequisite but rather an enabler. (b) Yes (c) It is not so sequential; very organic. Digital strategy formulation is more dynamic.
	4. Does the deliverable have immediate value to the industry?
Interviewee A	Yes, the proposed roadmap will provide others with a framework. It structures the thinking process.

Table 6.2: Feedback received from interviews

INTERVIEWEES	**DISCUSSION POINTS AND RESPONSES**
Interviewee B	Yes, assuming digitization is achieved, senior management buy-in regarding the value of digital transformation, and there is enough detail in each phase of the process, it is possible that an organization can be successful in digital transformation by applying the proposed roadmap. Nothing missing from the roadmap compared to the roadmap we have in our organization.
Interviewee C	Yes, it is valuable in its own right. It provides a framework; however, it has to be agile and in that sense how can it be called a roadmap. There are not many publications that will provide a framework like this consisting of all the elements. Therefore, it falls short of a roadmap but definitely provides a framework. It will also allow a company to do a gap assessment.
Interviewee D	Yes, it is useful to industry to breach the public knowledge gap.
Interviewee E	Yes, it is useful for firms that are not exploiting digital capabilities in their business and starting from a blank canvas.
	5. Additional comments

Table 6.2: Feedback received from interviews

INTERVIEWEES	**DISCUSSION POINTS AND RESPONSES**
Interviewee A	It is difficult to convince senior management of the need for any transformation, because they can see the value but also the many years of investment required to obtain value. It is important to find small wins in any transformation process and continuously demonstrating that the transformation is progressing in the right direction (continuously feed small proof points). There needs to be constant communication within all levels of the organization. Defining the right KPIs is important as it drives behavior and cultural change. Other points that the industry needs to ask itself while undergoing a digital transformation include the following: • How many greenfield projects are still going to be pursued? • What can be done with existing assets?
Interviewee B	Organizational digital transformation is possible to a certain extent without industrial digital transformation. A lot of assumptions in the work regarding senior management buy-in and digitization which should be mentioned in the boundary conditions.
Interviewee C	Digital transformation of entire supply chain. Digital transformation is an enabler – a means to an objective. Digital transformation should be pursued to solve specific business problem(s).
Interviewee D	Agile mindset is crucial. Digital projects should be done in an agile manner, not conventional stage-gate manner. Digital transformation can be pursued on a company-level without the industry level standardization, however it is just much more difficult.
Interviewee E	More agile work processes are essential. The digital transformation should be self-sustaining. Digital transformation is not about transformation for the sake of transformation, rather it is about extracting value out of your business in some way. Digital transformation is a tool in that process to allow you to create more value.

6.5 Interpretation of Feedback and Status of Validation

The feedback obtained from the industry leaders highlighted a few points to consider. The feedback can be interpreted by looking at each discussion point separately.

Problem statement

It is fully agreed by all interviewees that there is no *published* digital transformation roadmap available in the public domain. Many O&G companies have acquired digital transformation roadmaps from consulting companies; however, this is a service which is provided by the consulting companies and therefore it is kept from the public domain. Interviewee A and D reflect on the extreme importance of digital transformation in the upstream oil and gas industry which emphasizes the need for developing a digital transformation roadmap which is available in the public domain. Interviewee D even goes so far as to say it has become absolutely crucial for the industry as it aids in the industry's energy transition, and given his position as Vice President of a major international O&G company, it shows senior management support. This is not the case within all the companies, as Interviewee B expressed concerns about the assumption made regarding senior leadership's understanding of the value of digital transformation. However, convincing senior leadership of any transformational process, and the philosophical and cultural reasoning behind it, requires a separate study in its own right and this has been proposed as future research to improve on this study. The scope of this study is merely to propose a digital transformation roadmap for the industry. Interviewee B further raises the point that a fundamental problem facing the industry is that a future vision is effectively lacking. The proposed roadmap directs attention to the importance of the future vision and setting tangible outcomes. Interviewees C and E call attention to the quite different ways companies within the industry choose to structure and organize themselves, therefore questioning if a structured and systematic roadmap could be developed which would be broadly applicable to the industry. This is a valid point and it has been evident that developing a roadmap which would be applicable to all companies would be a near-impossible task; however, as stated in Chapter 5, the proposed roadmap serves only as a guideline for companies to develop their own unique tailored approaches based on specific organizational contexts. Interviewee E still considers this to be an ambitious task.

Literature review

The feedback confirms that the literature review is comprehensive. There were a few considerations from the interviewees; however, there were no commonalities which suggest that nothing evident is missing from the literature.

Interviewee A proposed briefly discussing the other initiatives being prioritized by the industry; namely, the energy transition and standardization. Interviewee B proposed the USPI's Orchid model for measuring digital maturity. This is a valuable consideration as it provides a good framework which companies can use to evaluate the current state during the third phase of the DTR. Interviewee C spent less time on the literature review and felt compelled not to comment; however, based on the study, he listed the best literature in his opinion. This included topics such as AI and other technologies, standardization of data specifications, data liberation and change management of which all topics were covered by the literature review. He further emphasized the importance of giving as much attention to change management as to technology. It was often found in literature that there is an overemphasis on the technological side of digital transformation and not enough attention given to people, culture, standardization and managing change. This is discussed in the literature review and therefore the comments made by Interviewee C further confirm the completeness of the literature review. Similar to the comments made by interviewee C, interviewee D agrees with statements made regarding the focus areas of digital transformation. Lastly, interviewee E points to a general inconsistency in the depth of literature presented in Chapter 2 and more recent literature on shale and other unconventional oil extraction, and composition of production. This is a valid point and is considered for further improvement.

Digital Transformation Roadmap (DTR)

It is generally agreed by all interviewees that there are no elements missing. Interviewee A suggests that the roadmap incorporate the other initiatives (energy transition and standardization) being prioritized by the industry to gain more leverage instead of working in isolation. This is a valid point, and is considered for future research to extend this study. The roadmap refers to standardization; however, the subject of standardization in upstream oil and gas is so vast that a completely separate Master's study can be done on standardization within the industry as is the case with the energy transition to new lower-carbon forms of energy. Interviewee A also points to what makes this roadmap unique to oil and gas or digital transformation. Literature pointed to many common digital transformation, and even general transformation approaches. These were incorporated in the roadmap which was developed in this work, which is why the major part of the roadmap is universally applicable. The difference is observed in the implementation phase. Each industry and organization will approach the implementation of a digital transformation differently depending on factors such as their organizational structure, business model and technological requirements. In this case, the implementation phase is specifically tailored to upstream oil and gas; however differences still exist on an organizational level and should be tailored further by the organization to meet its specific requirements. Interviewee B suggests that more discussion

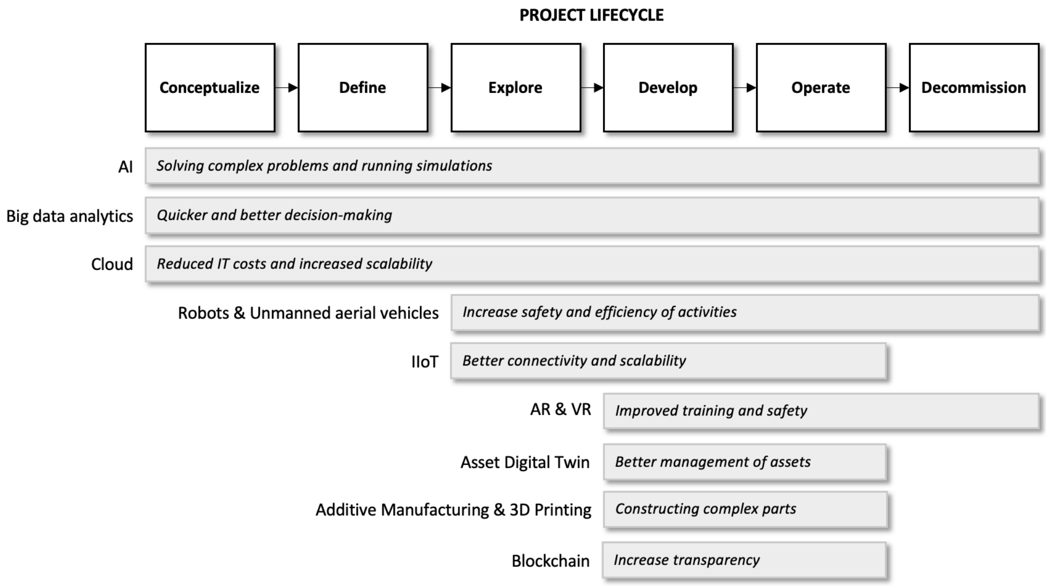

Figure 6.1: Proposed application of key digital technologies in upstream MCPs

on people and processes might be required both in terms of how important they are as building blocks as well as how they can be barriers to adoption. In addition, she suggests that greater emphasis should be placed on the corporate strategy during the process of formulating a digital strategy. The corporate strategy should rather be considered as a starting point for formulating the digital strategy as well as incorporating an additional alignment phase which has been done in the DTR, as it completely influences what the future vision should be. This is a valid point to ensure the digital strategy is based upon the corporate strategy and would encourage companies not to adopt a false dichotomy. Interviewee C suggests that more emphasis should be placed on tangible outcomes. In the DTR, the tangible outcomes are not treated in separation, they are included in the future vision and what is to be achieved by the digital transformation. He further raises the point of where a company should start the digital transformation. This is a valid argument which reiterates the uncertainty due to the differences that exist between organizations in the industry. Referring to the point of "fail fast and obtain small wins", it is important to choose a starting point where digital transformation can generate value quickly without undergoing excessively long periods of investment before obtaining a return. It is also crucial that the return can be quantified in order to provide senior management with proof points on the success and progression of digital transformation. Lastly, the digital transformation can be initiated in business areas where the transformation will solve problems. Thus, it depends entirely on the context of the organization and will differ from company to company.

