Benefits and implications of Augmented Reality Positioning Systems for Offshore Topside Installations

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Benefits and implications of Augmented Reality Positioning Systems for Offshore Topside Installations

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'If you want to feel secure
do what you already know how to do.
But if you want to grow…
go to the cutting edge of your competence,
which means a temporary loss of security.
So, whenever you don't quite know what you are doing,
know that you are growing…'

Viscott, 2003

Preface

This journey started two years ago, when I chose to conclude my engineering studies through a Management of Technology Master program at Delft University of Technology. This program has taught me to combine scientific insights from the different engineering disciplines and to apply the diverse aspects of technology and innovation management. In addition, it has provided me enriching personal and academic experiences, such as the opportunity to spend one semester abroad at National University of Singapore, where I extended my social, intrapersonal and educational skills.

This master thesis has been developed in collaboration with TWNKLS, an augmented reality company, and Heerema Marine Constructors, a marine contractor company. This research would have not been possible without the time, support and resources that they have provided me. I would also like to thank my supervisors for their valuable ideas and comments throughout this period. I am especially thankful to my first supervisor, Stephan Lukosch, and my external supervisor, John Schavemaker, for the continuous guidance, and the trust and confidence placed in me from the early beginning.

I would like to express my gratitude towards my family and friends, they are the ones who make me success and overcome every new challenge. I want to thanks my parents for the education they have provided me and for their unconditional support; and to my grandparents, for being my role models to follow. I wish to thank my friends, for becoming my family these last two years, for taking care of me. Family, friends, thank you for keeping on challenging me to raise the bar and for providing me with a cushion to land on when I fall.

Rocío Domínguez Ollero,

July 2017, Delft, The Netherlands.

Abstract

The oil and gas industry is seeking to improve safety on its current operations procedures (Choudarki, 2012). From all oil and gas operations, Topside Installation Processes (TIP) are the only offshore activity that counters one of the golden safety rules, “do not stand or walk under suspended loads” (Peuscher & Groeneweg, 2012). As a consequence, marine companies are seeking to improve these processes through different technological solutions (Heerema Marine Contractors, 2014).

TIP generally consist on the lifting of a heavy module, topside, and its placement on a fixed structure on the sea, jacket (Hee et al., 2007). Traditional positioning tools such as bumpers and guides are not suitable for these type of processes given the heaviness and big dimensions of topsides (Heerema Marine Contractors, 2017). As a consequence, part of the vessel crew is located on the jacket, under the suspended topside, to guide the positioning processes (Breidablikk, 2010). TIP imply the presence of crew members under a suspended load, which is contrary to oil and gas companies’ safety policy.

The offshore industry is currently investigating ways to circumvent having personnel on the jacket during topside installations (Heerema Marine Contractors, 2014). The implementation of a camera-based augmented reality positioning tracking system could fulfil the current safety requirements. The use of augmented reality as a positioning tool is a completely new technology that has never been used before in this domain. This research explores the potential expected benefits of the use of an Augmented Reality Positioning System (ARPS) during Offshore Topside Installation Processes (OTIP). This research also investigates the system’s usefulness and the users’ system perception on its usability in OTIP. Moreover, it explores the implications and factors that should be considered in order to successfully implement the ARPS in this type of processes.

The research is based on a case that relates to the first augmented reality positioning system for topside installation processes, that is being developed by TWNKLS and Heerema Marine Contractors. The research methodology is based on data collected from different experiments and interview processes. The conclusions include discussion about the benefits, usability and implications of ARPS in OTIP, and recommendations for the ARPS developing companies and for future research.

Key words: Augmented Reality, Innovation, Topside Installation, Safety, Offshore, Positioning Processes.

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Abbreviations

A	*Attitude Toward Behaviour*
BI	*Behavioural Intention*
ARPS	*Augmented Reality Positioning System*
CO	*Crane Operator*
E	*Easy to Use*
ENA	*Electronic Navigational Aids*
Eng.	*Engineering*
EV	*External Variables*
HMC	*Heerema Marine Contractors*
IAR	*Industrial Augmented Reality*
LLS	*Laser Levelling System*
MI	*Management Interface*
NASA	*National Aeronautics and Space Administration*
NMC	*New Media Consortium*
OTIP	*Offshore Topside Installation Processes*
PPT	*Power Point Template*
R	*Round*
RQ	*Research Question*
S	*Superintendent*
SLAM	*Simulation Localisation and Mapping*
SN	*Subjective Norm*
SME	*Scale Model Experiment*
SUS	*System Usability Scale*
TAM	*Technological Acceptance Model*
TIP	*Topside Installation Processes*
TPB	*Theory of Planned Behaviour*
TRA	*Theory of Reasoned Action*
U	*Perceived Usefulness*
UEQ	*User Experience Questionnaire*
UI	*User Interface*
UTAUT	*Unified Theory of Acceptance and Use of the Technology*
VRE	*Virtual Reality Experiment*

1. Introduction

The oil and gas industry is seeking to improve safety on its current operations procedures. Companies are adopting a continuous regulatory improvement policy that promotes high safety standards based in continuously developments and improvements (Choudarki, 2012). Concerning oil and gas operations, offshore installations are considered as one of the most challenging processes due to the uncontrolled environment and the generally complex operations involved (Heerema Marine Contractors, 2014).

Installation of topsides consists on the lifting of a heavy module, called topside, and its positioning onto a structure that is placed on the sea and support the module, called jacket (see Figure 1). This process is considered the most challenging offshore installation activity because it is a long process that requires the lifting of extremely heavy, up to 10,000 tonnes, and big structures on an uncontrolled environment (Breidablikk, 2010; Hee et al., 2007).

Nowadays, Offshore Topside Installation Processes (OTIP) are based on measurements estimations from the vessel crew, that stands on the jacket during the installation of the topside to observe its relative position to the jacket. Thus, this process requires employees to stand on the jacket under the suspended topside, what counters to one of the golden safety rules, “do not stand or walk under suspended loads” (Peuscher & Groeneweg, 2012). Traditional positioning tools such as bumpers and guides are not suitable given the heaviness and big dimensions of topsides (Heerema Marine Contractors, 2017), and therefore, part of the vessel crew is located on the jacket to guide the topside positioning processes. Topside Installation processes are the only offshore operation that breaks this golden safety rule.

Figure 1. Topside Installation.
Source: HMC.

Safety requirements on the oil and gas industry are becoming more and more stringent and OTIP should be adjusted to the current safety rules. Companies, such as Shell, specifically require that no one should stand under a suspended load in any of the operations. Therefore, every time a topside is installed, a waiver form declaring that the current topside positioning process applied is safe needs to be signed (Heerema Marine Contractors, 2014). Even though until now, no accidents on OTIP have taken place, the perceived safety concerns related to people standing under the topside during its installations are driving the offshore industry to explore different methods to allow offshore topside installation processes on unmanned jackets.

Different technological innovations that can replace human presence on the jacket are being considered, such as laser systems and drones (Heerema Marine Contractors, 2014). Laser systems technology is suitable for the positioning of structures and it has been recently tested offshore by several companies such as Heerema Marine Contractors. Drones has not been applied on offshore operations. Despite increasingly popular applications of drones in diverse sectors, drones are critically constrained by limited battery lifetime and they are conditioned by the dynamic operating environment (Tseng et al., 2017).

A third technology that could allow topside installation on unmanned jackets is the application of an augmented reality positioning system. In the past two decades, the applications of AR have been increasingly receiving attention, specially on the industrial sector. Augmented reality (AR) refers to technologies that combine the real and the virtual world in any location-specific way, where both real and virtual information play significant roles (Klopfer & Squire, 2008). AR takes place on the real environment, that is extended with virtual information and imagery (Lee, 2012). It is technically possible to use AR to measure objects (Daponte et al., 2014), and therefore to position structures.

However, the introduction of a new technology that increase safety usually leads to higher cost that hampers its introduction and usage (Mendes et al., 2014), this is the case of laser systems introduction on OTIP. As a consequence, it is important to manage the balance between cost and safety when introducing a technology such as AR as a positioning tool in OTIP on unmanned jackets.

The application of an AR technology for topsides installations represents an innovative approach that is especially challenging for the offshore industry, that is characterized for a traditional approach and lack of innovation (Barlow, 2000). Another main challenge on introducing a new positioning technology for OTIP is the complexity and low frequency of these processes (Breidablikk, 2010), that hampers the testing of new technologies in real offshore conditions.

The introduction of novel technologies, besides performance efficiency, requires user acceptance and willingness to use to be successful (Lin, 2013), and a study on possible implications of the system (Markham, et al., 2010). These factors are even more relevant in traditional sectors. Nowadays, it is uncertain which are the potential benefits of the introduction of an AR system, its usability and its implications on topside positioning process.

1.1 Research Objective

This research explores the potential benefits, users' acceptance and possible technological implications of introducing an AR system as a positioning tool for topside positioning processes, which is one potential technological solution to the current safety issues involved in OTIP. This is an explorative research based on the first Augmented Reality Positioning System (ARPS), that is currently being developed by TWNKLS, an augmented reality company, and Heerema Marine Constructors, a marine contractor company, for topside installation processes.

The research goal is to depict the potential benefits, usability and implications of ARPS in offshore topside positioning processes. There is a focus on the potential perceived safety and cost benefits, on the acceptance and usability perception by stakeholders, and on the impact and implications of the system introduction in the offshore industry. The final objective is to drive conclusions on the development, usability and impact of the introduction of an innovative AR positioning technology for offshore topside positioning processes.

1.2 Research Questions

The research goal is achieved through the formulation of a main research question that is addressed through three sub questions.

How can the use of an Augmented Reality Positioning System potentially benefit Offshore Topside Installations Processes and which will be its impact on current offshore processes?

- *Which are the potential expected benefits of ARPS for offshore topside installations in terms of safety and cost?*

  The balance between safety and cost is a key factor on technological applications. (Mendes et al., 2014). This sub question relates to the perceived potential economic and safety benefits of ARPS in OTIP. It explores the reasons on how the system can make the process safer and its perceived cost repercussion.

- *What is the perceived usability and usefulness of ARPS in the offshore industry?*

  The successful introduction of novel technologies requires user acceptance and willingness to use (Lin, 2013), The second sub question explores the usefulness and users' acceptability on an AR system as a topside positioning tool.

- *What are implications of the introducing ARPS in the offshore industry?*

  An innovative technological introduction requires study on possible implications of the system (Markham, et al., 2010), such as market impact, required organization modifications and future technology developments paths. A good forecast allows flexibility and anticipation to future changes in order to enhance a successful technological introduction.

Therefore, to assure the successful introduction of ARPS in OTIP, the system should prove to improve the topside installation processes and to be accepted by end users. In addition, a study of the implications of the introduction of ARPS in the offshore industry is a key factor to for the integration of this innovation. This study depicts users' needs, impacts on the market and modifications on organization structure in order to ease the technological development path of ARPS in OTIP.

1.3 Research Strategy

The research strategy is based on a research framework, that emerges from the research objective and question (Verschuren & Doorewaard, 2010). This section introduces both, the research framework and strategy followed through the thesis report.

A research framework is a schematic representation of the research objective and includes the approximate steps that need to be taken in order to realize the objective (Verschuren & Doorewaard, 2010). Figure 2 provides an overview of the research framework that constitutes the foundation of this research.

This research is mainly based on four methodologies, desk research, a Virtual Reality Experiment (VRE), a Scale Model Experiment (SME) and expert interviews; that answer the research sub questions as the research framework diagram indicates.