Figure 6.1 shows a correction of Figure 5.5 to include expected benefits of implementing digital technologies in the upstream segment in an effort to place more emphasis on tangible benefits. This is potentially a powerful tool for mapping the use of digital technologies to more complex business processes. It is accepted that including tangible benefits contributes to building a case for digital transformation in the upstream oil and gas industry.

Referring to point (b), it is agreed that the roadmap is understandable; however, Interviewee C pointed to the complexity of the roadmap. Digital transformation is a complex topic, just like upstream oil and gas is a complex industry. Therefore, it can be expected that a digital transformation roadmap for upstream oil and gas will be complex. However, the roadmap was developed in such a way as to be as understandable as possible, but some complexity still exists.

Referring to point (c), it is generally agreed that the DTR's logic structure is correct; however, Interviewee E states that the process is not so sequential, but rather more organic in nature. In addition, he further states that the digital strategy formulation process is more dynamic. This is a valid observation since it was stated in Chapter 5 that the digital strategy formulation process described is purely to contribute towards the greater roadmap and is merely all the elements that should be considered for the formulation process. In actuality, the formulation process is much more dynamic.

Value to industry
The feedback confirms that the work has immediate value for the industry. Interviewees A and C confirm that it provides others with a framework and structures the thinking process. Interviewee C expresses concerns regarding it being a roadmap and suggests it should rather be referred to as a framework, due to the dynamic nature of digital transformation which requires agile approaches and the vast differences that exist between organizations within the industry making it impossible to direct the entire industry with a single roadmap. Instead, a framework provides the required elements to incorporate and the set of constraints in which to operate. The point made is valid, since the proposed roadmap is essentially a generic starting point to a roadmap requiring organizations within the industry to develop their own digital transformation implementation roadmap tailored to their own organizational structure and context. Interviewee B confirms that organizations can be successful in their digital transformation by applying the proposed roadmap, assuming there is senior management buy-in to digital transformation and enough detail exists in each phase of the transformation process. She further states that there is nothing missing from the roadmap compared to the roadmap her organization is using which strengthens the argument that the roadmap provides value, thereby filling a gap in public knowledge as expressed by interviewee D.

Additional comments

Interviewee A reiterates the point made by interviewee B earlier in the discussion regarding the difficulty of convincing senior management of the need for any transformation. Therefore, he proposes finding small wins in any transformational process and continuously demonstrating that the digital transformation is progressing in the right direction and generating value for the organization. He further emphasizes the importance of communication within all levels of the organization and defining the right KPIs. Measuring the value of digital transformation is still an uncertain subject and should be considered for future research to improve on this study. Interviewees B and D point to the fact that digital transformation can be pursued on a company level to a certain extent without digital transformation on an industry level or industry level standardization; it is just much more difficult. This point is valid; digital transformation on an industry level is not a prerequisite but rather an enabler. However, the purpose of this study is to develop a digital transformation roadmap for the upstream O&G industry, and organizational digital transformation is an enabler for the digital transformation of the entire industry. Each organization needs to build their own capabilities in order to drive the digital transformation of the entire industry through collaborative efforts. Interviewees C and E agree that digital transformation should not be pursued for the sake of undergoing a transformation, it is rather a tool for solving business problem(s) and extracting value. It is an enabler i.e. a means to an objective. Interviewees D and E draw attention to the necessity of having an agile mindset and agile work processes. Digital transformation has been described as an iterative process requiring constant change and adaptation. Agility is a central theme when undergoing a transformational process such as digital transformation. Lastly, Interviewee A proposed points that should be considered in terms of how many greenfield projects are still being pursued and what could be done to existing assets. In this case, he reflects on the two areas of the industry, namely projects and operations. The proposed roadmap addressed the point that there are differences in the approaches used for digital transformation of projects and for operations. In addition, the reasons for undergoing digital transformation and what is finally achieved within the two segments are different. It is not necessarily that greenfield projects should precede the digital transformation of existing assets or vice versa. It all depends on the organizational contexts and where value can be transformed to generate value quickly while keeping in mind the bigger picture of a complete digitally transformed organization.

6.6 Chapter Conclusion

Based on the positive feedback received from the industry leaders and their overall impressions of the work confirms that the work is validated.

Chapter 7

Conclusion to the Study

This chapter draws conclusions from the study and presents limitations and future research opportunities.

7.1 Overview

In chapter one, the research idea of developing a Digital Transformation Roadmap (DTR) for the upstream oil and gas industry is introduced. The research proposal is presented in the form of a problem statement to address the reason for conducting the study, delimitations to set boundaries for the study, research objectives to structure and direct the study, and the research approach and methodology to describe the procedure for conducting the research. Chapters two, three and four form part of the literature study. Chapter two provides an overview of the oil and gas industry, particularly focusing on the upstream segment. Chapter three provides an overview of digital transformation, which starts by formulating a definition for digital transformation, then discussing drivers and objectives, building blocks, success factors, and implications of digital transformation. Appendix A forming part of chapter three, discusses the implementation of new technology. Chapter four investigates digital transformation projects in other industries to identify successful approaches in undergoing a digital transformation. Chapter five presents the proposed DTR and provides the final deliverable of the study. Lastly, the research validation is discussed in chapter six. In the next section, the limitations of the research are discussed.

7.2 Limitations

It is important for any research study to take note of any limitations which are discovered during the study. The limitations which were initially discussed in chapter one, as well as additional limitations which were identified during the course of the study are listed below:

- The study was initially focused on developing a digital transfromation roadmap for Major Capital Projects (MCPs), however, it was soon found that digital transformation must be implemented on an organizational level to create the correct context for MCPs. Thus, the scope of the study was expanded to upstream oil and gas. The upstream segment is chosen due to its high level of activity and capital investment.
- It is assumed that digital transformation will generate significant value for the upstream oil and gas segment and that the industry understands that value. The philosophical and cultural reasoning behind convincing senior management of the need of digital transformation falls outside the scope of this study. That being said, the benefits, as stated by the World Economic Forum (2017), numerous other publications and what has been observed in other industries, are clear.
- The industry knowledge obtained and presented in the study is limited to what is available in the public domain.
- Due to the dynamic and fast changing nature of both the O&G industry and digital transformation, as well as the vast differences that exist between upstream O&G organizations, it is impossible to direct the entire industry with a single roadmap. It was decided to structure the roadmap to be a high-level guide which is adaptable and implementable in organizations with vastly different organizational structures. Thus, as stated in previous chapters, the proposed roadmap serves the purpose of guiding organizations in developiing their own tailored approach to undergoing digital transformation, and is not meant to be a "one-size-fits-all" digital transformation roadmap.

Despite these limitations, valid and valuable outcomes were achived as part of the study. The next section makes recommendations for further future research to improve on this study.

7.3 Future Research

Even though all the objectives were met, during the course of this study areas emerged which will allow for its improvement through conducting further, future research.

- It was assumed that executives understand the benefits of digital transformation in solving business problems and share in the belief that digital transformation is necessary. However, in actuality executives are not always convinced of this necessity and the resistance to change culture is still prevalent throughout the industry. It would be valuable to conduct a study on the philosophical and cultural reasoning of executives and senior management in the presence of transformational change.

- Measuring the value of digital transformation can be difficult and not easily traceable. It is still unclear from literature as to the exact measurement techniques to quantify the value of digital transformation. It would be beneficial to the industry to conduct research on measurement techniques to quantify the value of digital transformation as it progresses. Quantifying the value of digital transformation in monetary terms would assist in building a case for digital transformation in the industry.

- This study provides a broad overview of all the elements upstream O&G companies should consider to effectively undergo a digital transformation; however, each of these elements is a detailed topic and requires a separate study. Determining which elements should be prioritized is also recommended as future research to improve on this study.

- As stated in this study, the recognition of the importance of change management is crucial in any transformation process. It would be beneficial to conduct future research on which change management model would be appropriate for the digital transformation of upstream oil and gas organizations.

- Collaboration within the industry is both a major enabler as well as a tangible outcome of digital transformation. More research is required regarding the extent to which industry knowledge should be shared and where competitive advantage should be pursued or maintained.

7.4 Conclusion

Digital transformation is currently a major topic of interest in many industries around the globe; the upstream oil and gas industry is no exception. Despite this increased attention, there is no published holistic roadmap available in the public domain which aids in the digital transformation of upstream oil and gas. The research study proposes a roadmap for digital transformation of the upstream oil and gas industry to breach this public knowledge gap.

The roadmap is constructed based on an in-depth literature review of the upstream oil and gas industry, digital transformation approaches and best practices, and lessons learned from digital transformation initiatives in other more digitally mature industries. The proposed digital transformation roadmap incorporates the important and relevant elements obtained from the literature study into a single, holistic picture which provides upstream O&G organizations with the required business dimensions and elements to consider for their digital transformation. Further, due to the fast changing landscape of digital transformation and the differences that exist between organizations, the roadmap will assist O&G organizations in structuring the thought processes involved in designing customized digital transformation implementation procedures which can be tailored to each individual organizational structure and context. The research was validated by conducting interviews with five very knowledgable professionals in the industry.

It can be confirmed that at the completion of this study all the research objectives listed in chapter one have been achieved.

(1) Relevant literature was studied and a general understanding of the different segments of the oil and gas industry was attained.
(2) Relevant literature was studied and an comprehensive understanding of the upstream segment was achieved.
(3) The dynamics of the oil and gas industry and the associated impacts on the industry were investigated and discussed.
(4) A thorough definition of digital transformation was developed for the study, based on definitions from peer-reviewed literature.
(5) Drivers and objectives of digital transformation have been identified from literature.
(6) The building blocks, or dimensions, of digital transformation were identified from literature.
(7) Success factors, best practices and implications of digital transformation have been identified.
(8) Relevant literature was studied on digital transformation in other industries.
(9) Trends, common elements, and similarities in the implementation approaches of digital transformation initiatives in other industries were identified.
(10) A Digital Transformation Roadmap (DTR) was formulated to assist upstream O&G organizations in undergoing a digital transformation.
(11) The research was validated through conducting interviews with carefully selected industry experts.