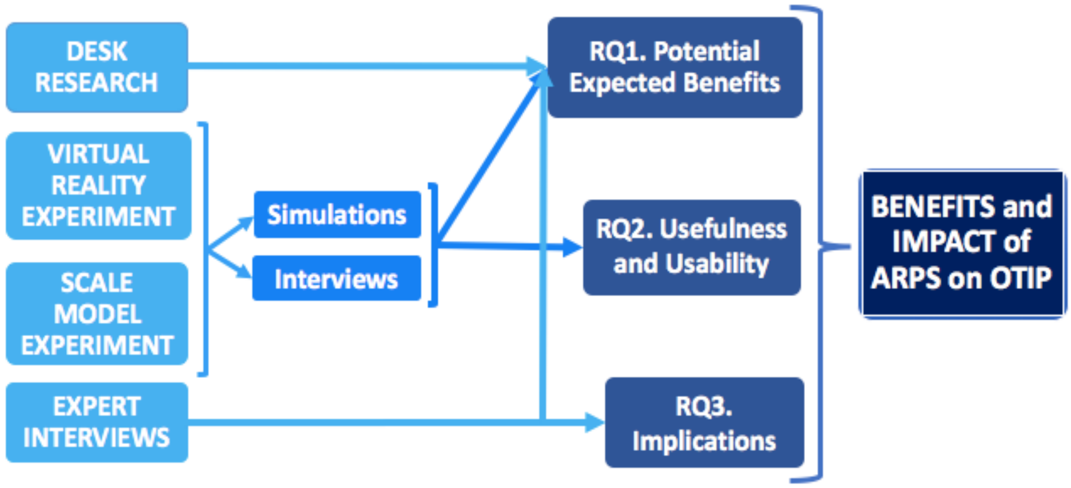


Figure 2. Research Framework Diagram

Initially, a desk research process furthers develop the potential expected benefits of an augmented reality positioning system on OTIP. This process introduces the topic and motivates the research.

Subsequently to the desk research there is a virtual reality experiment that has two main parts, a simulation phase and an interview phase with the participants of the simulation. The first phase is a virtual reality simulation process that uses computer-based techniques to simulate the complex offshore conditions of OTIP. It immerses the participants on a completely virtual environment that simulates the positioning of a topside. While the simulation phase allows the participants to use the system, the following interview phase gets inside of their experience and opinion about the ARPS. This experiment constitutes a first approach to how engineers interact with the system, which are its expected benefits and its usability (RQ.1 and RQ.2). In addition, this experiment helps to drive recommendations to better build the next experiment, the scale model experiment.

The scale model experiment provides a physical test of the system by the use of the ARPS on scale model OTIP. It allows offshore engineers to try the ARPS on scale model structures in order to test the system efficacy, operation and usability. The scale model simulation scenario includes all the equipment and steps that will take place during a real offshore topside position process using the system.

As it is depicted on the research framework diagram, VRE and SME further explore the ARPS' benefits already introduced during the desk research process, and gives answer to the second sub question related to the usability and usefulness factors. The reason for conducting two different experiments is that, while the VRE provides a first approach of the system and the user relation with it, the SME allows its technological testing based on a simulated scaled real environment that is designed following the future offshore configuration.

VRE and SME follow the same structure, a topside positioning process simulation and an interview process with the participants of the simulation. On the one hand, the simulation process includes two scenarios, simulation of the current positioning process and simulation of the positioning process with the ARPS. On the other hand, the interview process is based on semi structure interviews with the participants of the simulation about the benefits, usefulness and usability of the AR system.

The last part of the research includes expert interviews, the participants are employees and project managers that are closely involved and have high influence on the ARPS project. The participants include people from the technological development company, TWNKLS, and the implementation party, HMC. This last part of the research gives further information on the potential expected benefits of the system, first sub question, and gives answer to the last sub question related to the technology implications through the knowledge provided by the technical and offshore experts.

The research strategy is built on the research framework and it includes specifications on every step to be taken in order to answer the main research question. It refers to the subsequent decisions or steps that shows how the researcher plan to fulfil the research objective, which are derived from the research framework presented in Figure 2 (Verschuren & Doorewaard, 2010). The research strategy has been developed combining educational and industry requirements, in collaboration with TUDelft professors, and TWNKLS' and HMC' employees involved in the ARPS project. Every experiment and interview has been specifically developed in order to answer the research questions presented in this report.

The research process has been designed to answer the research sub questions in an orderly way through initial desk research, following virtual reality experiment and scale model experiment, and final expert interviews process (Figure 2). The goal is to start exploring the system, its benefits, and its usability through desk research and explorative experiments, while the last part of the research, expert interviews, further investigates the topic and explores ARPS introduction implications on the industry a OTIP process. Next table provides an overview of the research strategy, that defines the methodology and deliverable employed to answer each research question.

Table 1. Research Strategy

RQ	Sections	Methodology	Deliverable
1	*Which are the potential expected benefits of ARPS for offshore topside installations in terms of safety and cost?*	Desk research VRE SME Expert Interviews	Qualitative and quantitative assessment based on desk research, simulations and interviews.
2	*Which is the perceived usability and usefulness of ARPS in the offshore industry?*	VRE SME	Quantitative and qualitative assessment based on experiments
3	*What are the implications of the introduction of ARPS in the offshore industry?*	Expert Interviews	Qualitative assessment from the expert interview process

As it is represented in the previous Table, the first research question, that explore the potential benefits of the system, is answered through the four research methodologies desk research, VRE, SME and expert interviews. The second research question, that relates to the technology effectiveness and the users' relation to the technology, is driven through both experiments. The last research question is explored through experts' interviews with TWNKLS and HMC employees involved in the project.

1.3 Thesis Structure

The thesis report contains seven chapters that introduce the research topic, develop the research goal, and give answer to the research questions. The Figure below provides an overview of structure of this thesis report.

The first chapter introduces the problem statement, it constitutes the motivation of the research process. Moreover, it specifies the scope and research design of this process. The second chapter introduces AR technology as a positioning tool and describes the first ARPS, that is being developed by TWNKLS and HMC.

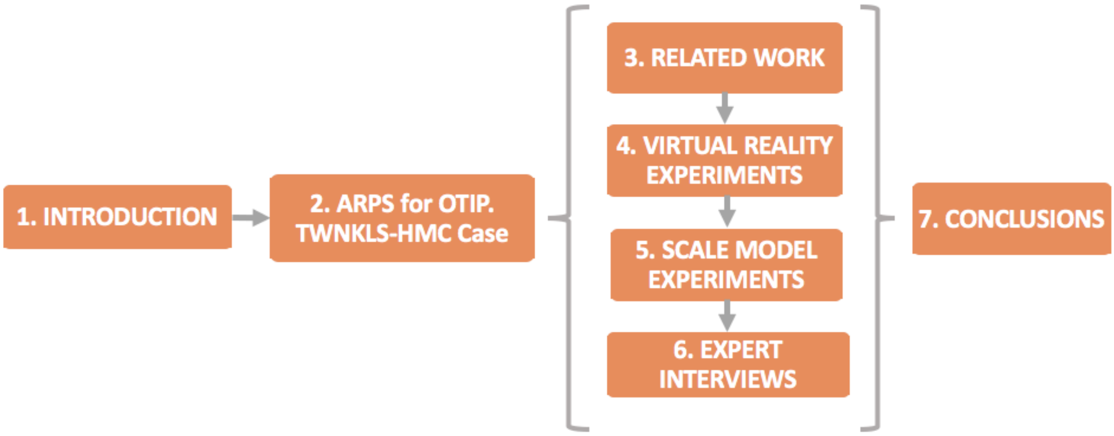


Figure 3. Thesis Structure

The third chapter is based on desk research. It provides an overview of AR and its industrial applications, and it describes positioning system technologies. This chapter also includes theoretical models about users' acceptance to technology.

The fourth and fifth chapters describe the virtual reality experiment and scale model experiment that explore the usability of ARPS. They include the methodology, design development, and results of the experiments. The sixth chapter explores the implications of the introduction of this AR system in the offshore industry and in the OTIP trough expert interviews to TWNKLS and HMC.

The last chapter examines the results collected through the research and it gives answer to the main research question and sub questions. It analyses the findings and explores its implications and limitations. In addition, it includes recommendations and future research based on these findings.

2. ARPS. TWNKLS-HMC Case

This research focuses on the application of augmented reality positioning systems in offshore topside installation processes by exploring the Augmented Reality Positioning System (ARPS) that TWNKLS and HMC are developing. TWNKLS, an augmented reality technological company, is collaborating with Heerema Marine Contractors, a marine contractor company in the international offshore oil and gas industry. Together, they are developing an ARPS in order to improve safety conditions on topside installation operations. This constitutes the first attempt of using augmented reality for offshore topside installation processes.

Augmented reality is a technology that combines the real-world environment with computer generated objects and elements on the real-time contest. AR has the ability of augmenting complex 3D models into structures in order to make measurements on its real collocation (Daponte et al., 2014). This AR tracking process enables the use of AR as a positioning tool, that can be used to determine the relative position between objects.

Offshore topside installation processes refer to the task of positioning a module on a structure that is on the sea, generally through crane vessels (Figure 4). There are four main parties involved in the process: assistant-superintendents, superintendent, crane operator and skipper. Assistant-superintendents are on the jacket and they communicate to the superintendent the relative position of the topside and the jacket. The superintendent stands on the vessel and he is the main responsible of the positioning process, he receives the positioning information from the superintendent-assistants and he communicates orders to the crane operator and skipper, who position the topside by following the superintendent's instructions (Shafy, 2004). The crane operator and skipper stay in the crane cabinet and bridge, and they deal with the crane and ship movement, respectively.

Figure 4. OTIP
Source: HMC

Augmented reality and offshore topside installation processes concepts are further explored in the next chapter, that describes the state of the art of AR on the industry, current structures positioning systems and OTIP.

The TWNKLS and HMC case refers to the augmented reality positioning system that is currently being developed. Figure 5 provides an overview of the system operation. It employs AR techniques for the initialization phase, that includes structures recognition and tracking through the matching of a 3D model and the real structures recording. Once the structures have been recognized, the system is able to measure and display the main information related to the structures' relative position.

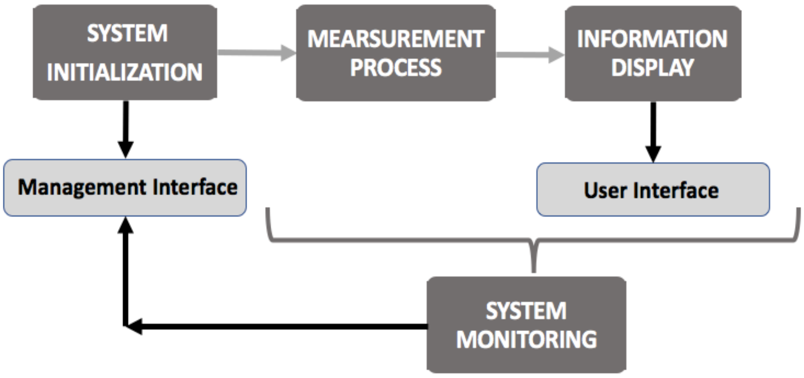


Figure 5. ARPS Diagram

The ARPS tracks the jacket and the topside to determine their relative position. It uses cameras to track the structures through the recognition of markers that are placed on them. Once the software recognises the markers and the structures, it is able to match the real the virtual structure representation in order to carry positioning calculations through image recognition techniques. The green lines in Figure 6 represent the virtual dimensioning of the topside and jacket onto the real positioning process images. This combination of real and virtual information allows the calculation of the relative position between both structures and it constitutes the end of initialization phase.

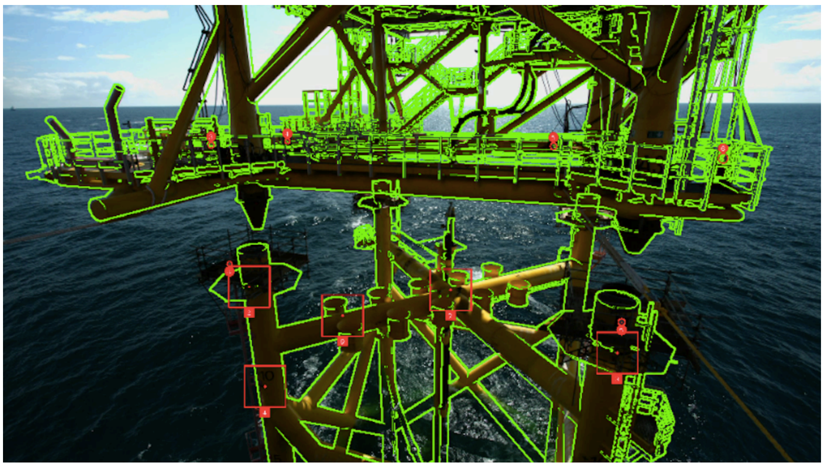


Figure 6. ARPS Initialization
Source: TWNKLS

The ARPS entails two interfaces, the Management Interface (MI) and the User Interface (UI). The management interface is used for the initialization and process monitoring, and it is displayed on a PC (Figure 7). It deals with the images and 3D model matching and it allows the process monitoring by controlling its alignment. On the other hand, there is a 2D user interface that runs in a tablet and provides information about the topside-jacket relative position (Figure 8). The management and user interfaces are designed to be used by the system administrator and the superintendent, respectively. Therefore, the ARPS entails two interfaces and two users, the system administrator that deals with the system set up and control, and the superintendent that uses the relative positioning information displayed on the user interface to give instructions to the crane operator and skipper to position the topside.

The management interface allows the initialization of the process by matching the jacket and topside real and virtual images through manual assignation of positioning points. These points refer to the markers, that are equally located in the real structures and their corresponding virtual models. Figure 7 shows the management interface during the initialization of the jacket structure.

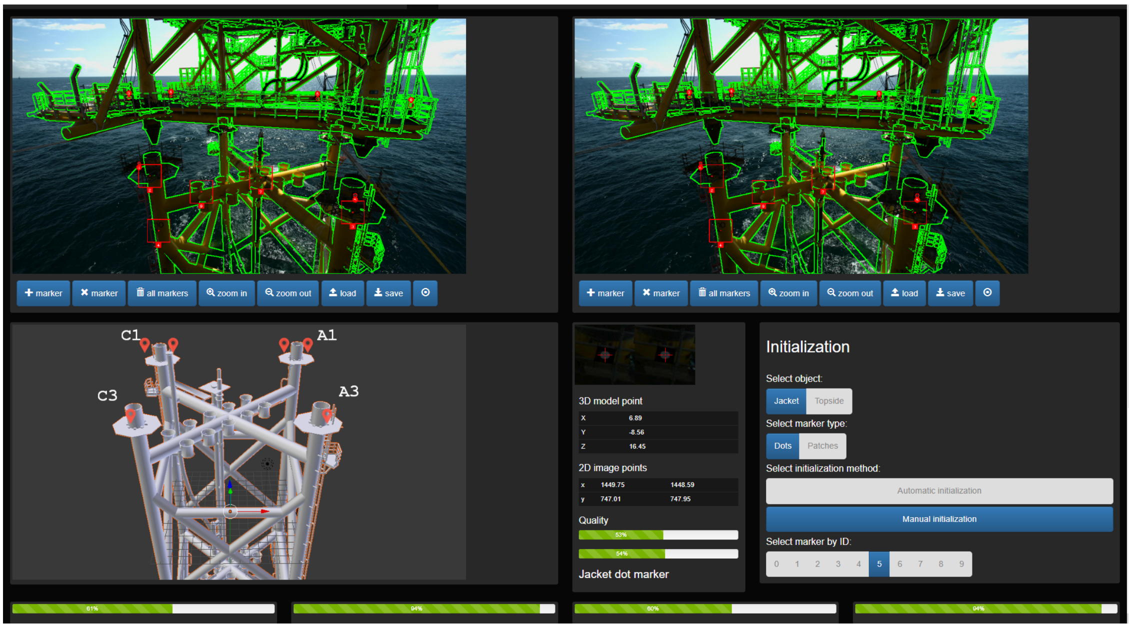


Figure 7. Management Interface
Source: TWNKLS

Each of the upper images represents the view from the two-camera system. The bottom image represents a virtual 3D model of the structure that is being initialized, in this case, the jacket. The rest of the interface displays tracking parameters such as the initialization method, the object that is being initialized and the marker type.

Once the system has been initialised and is running, it displays a 2D real-time interface that contains information about distances, heights and rotations of the topside with respect to the jacket. The user interface provides a bird view of the topside respect to the jacket. The superintendent uses this interface to give instructions to the crane operator and skipper to settle down the topside.

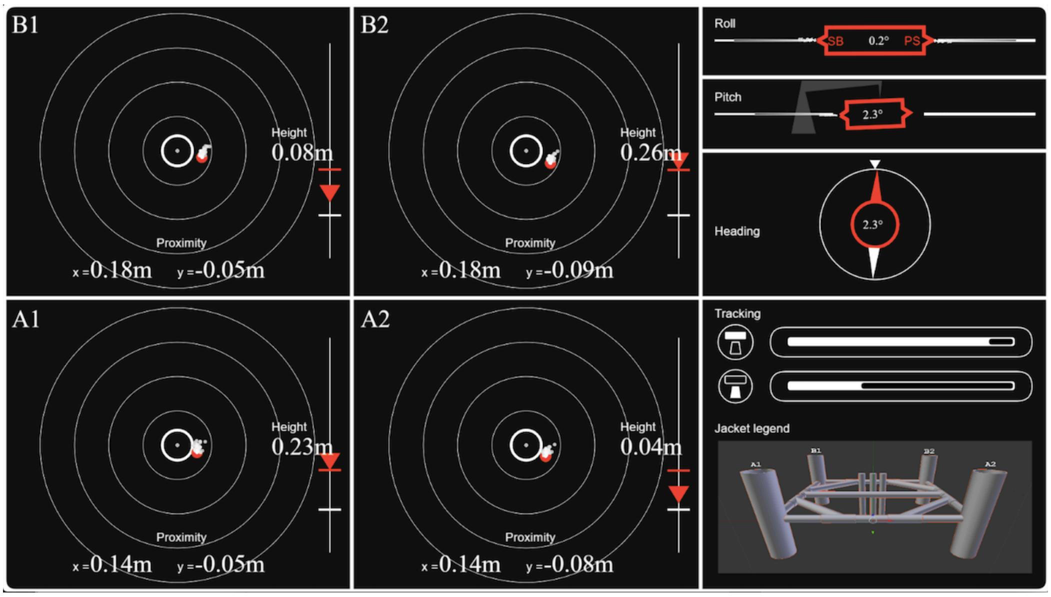


Figure 8. User Interface
Source: TWNKLS

The concentric white circles represent the jacket and the red point the stabbing cones of the topside. The white line next to the red point represent its immediate previous position. In order to position the topside, the stabbing cones should match the jacket centre position, once it happens, the red points become green. The relative position of both structures is accurately indicated trough XYZ, where Z represents the height of the topside respect to the jacket and XY indicate the position as follows:

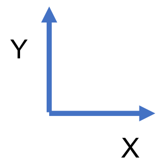


Figure 9. UI Reference System

The numbers in the top right corner show the three rotations of the topside in relation to the jacket through roll, pitch and heading indications. Finally, the bottom right corner includes information about the tracking precision of the structures and a 3D model of the jacket that indicates the position of each stabbing in relation to its bird view (A2, A2, B1, B2).

The ARPS case detailed in this chapter is the foundation of the present research. The research methodology: desk research, virtual reality experiment, scale model experiment and expert interviews; are related to the ARPS that TWNKLS and HMC are developing to improve safety conditions in offshore topside positioning processes by removing people from standing on the jacket under the suspended topside.

3. Related Work

This chapter introduces augmented reality, positioning system technologies and offshore topside installation processes. It provides information about industrial AR applications, current used positioning systems and OTIP. This chapter also presents acceptability and usability theories that are applied on this research.

Firstly, there is a description on augmented reality and virtual reality and the state of the art of AR technology within industrial applications. Subsequently, there is a description of positioning systems that can be applied to place big structures, such as topsides; and there is a detailed explanation of topside installation processes in offshore fixed jackets structures. The end of this chapter, sub chapter four, includes technological acceptance theories that constitute the theoretical foundation of the research methodology that has been applied.

3.1 Augmented Reality and Virtual Reality

Augmented Reality (AR) is an extension of Virtual Reality (VR) (Wojciechowski & Cellary, 2013) that overlays computer-generated virtual imagery information on a live direct or indirect real-world environment (Zhou et al., 2008). AR differs from VR in that VR users experience a computer-generated virtual environment, whereas in AR, the environment is real, but extended with information and imagery from the system (Lee, 2011). Virtual reality offers a digital recreation of a real-life setting, while augmented reality delivers virtual elements as an overlay to the real world (Gavish et al., 2011).

Virtual reality completely immerses the user in another world, usually through the representation of real complex situations (Langleyet al., 2016). It is commonly used in simulations of new technologies and trainings procedures (Borsci et al., 2015). On the other side, AR is frequently used due to its capability to provide the users with the necessary information about a process or a procedure directly on the work environment (Dini & Mura, 2015).

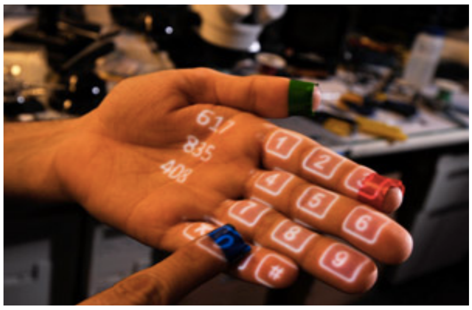
AR can augment complex 3D models into structures in order to make measurements on its real collocation (Daponte et al., 2014). This AR tracking process enables the use of AR as a positioning tool. An augmented reality positioning system is an innovative AR technological application that could potentially benefit the engineering industry, more specifically, the offshore industry.

This research uses both concepts, VR and AR, but on different applications. *AR is used in the initialization phase of the first ARPS* that is currently being developed and has been introduced in the previous chapter (Figure 6). On the other hand, *virtual reality is used during the virtual reality experiments* in order to immerse the participants into a virtual world that simulates OTIP and allows the virtual use of the ARPS. The complex environment and difficult access to offshore processes makes VR a suitable tool for this simulation process.

AR entails several methodologies of augmentation, variety of hardware components and different tracking procedures (Cheng, 2017). There are three AR main methodologies that can be used to overlay virtual components on the real-world environment: optical combination, image projection and video mixing (Figure 10). The first one consist of the projection of virtual information in the visual field of the user while he is directly observing the real world; the second one is about projecting images on real objects; and video mixing involves the display of digital information into a monitor that the user uses to indirectly observe the real world (Dini & Mura, 2015). The augmented reality technique applied in the ARPS is based on video mixing, the software displays the topside and jacket 3D model into a computer device that presents the real jacket and topside structures images, captured through a 2-camera system. See Figure 6, where the green lines represent the virtual dimensioning of the topside and jacket onto the real positioning process images. This combination of real and virtual information allows the calculation of relative positions.

a)

b)



c)

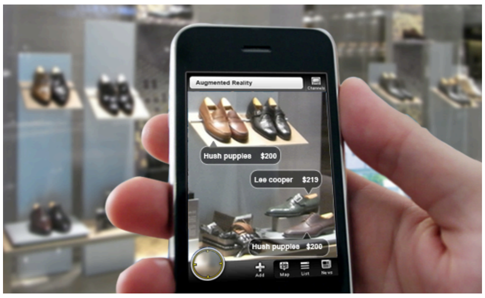


Figure 10. AR optical combination (a), image projection (b) and video mixing (c)
Source: Chen et al., 2017 *(a); Barry & Bonsor, 2017 (b) (c).*

Augmented reality requires three main hardware components: (1) computer that aligns real and virtual information, (2) display device, and (3) tracking system. The display devices can be head-mounted, hand-held or spatial world (Dini & Mura, 2015). At the beginning, AR development seemed to rely on head-mounted devices, however, nowadays hand-held devices are more common. They are simpler and its portability nature brings great opportunities to increase its use and applications (Cheng & Tsai, 2013). On the other hand, head-mounted devices have developed into new smart glasses, such as Hololens (see Figure 10.a), that offer the comfortable free-hands AR display (Dini & Mura, 2015). The ARPS employs a PC (1) a tablet (2) and a tracking system based on two cameras and image recognition algorithms (3).

AR applications require tracking the position of physical objects in order to accurately align the computer-generated graphics images with objects in the real-world view through algorithms (Beglov, 2013). AR systems can include two types of image processing systems, marker-based (Figure 11) and marker-less (Figure 10.c) tracking. Marker-based AR requires the placement of artificial markers, such as 2D barcodes, in the real environment to determine the position of physical objects in the environment (Beglov, 2013).