In conclusion, this proposed digital transformation roadmap for the upstream oil and gas industry was confimed to be valid and valuable.

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Appendices

Appendix A

Literature on New Technologies

The aim of this section is to provide literature on various technologies which are referred to throughout the thesis. This serves the purpose of equipping the reader with the relevant knowledge on the technologies mentioned to aid in the understanding of this research paper.

A.1 Artificial Intelligence (AI)

Artificial intelligence (AI) is a popular theme in modern digital innovations characterized by ubiquitous networks, data-drivenness, shared services, cross-border integration, automatic intelligence, and mass innovation (Li *et al.*, 2017).

Merriam-Webster (2011) defines artificial intelligence as:

> *"...a branch of computer science dealing with the simulation of intelligent behavior in computers"* and *"...the capability of a machine to imitate intelligent human behavior."*

Artificial Intelligence is a massive driving force towards digital transformation. It makes it possible for machines to learn from experience, adjust to new inputs and perform human-like tasks. AI relies heavily on deep learning and natural language processing. Using these technologies, computers can be trained to accomplish specific tasks by processing large amounts of data and identifying patterns in the data. AI systems can make decisions and reach different conclusions based on the analysis of different situations independent of human intervention. In other words, AI systems are able to operate autonomously rather than automatically (Čerka *et al.*, 2017).

Artificial Intelligence (AI) technology has numerous benefits. The SAS Institute (2020) identified several points. Artificial Intelligence:

- automates repetitive learning and discovery through data;
- adds intelligence to existing products;
- adapts through progressive learning algorithms;
- analyzes more and deeper data using neural networks that have many hidden layers;
- achieves incredible accuracy through deep neural networks – which was previously impossible;
- extracts the most information (insights) from data.

AI is comprised of numerous fields, shown in Figure A.1, which differ according to functionality, specifications and applications (Villanueva and Salenga, 2018)(Chowdhary, 2020). A brief description of each sub-field, as shown in Figure A.1, is given below.

A.1.1 Machine learning

The tech giant, IBM (2020), defines machine learning as:

> *"... a branch of Artificial Intelligence (AI) focussed on building applications that learn from data and improve their accuracy over time without being programmed to do so."*

In machine learning, algorithms are trained to find patterns and features in large volumes of data (training data) in order to make decisions and predictions based on new data. Today, examples of machine learning are in abundance. Websites recommend music, products, movies, and many other personal items according to a user's search history and purchase history. Autonomous vehicles and robots, covered separately later in this chapter, utilize machine learning algorithms to function (IBM, 2020). Machine learning drives efficiency in both consumer and industrial markets. It will drive greater and greater efficiency as computational power increases, big data gets bigger and data scientists develop algorithms with greater capabilities.

A.1.2 Natural Language Processing (NLP)

Natural Language Processing (NLP), or alternatively referred to as Neural Language Processing, is another sub-field of Artificial Intelligence which originated as the intersection of AI and linguistics (Nadkarni *et al.*, 2011). It is a

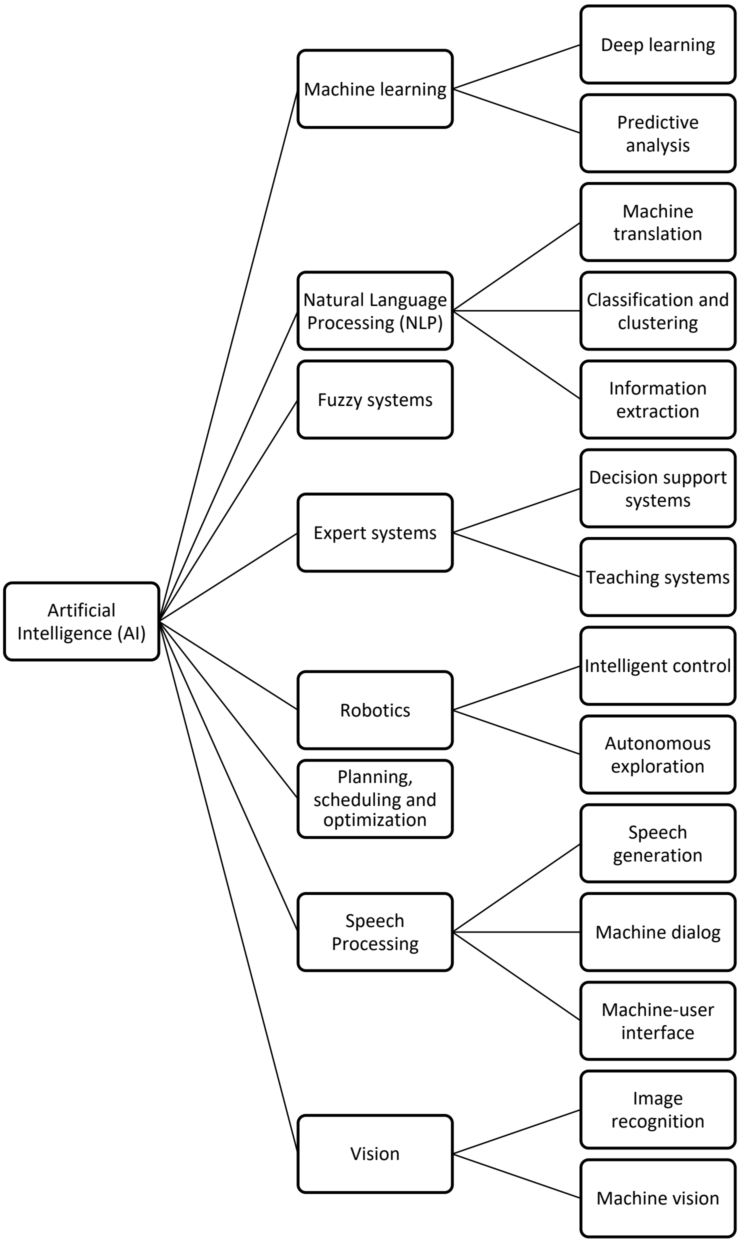

Figure A.1: Fields and applications of Artificial Intelligence, adapted from Villanueva and Salenga (2018) and Chowdhary (2020) research field aimed at extracting, understanding and retrieving rich knowledge resources from unstructured text (Liu *et al.*, 2011).

A.1.3 Fuzzy systems

Fuzzy systems are structures based on 'fuzzy' techniques oriented towards information processing, where the use of classical sets theory and binary logic is impossible or difficult (Prokopowicz *et al.*, 2017). The introduction of fuzzy sets theory was inspired by the necessity to model real-world phenomena, which are inherently unclear and ambiguous. Practical applications of fuzzy systems include problems where the optimization of a control system is based on technical expertise and/or experience by a human operator instead of mathematical models (Shaw, 2013).

A.1.4 Expert systems

Expert systems, alternatively referred to as knowledge-based systems or intelligent agent systems, are computer programs that exhibit a similar high level of intelligent performance to that of human experts. Expert systems solve difficult problems of the real world by performing inference processes on explicitly stated knowledge (Schmalhofer, 2001). In simpler terms, expert systems provide advice in problem solving based on the knowledge of experts, hence the name expert systems (Kim *et al.*, 2012).

A.1.5 Robotics

Artificial Intelligence (AI) is used extensively in the field of robotics which is described later in the chapter.

A.1.6 Planning, scheduling and optimization

Zahraee *et al.* (2016) argue that AI is composed of branches such as Genetic Algorithms (GA), Particle Swarm Optimization (PSO), Simulated Annealing (SA), Artificial Neural Networks (ANN) and hybrid models. However, it has become apparent from literature that the branches identified by *Zahreaee et al* (refer to Figure A.2) are optimization techniques which are used by AI systems, and ultimately fit into the fields of application of AI. Artificial intelligence is used extensively for planning, scheduling and optimization of operations and activities. It utilizes the identified optimization techniques in combination with machine learning to reach optimal solutions to given problems under a set of conditions. An intelligent system will determine what step to take (planning) and when to carry out certain steps (scheduling).

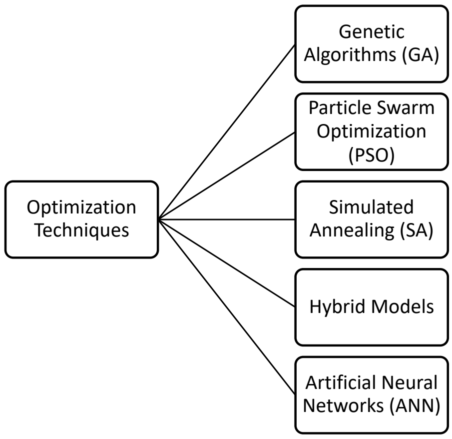

Figure A.2: Artificial Intelligence Optimization Techniques, adapted from Zahraee *et al.* (2016)

The multinational drink and brewing company, Anheuser-Busch InBev (AB InBev), launched a project to optimize last-mile logistics in Brazil by equipping delivery drivers with an AI smartphone application. This application determines the optimal delivery sequence and route for better service delivery by incorporating factors such as traffic, weather conditions, and other factors affecting the delivery of products (AB InBev, 2020). Another example of AI in planning operations is the Extensible Universal Remote Operations Planning Architecture (EUROPA) which is a class library and tool used for constructing timeline-based planners within a constraint-based planning model (Frank and Jónsson, 2003). Figure A.3 shows the main components of the architecture and the hierarchical relationship among them. The EUROPA architecture has been successfully applied in an expansive range of practical planning problems and has a legacy of success at the National Aeronautics and Space Administration (NASA) in the United States) (Barreiro *et al.*, 2012).