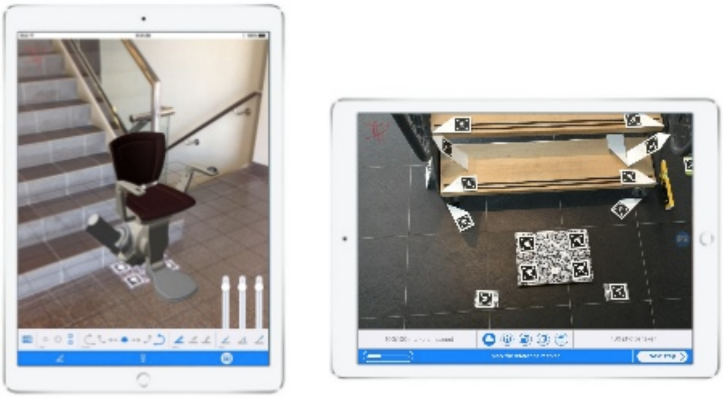


Figure 11. Otolift System. Marker-based AR
Source: TWNKLS

Marker-less AR uses natural features of physical objects present in the environment to track them (Wojciechowski & Cellary, 2013). Marker-less tracking can include 3D virtual models and/or it can be based on objects' natural features through Simulation Localisation and Mapping (SLAM) (Kudan, 2016). The ARPS is currently based on marker-based tracking and CAD models, further development on the system aims to achieve marker-less tracking of the structures based on CAD models and SLAM.

3.2 Industrial Augmented Reality

This sub chapter provides an overview of the current state of the art of augmented reality in the industry. It presents AR engineering, construction and offshore applications, and its technological limitations.

Although augmented reality exists from 1960s, AR did not gain real footing as a technical field until the early 1990s, when AR was further developed (Navab, 2004). The first Industrial Augmented Reality (IAR) application was originated by Boeing, who developed an AR system that blended virtual graphics onto a real environment display to help aircraft electricians with cable assembly (Caudell & Mizell, 1992; Cheng & Tsai, 2013). However, AR industrial applications were almost inexistent by the 90's (Siltanen, 2012). It is in the last decade, when academic research on IAR applications has exponentially increased. Thanks to technological advantages, AR is able to provide satisfactory and cost efficient industrial solutions (Dunleavy & Dede, 2014).

AR can be used in almost every phase of design and manufacturing, such as revision and evaluation concepts by displaying them as they would appear in the real world, and assembly and quality control processes by superimposing information into the work environment (Singh, 2016). AR can provide detailed information on maintenance procedures by overlaying them directly onto the device and it can be used for design by showing different configuration options and how the product might look in a client's setting (Singh, 2016). Therefore, augmented reality techniques can be used for applications such as the placement of virtual furniture and for automotive repairing and training services (Navab, 2004; Gavish et al., 2013).

Figure 12. AR Industrial Application Examples
Source: Gavish et al., 2013

Another example of AR applications on the industrial industry is "CyliCon" (Figure 13). It is a system that enables the users equipped with a mobile computer to move around the industry environment, while providing 3D model augmentation of industrial structures. This project was developed for reconstruction of industrial pipelines that allows workers to easily access engineering, monitoring and maintenance data (Navab, 2006).

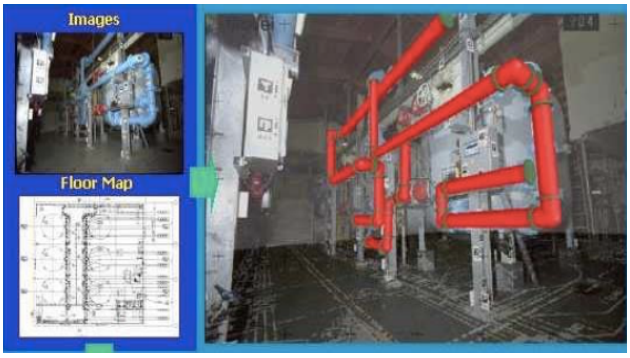


Figure 13. CyliCon
Souce: Navab et al., 2000

Regardless of the industrial process, AR can help to more efficiently interpret 3D digital data and its relation to real-world environments (Singh, 2016). According to the Horizon Report by the New Media Consortium (NMC), augmented reality represents a large amount of the investment undertaken by the technology industry and is indicated as one of the important developments taking place over the next few years (Cheng, 2017).

3.2.1 Engineering and Construction Applications

Augmented reality has significant potential in the engineering and construction industry. AR has been already applied for engineering inspection, quality control and supervision, and project feasibility analysis (Behzadan & Dong, 2015). AR has been used on underground utilities visualization for underground inspection (Roberts et al., 2002), visual perception for excavation safety and subsurface utilities (Behzadan & Kamat, 2009; Schall et al., 2008).

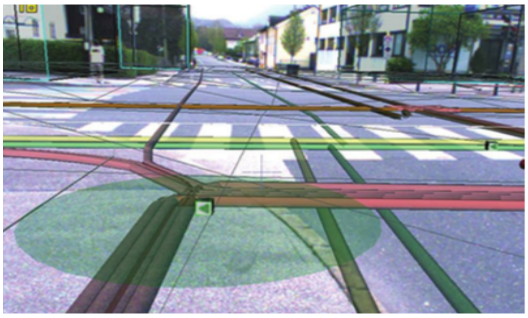


Figure 14. AR subsurface utilities
Source: Schall et al., 2008.

Another example of an AR application on the engineering and construction industry is AR construction supervision. Figure 15 a shows AR as a supervision tool for visualizing performance metrics that represent progress deviations through superimposition of 3D as-planned models over time-lapsed real jobsite photographs (Golparvar-Fard et al., 2009). Another supervision example is overlaying as-built drawings onto an site photo for continuous quality investigation of a pile construction (Behzadan & Dong, 2015).

a) b)

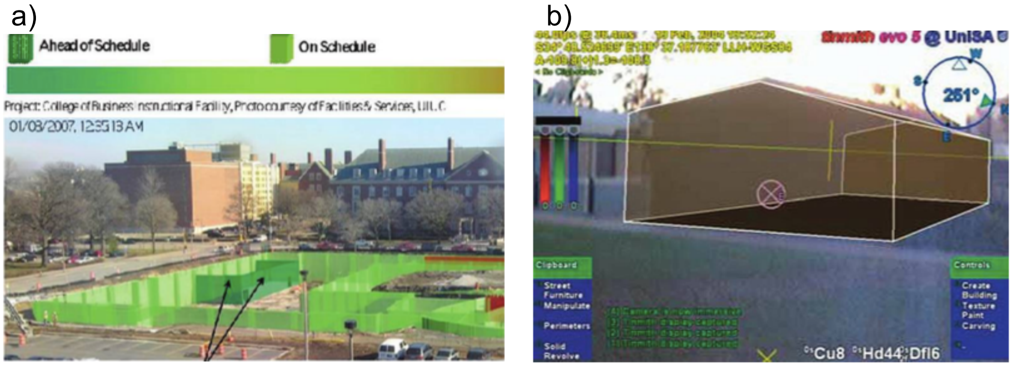


Figure 15. AR supervision (a); AR project feasibility analysis (b)
Source: Golparvar-Fard et al., 2009 (a); Piekarski, 2006 (b)

3.2.2 Offshore Marine Applications

Nowadays, AR applications in the offshore industry are mainly limited to Electronic Navigational Aids (ENA) and maintenance operations (Vasilijević & Borović, 2011). ENA provide information to help navigation processes, however, they often force users to turn their attention away from watch-keeping duty. AR fusions all added information to ensure optimal use of all resources available without interrupting ships operational procedures (Hugues et al., 2014).

Figure 16. Foggy day augmented ENA
Source: Molchan & Walker, 2010.

Figure 16 shows an AR navigation aid, in a form of virtual “rails” on both sides of the ship track, helps steering in low visibility conditions.

As in many other industries, AR is used in assembly, maintenance and repair of complex systems. Instructions, drawings, procedures and 3-D virtual guides overlaid in real time on see-through image of the actual equipment can help engineers to complete their job safer, easier and faster (Vasilijević & Borović, 2011).

3.2.3 AR Limitations

Augmented reality faces technical and social challenges such as tracking and calibration, information over-load and reliance, and social acceptance (Krevelen & Poelman, 2010).

Tracking in unprepared environments remains a challenge, and calibration of AR devices is still a complex process (Azuma et al., 2001). Engineering industry applications require a high degree of accuracy in measuring exact position and location of objects, which remains to be a problem to be further solved (Beglov, 2013). Aside from technical challenges, the user interface must also follow some guidelines as not to overload the user with information while also preventing the user to overly rely on the AR system such that important cues from the environment are missed (Stricker et al., 2001).

AR systems pose potential privacy and security concerns. Smart glasses are a good example of these concerns (Rauschnabel & Ro, 2016). There has been much discussion in the media concerning smart glasses technology due to potential privacy concerns. Smart glasses are still a relatively unknown and unfamiliar technology. Its small, portable and semi-invisible footprint (as in the case of Google Glass) makes the technology unobtrusive, and thus can easily be overlooked or unnoticed by the general public when being worn (Rauschnabel & Ro, 2016). Concerning security issues, the fact of wearing glasses that include virtual images into the user’s visual field, can lead to lower awareness of the real environment and subsequent safety reduction.

3.2.4 Summary

Augmented reality has been already applied on design, commissioning, manufacturing, quality control, training, monitoring and control, and service and maintenance industries (Singh, 2016). It has proved to be useful in engineering and construction areas, where they can be used to improve different stages of the construction process and data visualization (Beglov, 2013).

The offshore industry is characterized by traditional procedures and few innovation practices (Barlow, 2000) and AR is rarely used. Nevertheless, AR has a great number of potential applications in this industry (Sadeghi, 2007). However, AR faces technical and social challenges (Krevelen & Poelman, 2010) that should be considered before introducing AR systems on industry applications.

3.3 Positioning Systems

A literature review process explores current positioning systems that can be applied for positioning big structures. This sub chapter provides an overview of the systems that are currently used in the construction and offshore industry to position structures on specific locations.

Current structures positioning processes are mainly based on optical human assessment (Greaves & Hohner, 2015) and on the use of bumpers and guides (Veritas, 2014). Bumpers are attached or integrated to the installation structures in order to absorbs impacts on a minor collision (Helps, 2001); they are designed to get in contact with the guides, to get the structure in position (Heerema Marine Contractors, 2017).

The construction industry continuously requires to locate various components at precise elevations (Greaves & Hohner, 2015). Optical tooling has been used for this process for a number of decades. An alternative to this traditional measurement method is a Laser Levelling System (LLS). This system is used on some positioning processes on the construction industry to stablish distances. It is based on a laser instrument that transmit horizontally directed laser beam at laterally spaced locations to indicate distances (Akers, 2003).

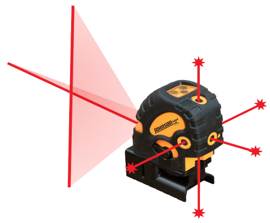


Figure 17. LLS
Source: Johnson Level, 2013

Concerning the offshore installation industry, it is mainly based on human assessment, bumpers and guides methods; and sometimes laser positioning tools are applied on topsides installations (Bakker, 2015; Daponte et al., 2014). Laser positioning systems are based on total stations, angle measuring devices integrated with an electronic distance measurement unit. This integration provides the ability to measure horizontal and vertical angles as well as slope distances using the same device at the same time, and allows structures measurements for positioning operation (Lemmes, 2015). Laser systems technology is suitable for the positioning of structures and it has been successfully tested offshore (Figure 18) (Heerema Marine Contractors, 2014). This system is able to provide information about the position of the topside with no need of human assesment. However, it requires high-equipment investment, usually six total station and its corresponding prism that are evenly located in the jacket and topside (Greaves & Hohner, 2015).

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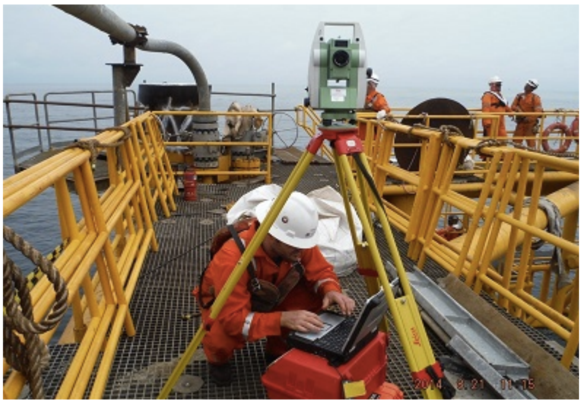


Figure 18. Laser Positioning System on Offshore Installations.
Source: Jarvis, 2015

A technological alternative to laser systems are drones, that could allow offshore positioning processes by using camera techniques to track and measure distances. However, drones are critically constrained by limited battery lifetime and they are conditioned by the dynamic operating environment (Tseng et al., 2017). Its significant susceptibility by wind and weather conditions makes this technology not appropriate for offshore environments (Tseng et al., 2017).

3.4 OTIP

A good comprehension on the research goal and methodology requires the technical understanding on offshore topside installation processes. This subsection introduces the definition of offshore platforms and describes topside installations processes on jackets structures.

Offshore platforms are supporting structures placed in the sea that are mainly used for oil and gas purposes. The most common type is “fixed platforms” (Bakker, 2015), immobile structures built on solid foundations that are fixed directly onto the seabed (Chakrabarti, 2005) and support an above sea level topside (Figure 1) (Ali, 2014). Topsides generally have four stabbing cones with different lengths. The two larger cones and the two shorter ones are located diagonally. The larger cones are inserted first, the posterior lower of the topside will result in an automatically match of the two remaining cones (Cherian & Suresh, 2013).

Topside installation is defined as the action of lowering the topside module by crane vessels to put it on the fixed offshore jacket structure. This process is considered one of the most challenging offshore installation activities given the high weights and dimension of topside structures (Hee, Pickrell, Bea, Roberts, & Williamson, 2007). Figure 19 shows the topside installation process at the moment in which the two larger cones are about to get in the jacket legs openings. The other two cones are shorter and they cannot be distinguished in the picture. Sometimes one of the larger cones is larger than the other, and it is the first one to be positioned (Hee et al., 2007).

Figure 19. Zoom - in on OTIP
Source: HMC

There are four main roles involved in the installation process: assistant-superintendents, superintendent, crane operator and skipper. Assistant-superintendents are on the jacket and communicate to the superintendent on relative position of the topside and the jacket (see the orange arrows in Figure 19). The superintendent stands on the vessel and he is the main responsible of the positioning process, the decision maker (Shafy, 2004). He receives the positioning instructions from the assistant-superintendents and he communicates orders to the crane operator and skipper, who position the topside by following the superintendent's instructions. The crane operator and skipper stay in the crane cabinet and bridge and they deal with the crane and ship movement, respectively.

There are usually two assistant-superintendent on the jacket, the main assistant superintendent and the rigger foreman, each of them monitors the positioning of the corners with the larger stabbing cones (Breidablikk, 2010). If these two cones are positioned correctly, the structure can be further lowered and the other legs would be automatically correctly positioned as well (Lret, 2011).

Although topsides installation has always been carried out with people on the jacket, without any major incident to date, having people operating under suspended loads of up to 10,000 tonnes is considered unsafe and not in line with company safety policies (Liu & Li, 2017; Heerema Marine Contractors, 2014). These safety concerns are driving the offshore industry to explore different methods to allow offshore topside installation processes on unmanned jackets.

3.5 Technology User Acceptance and Usability

One of the objectives of this research is to explore ARPS usefulness and usability (RQ.2). This sub chapter provides an overview of acceptance and usability theories that are applied along this research.

Technology acceptance is about how people accept and adopt technology (Louho et al., 2006). User acceptance of technology has further been explained as the demonstrable willingness within a user group to employ IT for the tasks it is designed to support (Dillon, 2001). Acceptance is a critical factor in determining the success or failure of any technology (Dillon & Morris,1996). A large number of theories, models and scales have been designed to explore the acceptance and use of technologies environment, such as Innovations Diffusion Theory, Task-Technology Fit, Theory of Reasoned Action (TRA), Theory of Planned Behaviour (TPB), Technology Acceptance Model (TAM), the Unified Theory of Acceptance and Use of Technology (UTAUT) (Samaradiwakara & Gunawardena, 2014).

Concerning the term usability, it is a too broad for just one theory (Jong & Angles, 2014). Some determinants of usability are product characteristics, such as simplicity, consistency, and intuitiveness. Usability is one of the factors included in most of the acceptance theories just mentioned, such as TAM and UTAUT, that include perceived usability as a predictor of people's intentions to use certain devices (Jong & Angles, 2014). Questionnaires are a commonly used tool for the user-driven assessment of usability. Broadly used questionnaires are the User Experience Questionnaire (UEQ) and the System Usability Scale (SUS) (Laugwitz, 2008).

The Technology Acceptance Model and the Unified Theory of Acceptance and Use of Technology are considered as two of the most efficient and valid theories to explain users' attitudes toward the use of technology (Chuttur, 2009). On the other hand, the System Usability Scale is one of the most common methods of measuring technological usability. This sub chapter provides a theoretical foundation on TAM and UTAUT, and presents the SUS.

3.5.1 Technology Acceptance Model

Technology Acceptance Model (TAM) was the first model to mention psychological factors affecting technology acceptance and it was developed from Theory of Reasoned Action (TRA) by Davis in 1989 (Davis at al., 1989). TAM explores user acceptance and rejection of computer-based technologies. It states that the user behaviour towards technology mainly depends on its behavioural intention of using it (BI). BI depends on several variables that are related to each other as the next diagram depicts.

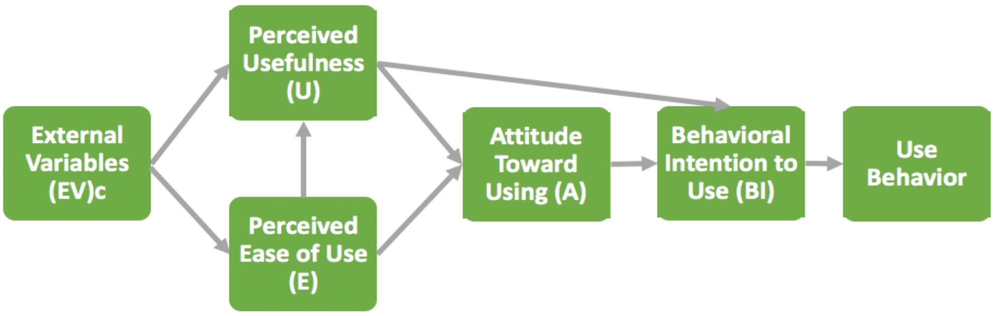


Figure 20. TAM

The BI determines the actual behaviour of an individual toward the use of a new technology. BI is mainly influenced by the person feelings toward a specific behaviour on using a technology (A) and the person`s usefulness perception of the technology (U). Davis furthers defined the model by addressing the factors that determine attitude toward behaviour and perceived usefulness (Davis, 2008).

BI= A+ U   A= U + E   U= E + EV

The attitude toward using a new technology directly depends on the person's perceived usefulness (U), and easy to use (E); and at the same time, perceived usefulness is determined by perceived easy to use and external variables (EV), which also affect easy to use perceptions (Fred et al., 1989).

3.5.2 Unified Theory of Acceptance and Use of Technology

The Unified Theory of Acceptance and Use of Technology Model is a successor of the Technology Acceptance Model. It states that behavioural intention on using technology depends on four main factors: performance expectancy, effort expectancy, social influence and facilitating conditions (Samaradiwakara & Gunawardena, 2014).

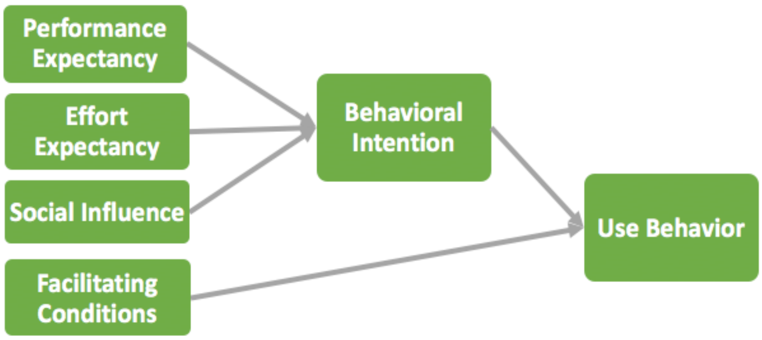


Figure 21. UTAUT

Performance expectancy is defined as the degree to which an individual believes that using the system will help him or her to attain gains in job performance. Effort expectancy is related to the degree of ease of use associated with the system. Social influence is defined as the degree to which an individual perceives that important others believe he or she should use the system. Facilitating conditions is defined as the degree of system-supportive organizational and technical structures (Venkatesh et al., 2017).

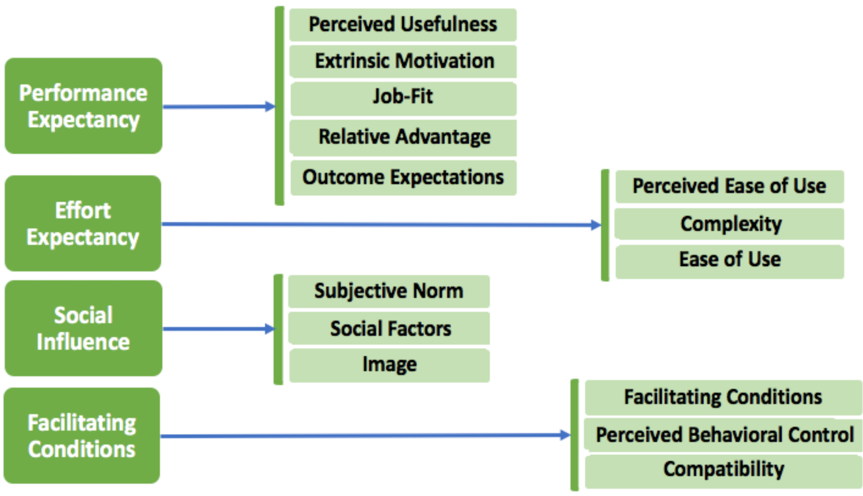


Figure 22. UTAUT Variables

This model also includes gender, age, experience and voluntariness of use as moderator between the four main factors and the behavioural intention and use behaviour (Venkatesh et al., 2017). Venkatesh et al., (2017) includes a more detailed explanation on this model and the definition of each variable.

3.5.3 System Usability Scale

The system usability scale is a scale methodology to measure usability through a questionnaire that contains ten usability statements. These statements present on this questionnaire (Appendix A) are mainly related to the complexity, ease to use of the technology, perceived time necessary to understanding and being able of using the system and to the willingness of the user to use the system (Lin et al., 2013).

Each statement of the system usability theory has five response options, from strongly agree to strongly disagree (Brooke, 2000). This scale is one of the most used methods to evaluate usability of technologies and its contents are closely related to UTAUT effort expectancy factor.

3.5.4 Summary

There are multiple methods, theories and questionnaires that deals with technology usability and user acceptance. The Technology Acceptance Model, the Unified Theory of Acceptance and Use of Technology and the System Usability Scale are commonly used and valid theories to explain users' attitudes toward the use of innovative technologies (Chuttur, 2009). Different theories that have been explained in this sub chapter have been used to research on the users' acceptance and usability of augmented reality positioning systems for offshore topside positioning in order to answer the second research question.

4. Virtual Reality Experiment

The virtual reality experiment and the scale model experiment have the same objective, to explore the safety and cost expected benefits of augmented reality positioning systems on offshore topside installation processes, the system usefulness and its usability. The expensiveness and complexity of real topside positioning processes (Chen et al., 2017) highlights the relevance of exploring augmented reality positioning systems through experiments before it is applied in the real offshore setting.

The structure of the VRE, that is the same as the one applied on the SME (Chapter 5), entails a simulation and subsequent interview phase. The simulation includes topside positioning on two scenarios, current positioning method and new positioning method with the ARPS. This practice allows the collection of quantitative data on the current and new simulation process, and the users interaction with the system. Immediately after the simulation each participant is gather for a semi-structure interview that provides qualitative information on the system usefulness and users' acceptance of the technology.