A.1.7 Speech processing

Speech processing is another application sub-field of artificial intelligence. Benesty *et al.* (2007) and Minker and Bennacef (2004) identified the following applications of speech processing:

- Coding speech for efficient transmission;
- Automatic Speech Recognition (ASR);
- natural language understanding;
- speech generation;
- aids for the disabled.

When speech generation is used in conjunction with ASR, it allows a

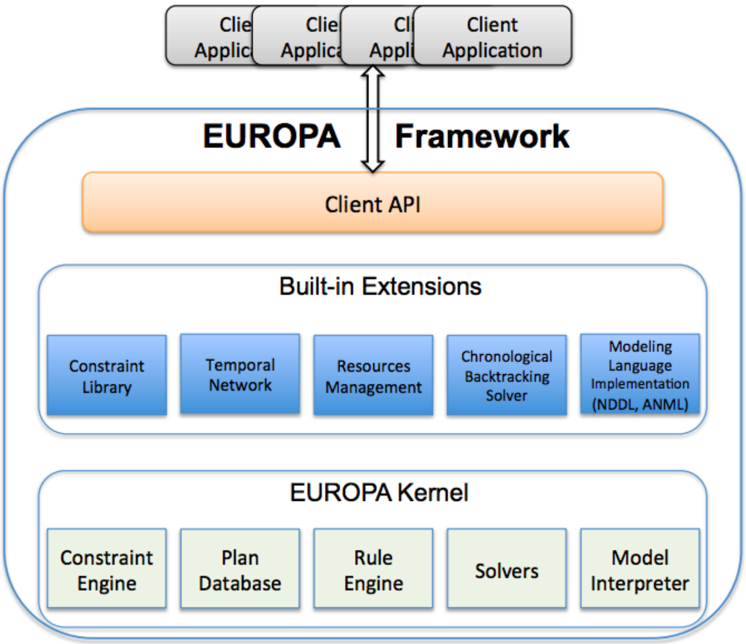

Figure A.3: *EUROPA* Architecture (Barreiro *et al.*, 2012)

complete two-way spoken interaction between humans and machines (machine dialog) (Benesty *et al.*, 2007). Digital assistants such as Amazon Alexa, Google Assistant and Apple Siri perform actions such as searching the internet, providing directions, or playing music in response to human voice commands. Advances in language-translating applications are as a direct result of improvements in the field of speech processing. Spoken phrases are translated to audible and written translated phrases through speech generation and ASR.

A.1.8 Vision

AI is a major component of machine vision, which is often used to inspect a product in a manufacturing operation. There are many more examples of machine vision applications which is discussed later in this section. It is important to identify the components involved in machine vision to understand how it functions, and the role of artificial intelligence in this sub-field. According to Marr (2020), machine vision systems typically consist of the following components:

- sensors;
- frame-grabber (digitizing device);
- cameras (source);
- lighting sufficient for cameras to capture quality images;
- software and computer capable of analyzing images;
- algorithms that can identify patterns (i.e. AI);

- output (e.g. screen or mechanical components).

The process is initiated when the sensors detect the presence of an object. This event triggers the light source to illuminate the object while simultaneously triggering the camera to capture an image of the object or component of the object. The frame-grabber translates the image into digital output. The digital output is then saved by a computer so it can be analyzed by the systems software utilizing AI algorithms. The algorithms compare the file against a set of predetermined specifications to identify defects (Marr, 2020). An example of AI vision application is in the healthcare field where medical image analysis systems aid doctors in identifying tumours.

A.2 Industrial Internet of Things (IIoT) and connected devices

The Internet of Things (IoT) is an emerging sphere of new innovations that promises universal connection to the internet, transforming common objects into connected devices. In other words, IoT is a concept which aims to connect all things to the internet (Mukhopadhyay and Suryadevara, 2014). It paves the way for creating ubiquitous connected infrastructures to support innovative services and promises better flexibility and efficiency (Sisinni *et al.*, 2018). The concept of IoT was first articulated by GE (General Electric) (Leber, 2012). A commonly accepted definition for IoT is given by Satyavolu *et al.* (2015) as:

> *"The IoT represents a scenario in which every object or 'thing' is embedded with a sensor and is capable of automatically communicating its state with other objects and automated systems within the environment. Each object represents a node in a virtual network, continuously transmitting a large volume of data about itself and its surroundings..."*

In simpler terms, IoT can be considered as a global network infrastructure consisting of numerous connected devices that rely on sensory, communication, networking, and information processing technologies (Tan and Wang, 2010). IoT relies on numerous technology components in order to function; a core technology is Radio-Frequency Identification (RFID), which allows microchips to transmit the identification information to a central reader using wireless communication. RFID technology allows the automatic identification, tracking, and monitoring of any objects attached with RFID tags (Jia *et al.*, 2012). Another core technology is Wireless Sensor Networks (WSNs), which mainly use interconnected intelligent sensors to monitor. The applications of WSNs

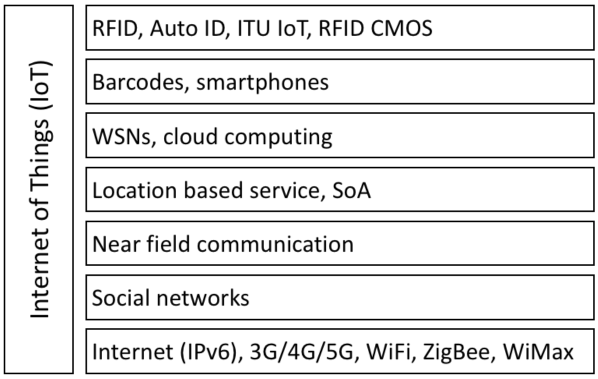

Figure A.4: Technologies associated with IoT, adapted from Da Xu *et al.* (2014)

include environmental monitoring, healthcare monitoring and industrial monitoring (Li *et al.*, 2012) (He and Da Xu, 2012). Advances in both RFID technology and WSNs have significantly contributed to the development of IoT. In addition, many other technologies and devices such as smartphones, barcodes, and cloud computing (refer to Figure A.4) are being utilized to form an extensive network supporting the Internet of Things (Da Xu *et al.*, 2014).

It is important to differentiate the vertical IoT strategies, such as the industrial, consumer, commercial and enterprise forms of the Internet from the broader horizontal concept of the Internet of Things (IoT) (see Figure A.5). They have very different technical requirements, strategies, and target audiences (Gilchrist, 2016). The consumer market has the highest market visibility with personal connectivity, smart homes, and other integrated devices. The commercial market has the highest marketability with services that consist of financial and investment products, such as insurance, banking, ecommerce and other financial services. In this case the focus is on consumer history, value and performance. The Enterprise IoT is a vertical IoT strategy that includes small, medium and large scale businesses. The Industrial IoT, or alternatively called IIoT, has the largest vertical IoT strategy which encompasses a vast amount of disciplines such as manufacturing, logistics, automotive, aviation, agriculture, health care, energy production, and numerous other disciplines (Gilchrist, 2016).

This thesis will focus on the Industrial Internet, or alternatively referred to as the Industrial Internet of Things (IIoT) which is applicable to Upstream MCPs and the entire oil and gas industry in general. To avoid confusion the term Industrial Internet of Things (IIoT) will be used. A complete definition for IIoT is given by Boyes *et al.* (2018):

"A system comprising networked smart objects, cyber-physical

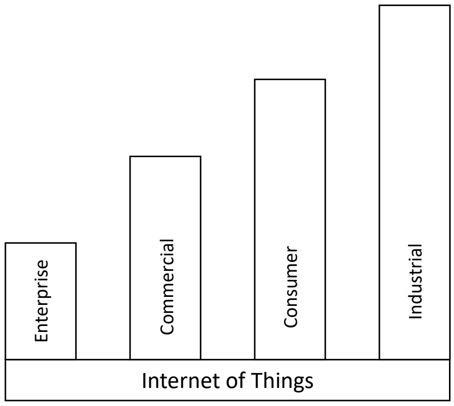

Figure A.5: Horizontal and vertical aspects of IoT, adapted from Gilchrist (2016)

> *assets, associated generic information technologies and optional cloud or edge computing platforms, which enable real-time, intelligent, and autonomous access, collection, analysis, communications, and exchange of process, product and/or service information, within the industrial environment, so as to optimise overall production value. This value may include; improving product or service delivery, boosting productivity, reducing labour costs, reducing energy consumption, and reducing the build-to-order cycle."*

The main difference between IoT and IIoT is in the focus for which the technology is intended. IIoT is built for larger things than smartphones and wireless devices. It aims at connecting industrial assets, like engines, power grids and sensor to the cloud over a network (Helmio, 2018). Other differences between IoT and IIoT, identified by Mathur (2020), are highlighted in Table A.1.

According to Floyer (2013) the definition of the Industrial Internet of Things includes two key components:

(1) The connection of industrial machine sensors and actuators to local processing and to the Internet;
(2) The onward connection to other important industrial networks that can independently generate value.