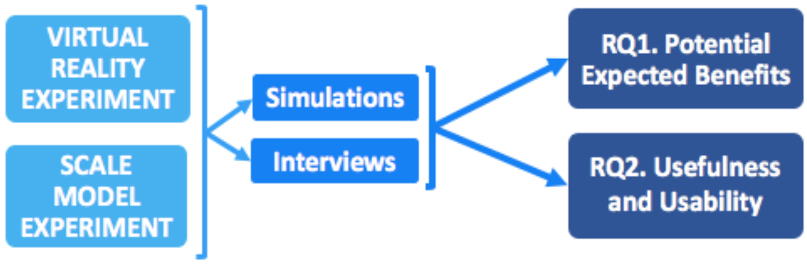


Figure 23. Research Framework Experiments

The virtual reality experiment allows the immersion of the participants on a completely virtual environment and provides a first approach of the system and the user relation with it. The VRE constitutes an initial exploration on the system in order to address how engineers deal and interact with the AR system, and which are their opinions on the system. It is a first attempt to answer the first two research sub question and it also helps to better define and structure the second experiment, the scale model experimentt, that includes real models and engineers with offshore experience and knowledge.

This chapter includes ten sub chapters, the first one includes the technology acceptance methodology that has been included to build the experiment. The following ones relate to the goal, participants, training, procedure, quantitative measurements, interviews, experiment implementation and results. The last sub chapter is a summary of the main findings of the VR experiment.

4.1 Methods

The interviews process of the VRE contains questions related to the usefulness, ease of use and participants' attitude toward the use of this technology (Appendix C). It is based on the Technological Acceptance Model (TAM), the Unified Theory of Acceptance and Use of the Technology (UTAUT) and the System Usability Scale (SUS) that are explained in the sub chapter 3.5 "Technology User Acceptance and Usability".

The questions used during the interviews of the VRE include two main concepts that are present on the Technology Acceptance Model and Unified Theory of Acceptance and Use of Technology, *perceived usefulness and perceived ease of use*. Both theories refer to the same concepts, however, UTAUT provides a more extensive definition of these concepts.

While TAM refers to perceived usefulness as an acceptance factor, UTAUT includes a broader definition. It defines performance expectancy, that includes perceived usefulness and additional factors such as outcome expectations, extrinsic motivation, job-fit and relative advantage of the system. The method used on this research mixes both theories by including perceived usefulness, relative advantage and outcome expectation factors as a performance expectancy concept (Langley et al., 2016).

Concerning the perceived ease of use, the methodology used during the research follows the effort expectancy definition from UTAUT, that includes perceived ease of use, complexity and ease of use factors on the effort expectancy concept. The interviews include questions related to the complexity of the use of the system compared with the current positioning method simulation.

Another concept present on the interviews that comes from the theories mentioned in the sub chapter 3.5, is the *intention to use*, that is a common factor to the three acceptance theories (TAM, UTAUT and SUS) and it is based on the willingness of using the new system. Questions related to the participant willingness to use the ARPS are present on all the interviews of this research.

Moreover, UTAUT contains one variable related to the *facilitating conditions* (see Figure 22). This factor has been also introduced during the interview phase, and it has been reflected as the need of training and preparation of the users before introducing the AR system. The perceived behavioural control variable, that refers to the facilitating conditions concept in the UTAUT, is introduced as the feeling of control during the new process simulation compared to the current one.

Finally, the interview process phase during the VRE, apart from the factors based on the acceptance theories already mentioned, includes question related to the role of the participant on the project and their previous experiences (personal data is required at the beginning of the interview), recommendations on further steps and opinion on the limitations of each test regarding realisms and system perception validity.

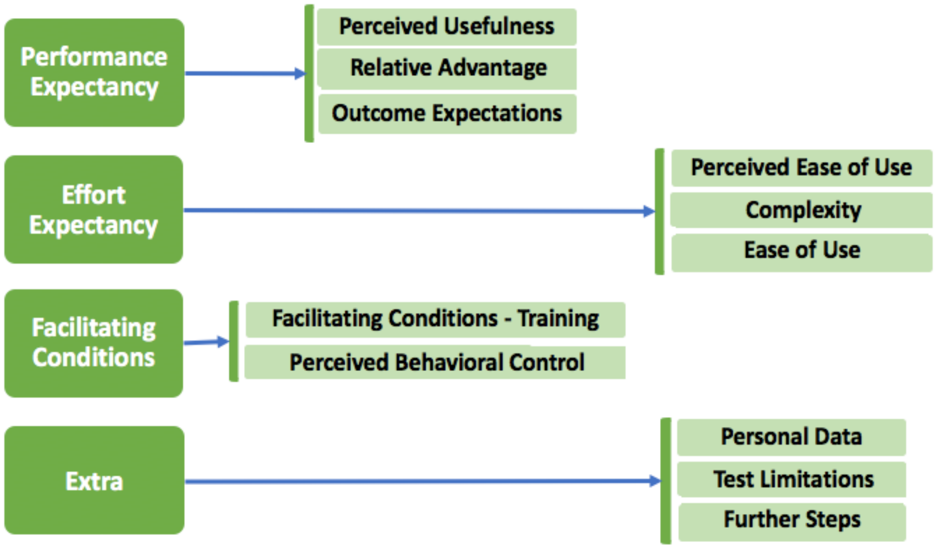


Figure 24. Experiments' Interviews Methodology

Additional concepts present on these technology user acceptance and usability theories (TAM, UTAUT and SUS), are also included in the last part of the research that explores the implications of the system through a process of expert interviews (Chapter 6). These interviews include questions related to performance expectancy and the facilitating conditions described on UTAUT in terms of resources, procedure, training and organization. Moreover, the social factor described in the Unified Theory of Acceptance and Use of Technology is also further explored during these expert interviews. This concept goes further away than the simple definition of social influence on users of using the technology, it means, superintendent using the system. This research also includes exploration on the social influence/client influence that is pushing offshore industry processes to change procedures in order to fulfil one of their safety policies: "do not stand or walk under suspended loads".

4.2 Goal

The design and development of a virtual reality experiment is based on the need to explore the technological impacts and users' behaviour of ARPS. A first good approach is to build a virtual reality environment to simulate the topside positioning process with and without the new AR system in order to explore the differences and the user reactions.

The goal of the VRE and SME is to answer the research question related to the system benefits, efficiency and the user perceptions. More specifically, the VRE is implemented before the SME in order to get a first approach on the system and people interaction with it in order to better conduct a suitable research process for the SME.

4.3 Participants

The simulation includes an assistant-superintendent on the jacket, a superintendent and crane control that drives the crane. The VRE includes the main roles of a real OTIP, except the skipper. The experiment limited resources and the challenging simulation requirements made not possible to include this forth role. The VRE requires all the three participants to simulate the current positioning process, assistant-superintendent, superintendent and crane operator; and just two participants for the new simulation process, superintendent and crane operator, because during the new process the role of the assistant-superintendent is overtaking by the ARPS.

The participants play the same role during both scenarios, current OTIP and new process using the AR system, in order to build a reliable experiment that is not bias by the user expertise with technology or offshore operations activities. It means that the superintendent from the current process plays the role of superintendent in the new process, and the same way with the crane operator. Each participant plays the role of assistant-superintendent, superintended and crane operator one time, thus there are three rounds of simulations and each round includes two scenarios simulations, current and new process. In this way, the experimental group is diverse and the learning bias are decreased. Therefore, the experiment requires three participants that simulate the current and new process for three times, during each of these three times, called Rounds (R), each of them play a different role Assistant-superintendent (A), Crane Operator (CO) and Superintendent (S).

Table 2. Roles of the participants each round

	R. 1	**R. 2**	**R. 3**
1	S	CO	A
2	A	S	CO
3	CO	A	S

The virtual reality experiment has been designed to be run twice, therefore the VRE entails two sub experiments, each of them with three different engineers as participants. Thus, they are six participants that are randomly divided in two groups, for the sub experiments 1 and 2. Each experiment has three rounds, where participants change role. Each round has two simulations: current and new process. As it is detailed in the following sections, the role of the participants in each round follows the same structure and nomenclature on both sub experiments.

4.4 Training

An introductory training on the virtual reality experiment and the ARPS is performed before the experiment (Appendix B). This training allows the participants to get familiar with the simulation process and the AR system before the tests. It includes the description of the simulation process and its scenarios, the role of the participants, and an explanation and trial phase of the ARPS. Thus, every participant gets familiar with the simulation process and its role before the experiments initialization.

The training includes the usage of VR software and a small simulation on their tasks: the assistant-superintendent explores the view from the jacket, the superintendent explores the application and user interface, and the crane operator gets familiar with the crane control. Once the participants are familiar with the simulation process and they do not have any further question, the experiments start.

4.5 Procedure

The experiment has been designed to be as close to reality as possible. It includes an assistant-superintendent on the jacket, a superintendent and a crane operator that that drives the crane on XYZ. The virtual scenario allows the different participants to get the right screen overview of the process, depending on their position during the real installation process. In addition, the software simulates offshore conditions through a marine sea algorithm that determines the movement of the topside on XYZ by including random swing movements to mimic reality. The software has been designed including real jacket and topside 3Dmodels from real previous offshore projects.

In the current process simulation, the assistant-superintendent has view of the topside from the jacket, the superintendent has view of the process from the vessel and the crane operator has no view on the process, he follows the superintendent instructions. Therefore, there are two screens, jacket and vessel view, that are used by the assistant-superintendent and superintendent, respectively; and a keyboard that simulates the crane control that is used by the crane operator.

Figure 25. Participants and software of the current process simulation

During the new process simulation, the superintendent has access to the user interface of the ARPS that provides information on the position of the topside with respect to the jacket (see Figure 26). Additionally, the superintendent has a computer-based view of the process from the vessel. The crane operator does not observe the process, as occurs during the current installation process, he follows the instructions from the superintended. In this simulation process the role of the assistant-superintendent is overtaken by the AR system. It requires two computer screens, user interface and vessel view, both for the superintendent, and a keyboard for the crane operator.

Figure 26. Participants and software of the new process simulation

Therefore, the VRE, independently on the simulation process (current or new), requires two computer screens, one that simulates the view from the vessel, and one that displays the view from the jacket or the user interface depending on the simulation process. The keyboard is used in the same way for the crane operator during both simulations. It allows the movement of the crane on XYZ through 6 keys.

A: Left
D: Right
W: Forward
S: Background
P: Up
L: Down

Figure 27. Keyboard with crane instructions

4.6 Quantitative Measurements

The quantitative measurement process takes place during the simulation phase and it compares performance and time factors from the simulation of the current and the new process through success and failure rate, total installation time, and number of operations/commands measurements. The simulations are recorded through two different media, the software, that includes the computer simulation process; and outside recording, that contains the interactions among participants. These tracking of the current and new process simulations from the software and outside perspective allows the reliable quantification of the variables just mentioned. The comparison of these measurements provides information on accuracy, efficacy and time benefits of the ARPS.

Each simulation round is initiated from a random topside-jacket position in order to guarantee the validity of the comparison on the quantitative measurements. These measurements provide a rough overview of the differences on successfulness, time and operations among both simulations, however, it does not aim to provide scalable conclusions to real OTIP.

4.7 Interviews

The interviews take place just after the simulation of both scenarios, without and with the AR system. They collect information about the user acceptance on the technology through questions based on the theoretical acceptance and usability theories previously mentioned on the sub chapter 3.5. This part of the research drives the uncertainty concerning the perceived usefulness of the system, ease of use, and willingness of using it; and it also gathers information about possible improvements, user interface complexity and the perceived similarity of the VRE and a real positioning process.

Since there are just six participants on the VRE, questionnaires are not a reliable measurement tool of users' acceptance (Lazar et al., 2017). Therefore, based on the questionnaires principles, a semi-structure interview process has been designed to explore users' attitude toward the technology by a set of questions. The interview is focused on the engineer that plays the role of superintendent, since he is the one that is in direct contact with the ARPS. The interview process is based on open questions that drive essential aspect of users' acceptance. It is a semi-structure interview process that gets insides about the users' perceptions on the new system. Since it is a semi-structure interview, the questions slightly change according to the answer of the subject in order to get better inside of his experience. The Appendix C provides an overview of the basic interview scheme that has been followed during the interviews, that it is divided in five main groups: performance expectancy, effort expectancy, facilitating conditions, attitude and behavioural intention, and perceived limitations of the simulation.