As a subset of IoT (refer to Figure A.6), the Industrial Internet of Things covers the domains of machine-to-machine (M2M) and industrial communication technologies with automation applications. Connecting unconventional objects to the internet will improve the sustainability and safety of industries and society, and enable efficient interaction between the physical world and its

Parameter	**IoT**	**IIoT**	**Description**
Focus	Consumer	Industrial	IoT caters to the consumer at large while IIoT focuses on industries and factory settings
Accuracy and precision	Low	High	Accuracy and precision for IIoT applications is higher than in IoT applications because industries need to have higher fault tolerant systems because they deal with giant machines
Risk impact	Low	High	IIoT systems work in spaces such as aerospace and healthcare, where the room for error is very low so the risk impact is very high in comparison to consumer-based IoT applications

Table A.1: Differences between IoT and IIoT applications, adapted from Mathur (2020)

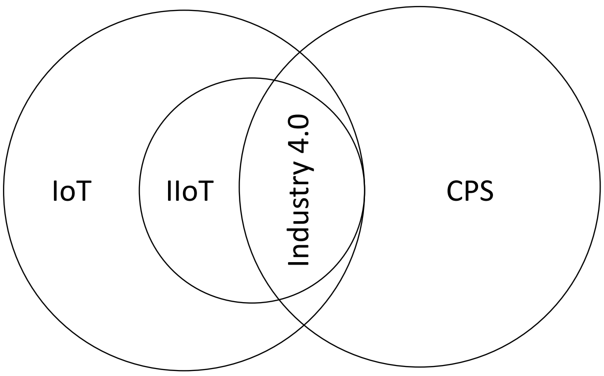

Figure A.6: Venn diagram of IoT, IIoT, CPS and Industry 4.0, adapted from Sisinni *et al.* (2018)

digital counterpart, what is normally referred to as a Cyber Physical System (CPS) (Sisinni *et al.*, 2018). While there are a numerous definitions of CPS, this thesis uses the definition of Boyes (2017):

> *"A system comprising a set of interacting physical and digital components, which may be centralised or distributed, that provides a combination of sensing, control, computation and networking functions, to influence outcomes in the real world through physical processes."*

What differentiates CPSs from more conventional information and communications systems (IT or ICT) is the real-time interactions with the physical world. Whilst both CPS and ICT systems process data and/or information, the focus of CPS is on the control of physical processes. CPSs use sensors to receive information and measurements of physical parameters, and actuators to engage in control over physical processes. Cyber Physical Systems often involve a large degree of autonomy. For example, CPS often have the capacity to determine whether to change the state of an actuator or to draw a human operator's attention to some feature of the environment being sensed (Boyes *et al.*, 2018).

Table A.2 lists common types of IIoT sensors along with their respective functions. Current research shows that IIoT, and Cyber Physical Systems (CPS) have been designed and developed to construct powerful smart factories and related applications (Bregell, 2015). IIoT relies not just on CPS, but also on embedded systems, cloud computing, edge computing, the generic technologies associated with the smart factory, and associated software (Emmrich *et al.*, 2015). In industry, there are alternative systems already in place with some of the functionality of IIoT, e.g. sensors that monitor machine status for maintenance scheduling purposes; however, these systems or sensors rarely communicate with each other or make decisions based on other sensor values; instead they depend on human inputs.

The advancement of IIoT undoubtedly benefits various smart machinery processes. The major advantage is to allow machine tool components to be monitored and/or controlled remotely in real time (Ferrari *et al.*, 2017), which makes IIoT extremely attractive for use in Upstream Major Capital Projects (Upstream MCPs).

Types of Sensors	**Function**
Machine vision	Optics and ambient light detection
Proximity and location	GPS location and presence of objects
Temperature	Detecting temperature in environment
Humidity/moisture	Detecting atmospheric humidity in an environment
Acoustic	Detecting infra and ultrasound vibrations
Chemicals	Detecting chemical content
Flow	Detecting gas and fluid flow in enclosed areas such as pipes
Electro-magnetic	Detecting electro-magnetic levels in the environment
Acceleration	Detecting the tilt of a connected electronic device
Load/weight	Detecting change in load or weight in the environment which is being monitored

Table A.2: Common types of IIoT sensors and their functions, adapted from Mathur (2020)

A.3 Robots and Unmanned Aerial Vehicles (UAV)

Similar to autonomous vehicles, developments in the field of Artificial Intelligence have led to rapid advances of UAV technologies and robotics. Due to the ever-increasing global demand and depleting resources of fossil fuels, the oil and gas industry is actively looking for advanced robotic solutions to increase their productivity and safety. Over time the difficulty of obtaining fossil fuel resources is increasing as the easy-to-obtain resources are shrinking whereas new reservoirs, needed to feed global supply and demand, are being located in more extreme environmental conditions such as deepwater, arctic zones and deserts, leading to logistical challenges in terms of deploying equipment, materials and labour (Shukla and Karki, 2016*b*). The extraction and production of fossil fuels in such inhospitable environmental conditions poses difficult challenges to the Health, Safety and Environment (HSE).

A.3.1 Robotics

Most of the robotics technologies, currently implemented in the oil and gas industry, are largely focused on Inspection, Maintenance and Repair (IMR) of plant facilities. According to Shukla and Karki (2016*b*), the fundamental idea in automating these processes is based on teleoperation with a skilled operator. This is a mechanism where master operators manipulate remotely located robots via communication channels. The automation of IMR tasks not only improves HSE standards, but also leads to economic efficiency by reducing production cycles, floor space and number of staff required for continuous inspection and manipulation of plant facilities. Intelligent drilling, underwater exploration, smart inspection and manipulation of pipes and tanks, and automated operations for final production are areas where teleoperation can provide critical value to the industry.

The largest drawback of robotics currently used in the oil and gas industry is their lack of desired autonomy, robustness and dependability (Albiez *et al.*, 2011). Most of these robots work in highly supervised short-term missions. The lack of autonomy is due to the explosive nature of the product. The associated risk coupled with the extreme environments prevents the replication of automation processes followed in other industries, such as the manufacturing industry, without exercising additional caution. In the manufacturing industry the design of the production line, product and production environment are well defined and nearly static in nature. Thus, since the materials involved in the oil and gas industry are highly sensitive, usage of fully autonomous robotic technology is still not feasible. Alternatively, supervised semi-autonomous operations of robotic technology provide better functionality within the industry.

The function and usage of robotic technology differs in upstream oil and gas depending on the production environment. Table A.3 shows the different uses of robotics in onshore and offshore conditions (Shukla and Karki, 2016*b*). At onshore production facilities, pipelines are used as a means to transport oil, natural gas and other liquids from production sites to refining facilities, and ultimately to distribution sites. The environmental impact on the pipelines can cause corrosion, leaks and other degrading effects leading to loss of revenue and ecological disaster. A variety of tanks are used throughout the production process for storing and transporting oil, natural gas and other liquids both at onshore and offshore production plants. The condition of these tanks also gradually deteriorates over time causing problems. Therefore, regular inspection of transportation pipelines and tanks is required for safe operations. Pipelines are often located underwater or underground making manual inspections an expensive endeavour (Bretschneider and Shetti, 2015).

Inspection robots have greatly simplified this process by reducing the disturbance to the pipelines associated with manual flaw detection procedures. In-pipe Inspection Robots (IPIRs) are inserted into an opening in the pipeline, inspecting the inside as it moves along the pipeline. In addition to being fitted with inspection sensors and cameras, IPIRs are fitted with other sensors such as gravitational sensors (Choi and Ryew, 2002), temperature sensor and

Onshore conditions	**Offshore conditions**
Pipe inspection	Explorations
Tank inspection	Production structure
Automated gas sampling	ROVs and AUVs
Inspection drones	Mobile inspection
Wireless sensor networks	Welding robots for double-hulled ships
	Oil spill situations
	Geographic Information Systems (GIS)

Table A.3: Use of robotics in onshore and offshore conditions, adapted from Shukla and Karki (2016*b*)

Figure A.7: An example of an IPIR (Beuker *et al.*, 2009)

humidity sensors. Figure A.7 shows an example of an IPIR.

Similar to pipeline inspections, robotic solutions have allowed significant improvements in tank inspection procedures. Manual inspection of tanks usually requires the tanks to be emptied, stopping production for a few weeks and resulting in a lengthy process, high capital expenditures and hazard concerns (Shukla and Karki, 2016*b*). Wall-climbing robots with permanent magnet adhesion mechanisms equipped with non-destructive sensors have been developed to carry out inspection tasks. These robots can be operated autonomously or manually. In autonomous mode these robots use a smart coverage algorithm to scan the complete tank surface without human intervention (Kalra *et al.*, 2006). The robots provide data on tank status allowing valuable insight in terms of preventative maintenance and HSE improvements. The use of Unmanned Aerial Vehicles (UAVs) have been beneficial in a large variety of in-

Figure A.8: Examples of ROVs and AUVs (Shukla and Karki, 2016*a*)

spection tasks. The use of UAVs in the oil and gas industry is described later in this section.

In addition to inspection tasks, robotics have allowed the automation of gas sampling tasks required to determine composition and quality of hydrocarbons. Measurement data is automatically gathered from automated measurement and control devices that are located in hydrocarbon production systems. Well-test data, system balance data and hydrocarbon composition data are obtained and compared against data stored in the database to manage the hydrocarbon production and delivery process (Suter *et al.*, 2005).

Lastly, Wireless Sensor Networks (WSNs) which are battery-powered sensors are installed at regular intervals on pipelines to monitor pipeline status. This is to overcome inefficient, costly, hazardous and labour-intensive manual tasks. This is another application of the Industrial Internet of Things (IIoT).

At offshore production plants robotics are used for exploration, inspection, alleviating oil spills and welding tasks. As exploration of new oil fields is moving to deepwater and ultra-deep water environments, sophisticated technological innovations are required to extract fossil fuels from these inhospitable and hard-to-reach conditions. The successful use of robotics in the manufacturing and space industries are examples of how robotic assistance and automation are crucial to the safe and cost-effective future of offshore oil and gas production plants (Shukla and Karki, 2016*a*). Unmanned robotic vehicles such as Remotely Operated Vehicles (ROV) and Autonomous Underwater Vehicles (AUVs) equipped with multiple advanced sensors are able to perform exploration tasks, underwater production structure Inspection, Maintenance and Repair (IMR) and provide surveillance and assistance on drilling operations (Shukla and Karki, 2016*a*). Figure A.8 shows examples of ROVs and AUVs used in the industry.