The interview process of both, the VRE and SME, is based on the principles exposed in the book "Research Methods in human computer interaction" (Lazar et al., 2017) and the knowledge obtained during the module "Research Methods" at TUDelft. A correct semi structure interview process should include an introduction of the process, agreement of the participant on the record and analysis of the interview data, an objective and adaptable questionnaire, an open-ended question that allows the participant to explain or add any idea or opinion, and an analysis of the results that should be validated by the participant in order to avoid interviewer misunderstandings on the participant answers (Lazar et al., 2017). The introduction of the interview process takes place through the initial training, where participants are introduced to the research, system and simulation process. The validation of the analysis is performed by obtaining approval from the participant, who confirmed the correctness of the interview summary via email.

4.8 Implementation

The virtual experiments took place in Zwijndrecht on the 23rd of May 2017. The experiments were structure assuring that each participant could perform the task related to his simulation role, and he was provided with all the required information and training before the experiment. This section shows the process overview of the experiment and the communication process.

Concerning the experiment overview, it follows the main guidelines of a real OTIP. The superintendent is responsible for the process, he requires information to the assistant-superintendent and gives instructions to the crane operator. The other two participants, the assistant-superintendent and the crane operator, give information or move the crane, respectively, following the orders from the superintendent.

Figure 28 depicts the experimental set-up (the picture on the left shows the set-up of the current process, the picture on the right shows a more detailed view of each computer screen) for the current process, that follows the initial experiment design (Figure 25). The crane operator uses the keyboard, the superintendent uses the screen that is on the right (view from the vessel) and the assistant-superintendent uses the screen on the left (view from the jacket). Any of them see each other screen.

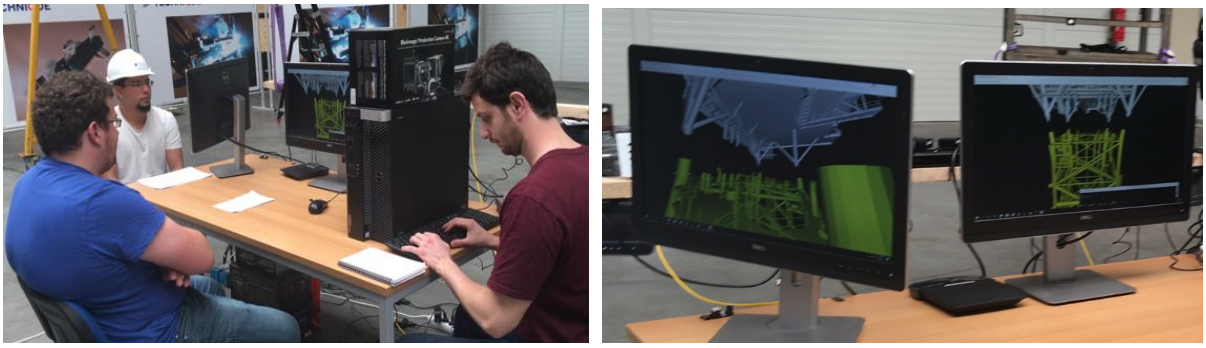


Figure 28. VRE Current Process Overview

Figure 29 depicts the new process set up, that follows the initial designed structure (Figure 26). The crane operator uses the keyboard on the right and the superintendent uses the two screens, with the user interface (left) and vessel view (right).

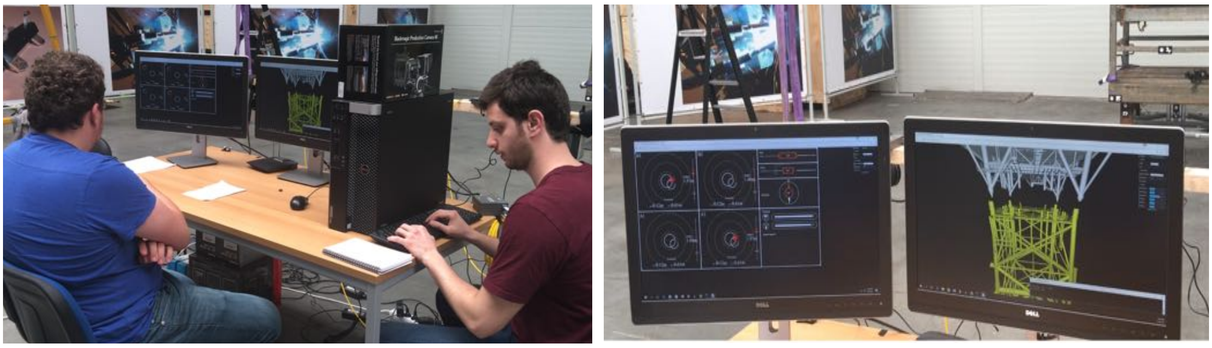


Figure 29. VRE New Process Overview

Regarding the communication process, since all the parties are close to each other during the virtual reality simulation, the communication process takes place through direct oral communication.

The communication flow includes information about the positioning of the jacket and topside, through the marine nomenclature that is used in real topside positioning processes. This system is related to the position of the vessel as follows: bow indicates the front of the boat, stern the back, starboard the right side and port the left side (see Figure 27). The flow of information between the participants is based on this system since different parties have different perspectives and locations during the positioning process. During the positing of a topside the crane operator and the superintendent are located on the back of the boat, that faces the jacket as the next picture depicts.

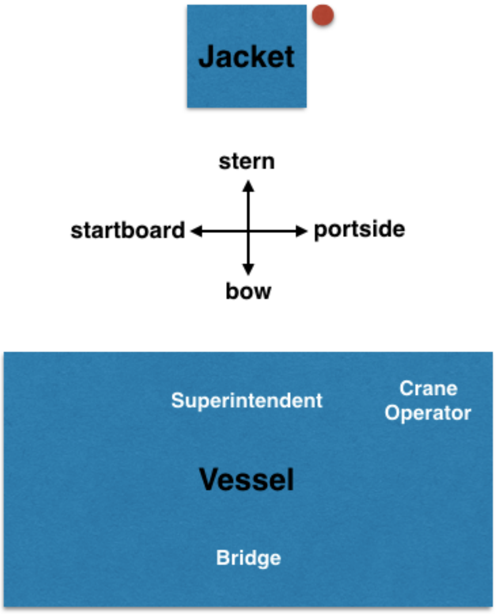


Figure 30. Marine Positioning Nomenclature

The position of the assistant-superintendent varies depending on the positioning process. It stands on the larger cone. The red circle close to the jacket indicates the position of the assistant-superintendent during the VRE. As an example, to better understand the communication process, the positioner, to communicate to the superintendent that the topside should be moved to the positioner's right, he should say stern, which means forward for the superintendent and crane operator.

Every participant was instructed on this positioning system during the training and they were provided with a guide in order to be able to remember his position and the marine positioning nomenclature during the simulation. The keyboard instructions, used for the crane operator participant, are adapted to this system:

A:	Left	Starboard
D:	Right	Port
W:	Forward	Stern
S:	Background	Bow
P:	Up	Up
L:	Down	Down

Figure 31. Keyboard with crane instructions

4.9 Results

The data collection relates to the quantitative measurements of the simulations and qualitative data collected during the interviews.

The six participants were randomly distributed, three for each experiment. The personal information of the participants and the quantitative measurements of the first sub experiment are depicted in the Table 3 and 4, respectively.

Table 3. Participants Sub Experiment 1

Participant	1	2	3
Background (Eng.)	Civil	Computer	Mechanical
Experience OTIP	Yes	Yes	No
Experience AR	No	Yes	No

Table 4. Simulation Results Sub Experiment 1

Round 1	**Factor**	**Current**	**New**
	Performance	Success	Success
	Time	3 min	2:20 min
	Nº Operations	238	186
Round 2			
	Performance	Fail	Fail
	Time	2 min	1:45 min
	Nº Operations	229	162
Round 3			
	Performance	Success	Fail
	Time	4:30 min	1:25 min
	Nº Operations	161	126

As it was mentioned before, the VRE includes data on the number of operations during the simulation of the current and new process scenarios. This data has been collected through the virtual reality software that was designed for the VRE. A detailed transcript of this data related to this first sub experiment is included in the Appendix D.

The personal information of the participants and the quantitative measurements of the second sub experiment are depicted in the Table 5 and 6, respectively.

Table 5. Participants Experiment 2

Participant	4	5	6
Background (Eng.)	Mechanical	Systems	Electrical, Electronical
Experience OTIP	No	No	No
Experience AR	No	No	No

Table 6. Simulation Results Experiment 2

Round 1	**Factor**	**Current**	**New**
	Performance	Success	Success
	Time	4:15 min	0:50 min
	Nº Operations	375	78
Round 2			
	Performance	Fail	Fail
	Time	2 min	1:25 min
	Nº Operations	136	218
Round 3			
	Performance	Fail	Fail
	Time	2:30 min	1:25 min
	Nº Operations	95	125

The detailed data related on the number of operations during the simulation of the current and new process scenarios regarding this second sub experiment is also included in the Appendix D.

The individual results of the interviews of each participant is presented in this section. Each participant was interviewed after playing the role of Superintendent. The questions are based on: usefulness, easy to use, improvements proposals, intention to use, limitations of the simulation and further steps. A more detailed transcript of the interview results is presented in the Appendix E.

<u>Participant 1</u>

"The system can be very useful because it provides better information than the one provided though current positioning methods. The system is easy to use and to control, however, I did not expect the system zoom in during the simulation process, I would prefer it to be smoother. I would be willing to use the system if is tested offshore and includes a back-up. The VRE is a simplification of the process so accuracy is not guarantee, however the tests is able to give a correct impression about the system to the user. The next step should be real simulation on scale models and interviews with offshore workers."

<u>Participant 2</u>

"The system can be very useful because it provides accurate measurements, it leads to a better feel of control and eliminates the need of communication with the assistant-superintendent on the jacket, what can make the process quicker. The system is easy to use and understandable, I will be willing to use it. As future improvements, I would suggest a system prediction of the topside movement and adjustable user interface features depending on the characteristic of the process. The test provides a good overview of the process and the what the system can do."

<u>Participant 3</u>

"The system is very useful because you can easily view from the topside where the cones are. However, you will use it as a backup system since you feel instructions from real people are more reliable, I do not completely rely on a 2D screen. The system is easy to use and to learn, my only difficulty was to get familiar with the marine positioning language and my virtual position on the jacket. I will be willing to use the system if it is tested before."

<u>Participant 4</u>

"The system is useful because it makes the process easier, it provides a better view, it makes the process faster and it reduces the communication parties on the process. The system is easy to use and it provides you a better feeling of control. I will be willing to use the system."

Participant 5

"The system is useful because it improves safety and gives good feedback, however, replacing a human with sense is very challenging since human learn and get experience. The system is understandable, it gives more feedback and better feeling of control. After a real camera-tracking test, I will be willing to use the system. The limitation of this experiment is that the virtual simulation has the option to restart, it creates a tendency to rush, unlike in offshore operations, where you do it right rather than quickly."

Participant 6

"The system is useful because it provides a better perspective, eliminates the need of a person on the jacket, improves safety, makes the process easier and leads to fewer communication parties. The system comes naturally to understand and provides higher feeling of control. After the system testing, I will be willing to use it."

The results present on this section regarding the VRE, are analysed and discussed in chapter 7, together with the summary of the results of the SME.

4.10 Summary

The quantitative data collected during the VRE indicates that the positioning time is considerable shorter during the simulation of the new process (the topside positioning using the ARPS). While positioning the topside in the current simulation process takes about 3:00, the ARPS simulation reduces the time to 1:30 min.

Concerning the number of operations (Appendix D), the data reveals that the use of the AR system can potentially reduce the number of operations. During 5 out of 6 rounds of simulations of the current and new process, the number of operations is considerably lower when the simulation includes the use of the ARPS, from an average of 206 to 149.