Oil spillage is a major crisis for the oil and gas industry as a whole. It has severe ecological effects, causing mass media scrutiny, public criticism and sanctions to be implemented. Robots can also serve a purpose in the early detection, mapping, surveillance and clean-up operations of oil spills to actively reduce the environmental effects of offshore oil and gas production (Shukla and Karki, 2016*a*).

A.3.2 Unmanned Aerial Vehicles (UAVs)

UAV technology, alternatively referred to as 'drone technology', has improved rapidly over the past few years, transitioning from originally militarized applications to broader civil and industrial markets (Vergouw *et al.*, 2016). The use of drones for civil purposes is becoming increasingly more popular constantly growing in potential applications such as law enforcement activities, global environmental monitoring, fire services, traffic management and monitoring, power line surveying, aerial photography, oil and gas pipeline condition monitoring, agricultural management and crop monitoring inspections (Vergouw *et al.*, 2016). The potential far-reaching benefit that UAV technology could bring to the oil and gas industry is being seen in other industries. UAVs have the ability to be configured to carry out a variety of different tasks, from performing inspections, surveillance and mapping to delivering payloads. One field where UAVs have provided value is with pipeline surveillance and monitoring. Traditional pipeline condition monitoring has often been restricted to visual inspections and volume and mass balance measurements. Currently, UAV technology is emerging as an opportunity to completely replace traditional pipeline condition monitoring systems (Gómez and Green, 2017).

UAVs are selected based on required task. The data obtained from the UAVs could provide valuable insights into production plant and pipeline condition, enabling automatic scheduling of IMR tasks. Given the popularity of UAVs and reduction in cost, it is generally expected that the ubiquity of drones will increase significantly within the next few years.

A.4 Big data analytics and cloud

A reduction in the cost of sensors, ever-growing computing capabilities and widening connectivity are driving increased volumes of data collection by Oil & Gas companies. Modern offshore production platforms contain roughly 80 000 sensors, which generate an estimated 15 petabytes (or 15 million gigabytes) of data during the asset's life cycle (World Economic Forum, 2017). Big data analytics will enable oil and gas companies to analyse these huge volumes of data.

First, it is important to understand what is meant by the term "big data". Gartner (2020*a*) defines big data as:

> *"... high-volume, high-velocity, and/or high-variety information assets that demand cost-effective, innovative forms of information processing that enable enhanced insight, decision making and process automation."*

Big data generally refers to data that exceeds the typical data storage, processing, and computing capacity of conventional databases and data analysis techniques (Najafabadi *et al.*, 2015). The volume of data generated and operated upon by modern applications is growing at an alarming rate, posing significant challenges to parallel and distributed computing platforms. Big data has emerged as a result of increased storage capacities, increased computational processing power capabilities, and the availability of increased volumes of data provide companies with more data than they can process (Najafabadi *et al.*, 2015). In addition to analyzing massive amounts of data, big data is also associated with other specific complexities, often referred to as the 'five V's' of big data: Volume, Velocity, Variety, Veracity and Value as shown in Figure A.9 (Hwang and Chen, 2017). The high volume of data requires large storage capacity and analytical capabilities not possible with conventional computing environments. The high variety of data implies that the raw data is increasingly diverse and complex, consisting of many different formats such as largely uncategorized data with small quantities of categorized data. This requires preprocessing of uncatergorized/unstructured data in order to obtain structured representations of the data needed for further analysis (Najafabadi *et al.*, 2015). The high velocity refers to the increasing rate at which data is gathered and obtained. It also refers to the inability to process big data in real time and to extract useful insights from it, since data loss can occur if it is generally not processed or analyzed immediately. Real-time data streaming is only useful if it is interpreted in near real time as well (Amundrud, 2017). The importance of velocity is to speed up the process of translating data input into usable information, that is to increase the speed of the feedback loop. The

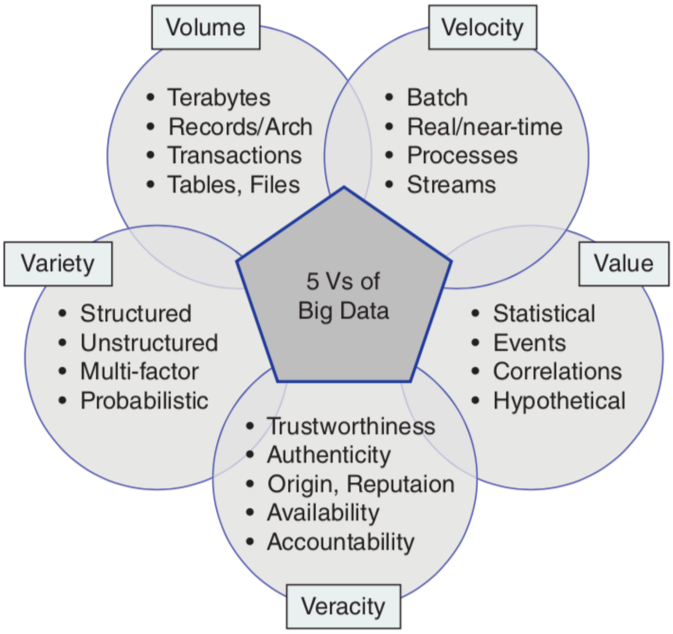

Figure A.9: Five V's of Big Data (Hwang and Chen, 2017)

veracity in big data refers to the trustworthiness, authenticity and usefulness of results obtained from data analysis. It also implies that it is difficult to verify data (Hwang and Chen, 2017). The quality of results obtained from data analysis is directly linked to the quality of the data input. Lastly, value is the most important aspect of big data. It is important to create value from big data such as predictions and other valuable insights, otherwise the big data becomes useless (Anuradha *et al.*, 2015).

Big data analytics is the process of inspecting large and complex data assets that require cost-effective management and analysis to uncover hidden patterns, determining correlations and extracting other useful information and insights (Gupta and George, 2016). Big data is concerned with data volumes measured in terabytes and petabytes (Anuradha *et al.*, 2015), but according to Hwang and Chen (2017) by today's standards, one terabyte of data or greater is considered big data. The goal of big data analytics is to enhance organizational decision-making capabilities and decision execution processes (Tabesh *et al.*, 2019). Information uncovered from such big datasets can provide organizations with competitive advantages over rivals, and result in higher business intelligence, scientific discovery and better decision-making (Hwang and Chen, 2017). The growing interest in the field of big data analytics is justified through the volume of global digital data doubling every 2 years and the continuous exponential growth of the amount of useful business-related data (Turner *et al.*, 2014). Henke *et al.* (2016) estimated that roughly 90% of digital data available in 2016 had been generated in the previous 2 years.

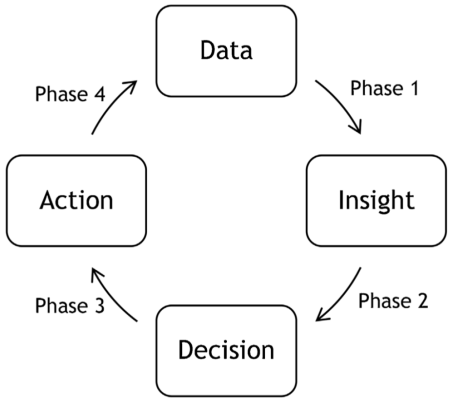

Figure A.10: Big Data Analytics Cycle (Tabesh *et al.*, 2019)

Today, continuing on the digital data trend, the same percentage of available digital data is generated in even less time.

From a managerial perspective, the high-level process of big data analytics can be divided into four important phases as shown in Figure A.10 (Tabesh *et al.*, 2019):

(1) Phase 1: Data is collected, processed and analysed;
(2) Phase 2: Information and insights obtained from data analysis are used in decision-making;
(3) Phase 3: Decisions are transformed into specific operational action;
(4) Phase 4: Actions generate additional data and the cycle starts again.

Since most of the actual big data analytics occurs in phase 1 and phase 4, it is important to gain a more in-depth explanation regarding data generation (Phase 4), data collection, preprocessing, storage, cleaning and analysis (Phase 1). Data generation is the first step in big data. Data can be generated from multiple data sources such as sensing information in IIoT, human inputs, scientific discovery, and all other available data sources including Log files. After data is collected, data transmission occurs to transfer the raw data to storage management systems to support different analytical applications. Big data storage refers to the storage and management of large datasets while achieving reliable data access. The storage infrastructure needs to provide information storing services with capable storage capacities, as well as powerful access interfaces for query and analysis of data (Hwang and Chen, 2017). Raw data often contains redundant and useless data. Once data is successfully collected and stored, data preprocessing is necessary to eliminate redundant and useless information to optimize storage space, as well as transform the raw unstructured data into a structured form necessary for data analysis. The data preprocessing involves cleaning the data to identify, modify and/or eliminate inaccurate, incomplete and unreasonable data to improve data quality. During data cleaning, data formats, completeness, rationality, and restriction should by examined (Hwang and Chen, 2017). Another facet of preprocessing involves data integration which is the combination of data from multiple sources to provide a comprehensive and uniform view of the data. There are multiple techniques that can be employed in data analysis. The type of techniques used depends on the type of data being analyzed, the available technology and the desired information to be obtained (Anuradha *et al.*, 2015). Machine learning and other AI techniques can provide invaluable analyzing capabilities.

The concept of cloud computing provides ubiquitous services, resource efficiency and application flexibility (Hwang and Chen, 2017). Cloud computing is a construct that allows you to access applications and databases that reside at a location other than your computer or other internet-connected device, most often this will be a distant data center (Velte *et al.*, 2009). The National Institute of Standards and Technology (NIST) provides a definition which is often cited in literature:

> *"Cloud computing is a model for enabling ubiquitous, convenient, on-demand network access to a shared pool of configurable computing resources (e.g., networks, servers, storage, applications, and services) that can be rapidly provisioned and released with minimal management effort or service provider interaction"* (Mell *et al.*, 2011).

For the purpose of this study it is not necessary to provide detail on the various tools and infrastructures involved in big data analytics and cloud computing. However, a general characterization of big data analytics and cloud computing according to theoretical foundations, hardware, software, networking enablers and service providers is provided in Table A.4. This is not a comprehensive list; it only serves as an example of big data and cloud characterizations.

A strong analytics capability is key to digital transformation as big data analytics have become a necessary resource in value creation. This ability to effectively deploy technology and talent to capture, store and analyze data, towards value creation and business change is vital to digital transformation (Gupta and George, 2016)(Loebbecke and Picot, 2015)(Mikalef *et al.*, 2018). To achieve this a data-driven culture is required, which will allow decision-makers to base their decisions on insight rather than on instinct (McAfee *et al.*, 2012). Pappas *et al.* (2018) conceptualized the big data and business analytics ecosystem in the Digital Transformation and Sustainability (DTS) model (see Figure A.11), along with the factors that need to cooperate, coor-

	Big Data Analytics	**Cloud Computing**
Theoretical Foundations	Data mining, machine learning, artificial intelligence	Virtualization, parallel and distributed Computing
Hardware Advances	Data centers, clouds, search engines, big data lakes, data storage	Server clusters, clouds, virtual machines, interconnection networks
Software tools and libraries	Spark, Hama, DatTorrent, MLlib, Impala, GraphX, KFS, Hive, Hbase, OpenStack, GFS, HDFS, MapReduce, Hadoop, Spark, Storm, Cassandra	Spark, Hama, DatTorrent, MLlib, Impala, GraphX, KFS, Hive, Hbase, OpenStack, GFS, HDFS, MapReduce, Hadoop, Spark, Storm, Cassandra
Networking enablers	Co-location clouds, mashups, P2P networks, etc.	Virtual networks, OpenFlow networks, software-defined networks
Representative service providers	AMPLab, Apache, Cloudera, FICO, Databricks, eBay, Oracle	AWS, GAE, IBM, Salesforce, GoGrid Apache, Azure Rachspace, DropBox

Table A.4: Big data analytics and cloud computing technologies characterized by theoretical foundations, hardware, software, networking and service providers, adapted from Hwang and Chen (2017)

dinate and collaborate to enable the use of big data towards achieving digital transformation and creating sustainable societies.

Software as a Service (SaaS) allows users to connect to and use cloud-based applications over the internet, while Platform as a Service (PaaS) is a complete development and deployment environment in the cloud, with resources that enable you to deliver everything from simple cloud-based applications to sophisticated, cloud-enabled enterprise applications.

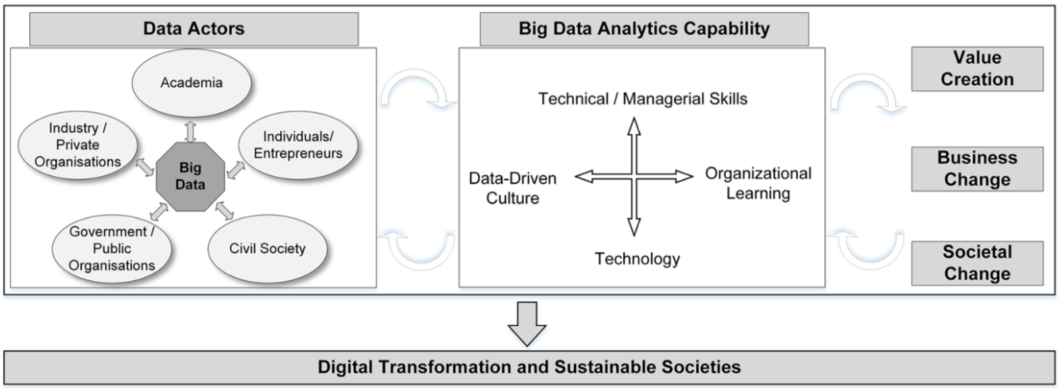

Figure A.11: The Digital Transformation and Sustainability (DTS) model (Pappas *et al.*, 2018)

A.5 Custom manufacturing and 3D printing

Additive manufacturing (AM), commonly referred to as 3D printing, translates Computer-Aided Design (CAD) virtual 3D models into physical objects. It has emerged as a versatile technology platform for CAD and rapid manufacturing by which an object is produced in an additive fashion, layer-by-layer (Zhang and Jung, 2018). AM allows the production of customized parts from metals, ceramics and polymers without the need for moulds and machining typical for conventional subtractive and formative manufacturing techniques as shown in Figure A.12 (Ligon *et al.*, 2017). The advancement of additive manufacturing techniques has initiated a new round of manufacturing revolution by providing greater flexibility for design and fabrication of customized products and parts with complex geometries. AM has branched out from primarily serving as a prototyping technique, to the production of functional parts and end-use products (Yuan *et al.*, 2019). In this thesis, the terms additive manufacturing (AM) and 3D printing are both used to refer to the same general manufacturing principle.

The basic principles of additive manufacturing are shown in Figure A.13. (a) Design and development of product idea that is transformed into digital data by means of CAD or analysis of geometric data by 3D scanning; (b) the preprocessing of model data involves slicing the virtual model into layered data, path planning, generation of support structures for overhanging portions, and subsequent transfer of layered data to 3D printer; and (c) the actual additive manufacturing of product and post-processing such as surface smoothing and removal of support structures (Ligon *et al.*, 2017). Support structures are necessary to stabilize overhanging structures during the manufacturing process, for example the handle of the coffee mug pictured in Figure A.15.

The key benefits of AM, identified by Vendra and Achanta (2018), are

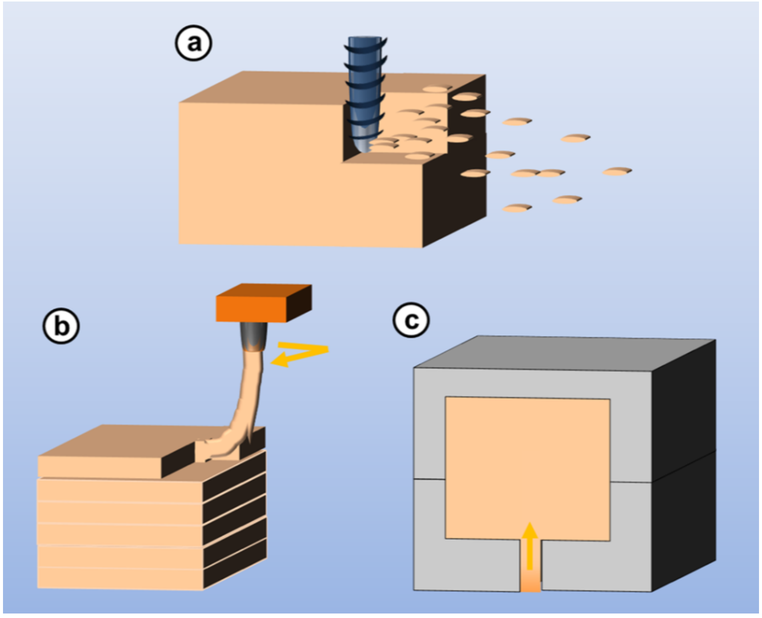

Figure A.12: Comparison of (a) subtractive manufacturing, (b) additive manufacturing, and (c) formative manufacturing techniques (Ligon *et al.*, 2017)

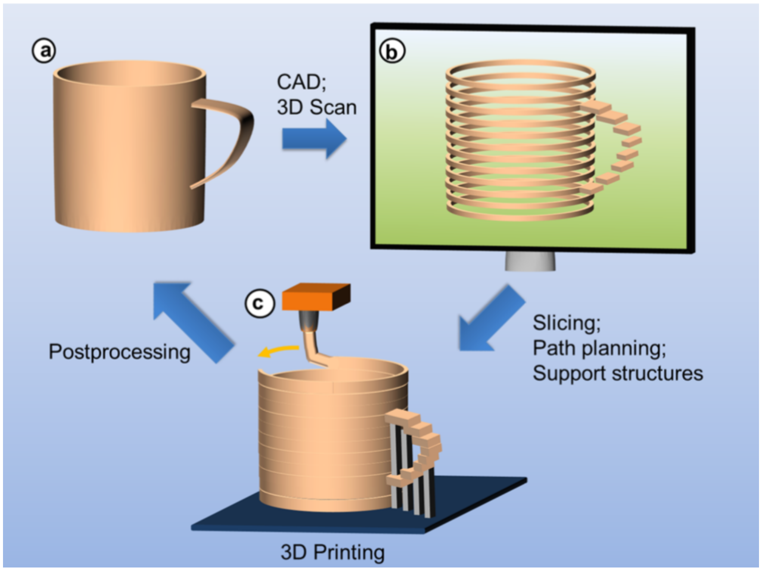

Figure A.13: Basic principles of AM (Ligon *et al.*, 2017) listed below:

(1) **Accelerate design innovation** – AM allows for faster testing of prototypes, innovative design through iterations to improve quality and reduce lead time of new parts.
(2) **Increase product performance** – AM allows for the manufacturing of parts that are lighter, stronger, more efficient in design and functionality, and of higher complexity than previously possible with traditional techniques.
(3) **Reduce supply chain cost** – AM facilitates rapid manufacturing through the reduction in the total number of assembled parts.
(4) **Simplify systems** – AM simplifies structures by reducing part counts through parts consolidation, assembly elimination and more robust designs.

Additive manufacturing is inherently agile, allowing faster turn-around of designs and significantly shorter product development cycles of customised objects due to parts consolidation and elimination of machining and/or moulding processes. AM in conjunction with IIoT has the potential to revolutionize computer-guided fabrication, change the supply chain architecture by on-site production of parts and on-demand manufacturing, eliminate inventories of spare parts, and reduce costs and lead times (Ligon *et al.*, 2017)(Vendra and Achanta, 2018).

3D printing has seen widespread application in the aerospace, automotive and healthcare industries, with the benefits being realized in other industries as well. The oil and gas industry is in the early stages of the adoption of additive manufacturing, mostly using AM for rapid prototyping. However, there has been a major shift in the oil and gas industry's focus, from regarding additive manufacturing as a rapid prototyping tool to regarding it as a rapid manufacturing tool (Vendra and Achanta, 2018). General Electric utilize additive manufacturing for components in their oil and gas turbines, and is expected to start 3D printing of parts for centrifugal pumps and artificial lift systems. Other examples in the oil and gas industry include AM to reduce part counts in drilling assemblies from several parts to a single part. Manufacturing processes are completed in a few hours, compared to days or weeks needed for machining processes. This new transition from rapid prototyping to rapid manufacturing prompts new challenges both for mechanical engineers and material scientists.

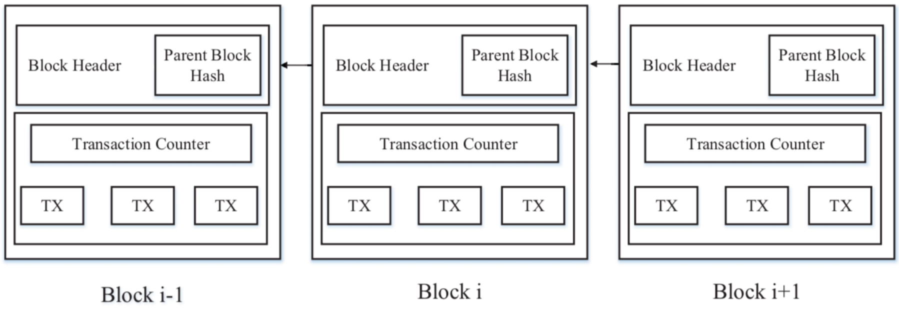

Figure A.14: An example of a blockchain (Zheng *et al.*, 2017)

A.6 Blockchain

Blockchain has demonstrated its value in financial services and now presents a great opportunity for implementation in the oil and gas industry to drive cost savings (Kim, 2018). Blockchain is contributing towards laying the foundation for a digital finance revolution within the oil and gas industry, streamlining finance and accounting processes and data within the modern enterprise (Olmedo and Megna, 2018). Implementing blockchain could pave the way towards collaborative ecosystems between business partners; in this case, collaboration between upstream, midstream and downstream oil and gas companies. Gartner (2020*b*) defines blockchain as:

> *" ...an expanding list of cryptographically signed, irrevocable transaction records shared by all participants in a network. Each record contains a time stamp and reference links to previous transactions. A blockchain is one architectural design of the broader concept of distributed ledgers."*

More simply, blockchain can be described as a distributed database technology allowing for the secure transmission of information between external parties without reliance on a central authority (Olmedo and Megna, 2018). It holds a complete list of transaction records in a sequence of blocks. The chain grows as new blocks are continuously added to it. Figure A.14 shows an example of a blockchain. For the purpose of this study only a brief explanation of the blockchain architecture is necessary. A block consists of a block header and a block body. Figure A.15 shows the contents of the block. First it is important to understand the term *hash*. A hash is a function, created by an algorithm, that converts an input of letters and/or numbers into an encrypted output of a fixed length (Investopedia, 2020).

The block header consists of the following (Zheng *et al.*, 2017):

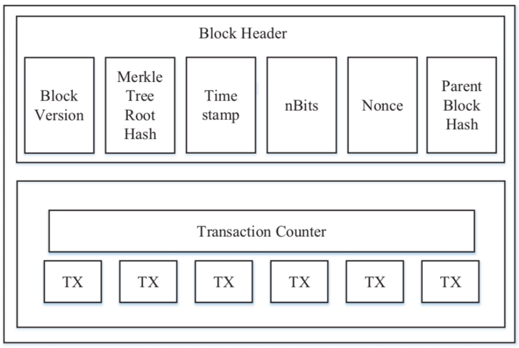

Figure A.15: Block structure (Zheng *et al.*, 2017)

- Block version: indicates which set of block verification rules to follow;
- Merkle tree root hash: hash value of all transactions in the block;
- Timestamp: current time in universal time;
- nBits: target threshold of valid block hash;
- Nonce: abbreviation for "number only used once" which is a number that increases for every hash calculation;
- Parent block hash: hash value that points to the previous block.

The block body consists of a transaction counter and transactions. The number of transactions a block can contain depends on the block size and the size of each transaction. The transactions are repeated in identical copies in multiple nodes. Asymmetric cryptography and distributed consensus are used for security and ledger consistency (Zheng *et al.*, 2017), to ensure that copies are identical and there no duplicated transactions exist (Kim, 2018). Blockchains order and validate transactions in the database to achieve the necessary consensus between the service performed, the service ordered, and the invoice received. Using blockchain to share secure access to transactions would eliminate the need for costly reconciliations, audits and third parties. The risk of overpayment is also greatly reduced in the process. More simply, blockchain has the potential to significantly reduce discrepancies in the process by enhancing transparency and improving accuracy in financial and accounting processes (Kim, 2018).

In addition to financial and accounting processes, blockchain can be used in other fields such as smart contracts (Kosba *et al.*, 2016), the Internet of Things (IoT) (Zhang and Wen, 2015) and security services (Noyes, 2016).

A.7 Digital Twin

A digital twin is a comprehensive digital representation, or virtual replica, that mirrors a physical product or facility in real-time (Grange *et al.*, 2018; Haag

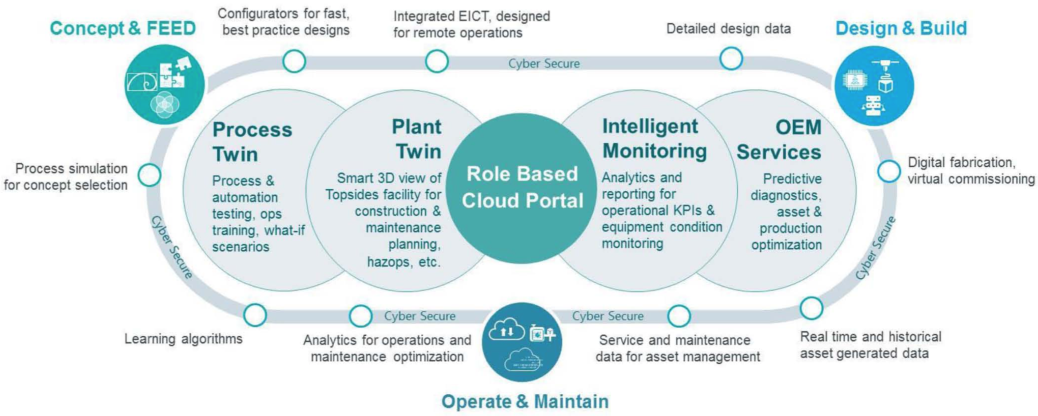

Figure A.16: Intelligent digital twin structure (Grange *et al.*, 2018)

and Anderl, 2018). The digital twin includes the condition, behaviour and properties of the physical object through data and models.

The digital twin is developed in conjunction with its physical twin and remains a virtual counterpart across the entire product lifecycle (Haag and Anderl, 2018). The objective of the intellegent digital twin is to realistically replicate the process and equipment behaviours of the physical asset in the digital world. The intelligent digital twin gives operators the capability to monitor changing site conditions, predict equipment failures before they occur, plan outages, manage inventories, optimize equipment performance, and model how the equipment will perform if site conditions change. Digital twins provide a host of advantages, including the ability to run virtual what-if scenarios on an asset and better understand how process, equipment, and maintenance would be impacted by different operating conditions (Grange *et al.*, 2018).

An example of the structure of an intelligent digital twin is shown in Figure A.16. In this case, the structure is that of a topside facility digital twin for offshore oil and gas assets.

A.8 Augmented Reality (AR) and Virtual Reality (VR)

Virtual Reality (VR) and Augmented Reality (AR) are important technologies for virtual engineering and form the basis for functional virtual prototyping. These technologies enable engineers to analyse and design future products in an immersive and interactive virtual environment (Ma *et al.*, 2011). These technologies can bring about significant changes to work processes, which can be applied to improve productivity, safety and communication, and help guide work flows. Albeit these two technologies share many similarities, they are discussed seperately due to the different applications and opportunities they present to the upstream oil and gas industry.

A.8.1 Virtual Reality (VR)

VR technology consists of a fully computer generated, three dimensional environment, in which the engineer can interact wit and manipulate a realistic representation of the product in real time (Ma *et al.*, 2011). A VR system typically consists of a Head Mounted Display (HMD) with screens in front of the eyes or projection-based display systems that consist of several projections in different configurations to create the virtual environment. VR technology pose great potential for aiding in the design of projects and training of workers. As stated earlier, VR enables virtual prototyping which can reduce costs and lead times of projects.

A.8.2 Augmented Reality (AR)

AR takes the notion of VR one step further, where it enriches the user's view on the real world with virtual objects, which are overlayed at the right time and position regarding the user's perspective (Ma *et al.*, 2011). Augmented reality can be applied to numerous devices such as HMDs fitted with cameras or mobile devices. AR have seen widespread application in many products and industries alike and the possibilites and opportunities it presents keep on growing. One of the most basic AR applications is the Heads-up Display (HUD) which are being implemented in many automobiles and aircrafts where important information is overlayed on the pilot's direct line of sight. AR technology pose great potential for improving projects and operations in upstream oil and gas. Maintenance procedures can be relayed to workers on the asset via AR systems which could reduce asset downtime and increase operational efficiencies. This is just one example of a possible AR application which would be beneficial to the industry, in reality AR can be applied in many different forms to assist all types of workers to better carrying out their tasks.