Table 7. VRE Number of Operations

EXPERIMENT	PROCESS	R.1	R.2	R.3
1	CURRENT	238	229	161
	NEW	186	162	126
2	CURRENT	375	136	95
	NEW	78	218	125

AVERAGE	
CURRENT	206
NEW	149

The rate of failure of the simulation of the current and new process scenarios is equal and higher than the success rate, respectively. For the current simulation process the failure rate is 50% and for the new process simulation it reached the 67%.

The qualitative data collected during the interviews (Appendix E) shows the participants opinions in relation to usefulness, ease to use, possible improvements, limitations on the tests and future steps.

All participants considered the ARPS a useful tool. The perceptions on the usefulness of the system are related to safety, clear and abundant information provision, reduction of communication parties and process speed up. These factors lead to the reduction of the process complexity and generally provides them a better feeling of control. Some of the participants considered technology accuracy an advantage of the AR system while others took it as a possible limitation or disadvantage of the introduction of the system. Reliability is one of the main problems that the participants mentioned in relation to the usefulness of the system: system failure rate and human reluctant to trust technology.

Every participant stated that the AR system is easy to use, easy to control and understandable. They agreed on the need of a training procedure for the superintendent on the features of the system. Some of the participants, stated that the only difficulty was to get familiar with the marine nomenclature (mostly, those that had no offshore experience).

Suggested improvements are related to changes on the unexpected sudden zoom in of the interface, modifiable user interface according to the topside and jacket features in each case, and a future implementation of the system by including a system prediction of the topside movement.

All participants stated to be willing to use the system once it has been further tested. Some people linked further testing to the use of the system on offshore conditions, others to ARPS testing in a virtual simulation centre, and others to the inclusion of backup and warning systems.

Participants stated that the VRE is a simplification of the real process with limitations in terms of the movement of the topside, weather conditions simulation and lack of several viewpoints from the jacket. One of the participants highlighted the restart possibility during the VRE, he stated that “having the chance to restart the process anytime creates tendency to rush, and it does not happen offshore, where processes are rather done right than quickly”. Even though all agree on the limitations of the VRE simulating the topside positioning process, they all considered that the VRE provides a good overview of the system to the user.

Future steps recommendations for the development and implementation of the technology are real scale model tests, interviews with experienced offshore engineers and the establishment of a good training procedure that guarantees safety.

5. Scale Model Experiment

The scale model experiment represents a real topside positioning process by scale model structures and a crane. The structure of the SME is the same as the one applied on the VRE (Chapter 4): simulation and subsequent interview phase with the participants.

While the virtual reality experiment allows the immersion of the participants on a completely virtual environment, the scale model experiment allows offshore engineers to try the ARPS on scale model structures in order to test the system efficacy and operation. The SME allows a first technological testing based on a simulated scaled real environment that is designed following the future offshore configuration.

This chapter includes ten sub chapters that detail the design, development and results of the experiment. The first one includes the methodology that has been used to explore the technology acceptance and usability. The following ones relate to the goal, participants, training, experiment procedure, quantitative measurements, interviews, experiment implementation and results. The last sub chapter is a summary of the main findings.

5.1 Methods

The research methodology applied on the SME is the same used during the VRE. The interviews process contains questions related to the usefulness, ease of use and participants’ attitude toward the use of this technology (Appendix G) based on the Technological Acceptance Model, the Unified Theory of Acceptance and Use of the Technology and the System Usability Scale (see Figure 24).

5.2 Goal

The goal of the SME is to answer the research question related to the benefits of the system, in terms of safety and cost, and the user perceptions (RQ.1 and RQ2), by using the ARPS on scale model structures.

5.3 Participants

The simulation includes an assistant-superintendent on the jacket, a superintendent and a crane operator that drives the crane. The SME includes the main roles of a real OTIP, except the skipper because the experiment limited resources and the challenging simulation requirements made not possible to include this forth role.

Seven engineers from HMC whom are familiar with topside positioning process actively participated on the scale model experiment. One as the assistant-superintendent, one other as the crane operator and the remaining five played the role of superintendent.

Thus, the experiment was performed five times, each of these sub experiments includes a new superintendent participant, and the same assistant-superintendent and crane operator participant.

Figure 32. VRE Participants and Sub Experiments

As Figure 32 shows, there are five sub experiments during the SME, the crane operator and assistant-superintendent (green and red colour) keep the same role during all sub experiments while the superintendent role is overtaken by a new participant each sub experiment.

5.4 Training

An introductory training on the SME and the ARPS is performed before the experiment (Appendix F). This training follows the same scheme as the VRE training (Appendix B) and the same goal, it allows the participants to get familiar with the simulation process and the ARPS before the tests. It contains the description of the simulation process and its scenarios, the role of the participants, and an explanation and trial phase of the ARPS. The training includes the usage of the scale model facilities and a small simulation on their tasks. Once the participants are familiar with the simulation process and they do not have any further question, the experiments start.

As it is detailed on the previous chapter, the results of the VRE were taking into account to design the SME. For example, during the first sub experiment of the VRE, the participant that played the role of superintendent during the first round, stated "Suddenly it zoomed in when we got closer and I did not expect that, so maybe the zoom in can be smoother". The SME training was implemented to include the description of this system feature.

5.5 Procedure

The scale model structures, software and camera tracking system were designed during May, 2017. The model structures include a jacket, a topside and a crane with movements in XYZ; the software is an adaptation of ARPS to the scale model scenario and conditions; and the tracking system is based on two high-resolution cameras that record the structures and process. The ARPS was specifically built and modified with the dimensions of the scale model structures in order to be applied to this scale model scenario.

Figure 33 shows the planned *designed* scale model experiment scenario. The left side of the picture depicts the crane (gantry crane), topside and jacket (yellow and grey colour respectively); and the right side represents the vessel, where the tracking system (two cameras, a PC) is located.

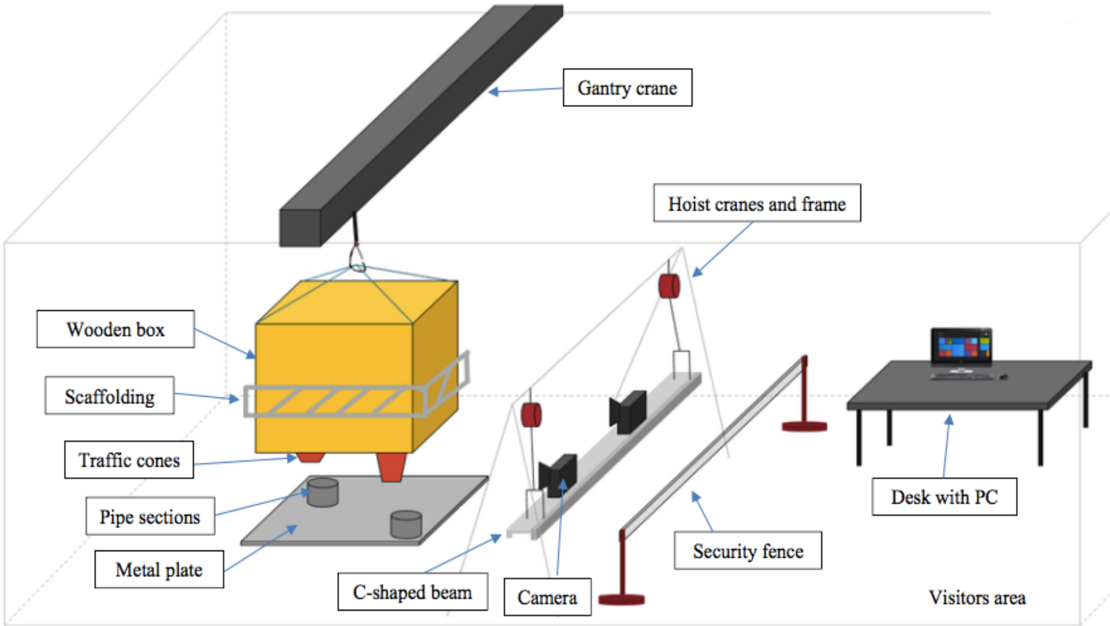


Figure 33. Scale Model Scenario Sketch
Source: HMC

As it can be observed in last Figure, the SME is designed to simulate the positioning process through two stabbing cones (red cones under the topside), that correspond with the larger cones of the topside that determine the positioning of the structure in the real process. As it is detailed in the sub chapter 3.4 related to OTIP, after the introduction of the two main stabbing cones, the lower of the structure leads to the finalization of the positioning process.

The real topside positioning process includes tugger lines that limit the rotation of the structure (Liu & Li, 2017). In order to simulate this process, the topside scale model includes two tugger lines that allow the manual control of the rotation of the structure during the positioning process (Figure 36). The experiment includes the simulation of the current and new process. During both scenarios, the superintendent and system manager stand on the vessel side, on the right side of the security fence. On the other hand, two people control the rotation of the topside from the left side of the security fence (Figure 33). Depending on the simulation process, current or new, the two-people controlling the rotation play the role of crane operator and/or assistant-superintendent.

- In the current process, the assistant-superintendent and crane operator are the two-people controlling the tugger lines, and the superintendent has view of the process from the vessel. The crane operator follows the superintendent instructions independently of his process view.

- During the new process, the superintendent has access to the 2D user interface of the ARPS (Figure 8) that provides information on the position of the topside with respect to the jacket while he stands on the vessel, standing blackguards to the structures to not see the process and just rely on the ARPS user interface (Figure 36). The crane operator, as occurs during the current installation process, follows the instructions from the superintended while he controls one tugger line. Since the role of the assistant-superintendent is overtaken by the AR system, the other person on the second tugger line has not further role than controlling the topside rotation.

The implementation of these two processes can be observed in Figure 36.

5.6 Quantitative Measurements

The SME collects time data and data about the failure rate while positioning the scale model topside on the jacket. The SME simulations are recorded through an external camera in order to measure time and failure factors. The comparison of these measurements on the current and new process simulations provides information on possible performance and time benefits of the ARPS.

Every simulation round of the SME, as in the VRE, is initiated from a random topside-jacket position in order to guarantee the validity of the comparison on the quantitative measurements of the current and new process simulation.

5.7 Interviews

The interview process (Appendix G) explores the user acceptance on the technology, since technology is of little value, unless it is accepted and used (Oye et al., 2014).

The SME interviews follow the same scheme as in the VRE (Appendix C), including factors such as perceived usefulness of the system, easy-to-use, current and new process perceived differences, possible improvements, willingness of using it and limitations of the simulation. The initial block concerning personal data includes additional question about the involvement of the participant with the project, topside operations experience and their attitude toward technology.

Unlike the VRE, the SME, includes two types of questionnaires, one designed for the participants playing the role of superintendent and one for the participant that plays the role of crane operator (Appendix G). These factors and questions are basically the same for both participant except for the block related to effort expectancy. Since the crane operator does not directly use the system, he cannot answer questions related to the perceived effort of using the systems. Instead, he is asked about the perceived differences between the current positioning process and the new positioning process (such as clearance on the instructions received by the superintendent).

The interview process includes five interviews with each engineer that played the role of superintendent and an interview with the engineer that played the role of crane operator during all the five sub experiments.

The collection of quantitative data takes place through the recording of the simulation process and the qualitative data is obtained during the interview phase.

5.8 Implementation

The Scale Model Experiment took place on Zwijndrecht, May 30, 2017. This section shows the process overview of the experiment and the communication process.

The experiment set up follows the general scheme of Figure 33. The hoist crane and frame support the two cameras, and the people on the vessel are located behind the red and withe cord that simulates the security fence. The cameras were mounted on a beam that could swing to simulate vessel motions. The crane, topside and jacket are scaled model items. As it was detailed in the procedure sub chapter (5.5), the topside includes just two stabbing cones simulated by two orange traffic cones, these are the two larger ones that determine the correct topside positioning.

Figure 34. SME

The experiment includes two cameras that track the structures, a tablet and two PC screens. The tablet and one of the PC (the one on the left in Figure 35) show the user interface, for the superintendent and the people observing the experiment, respectively. The other screen shows the management interface (Figure 7), that is controlled by a TWNKLS' employee because the ARPS is in the development process and it currently requires AR technical skills to be operated.

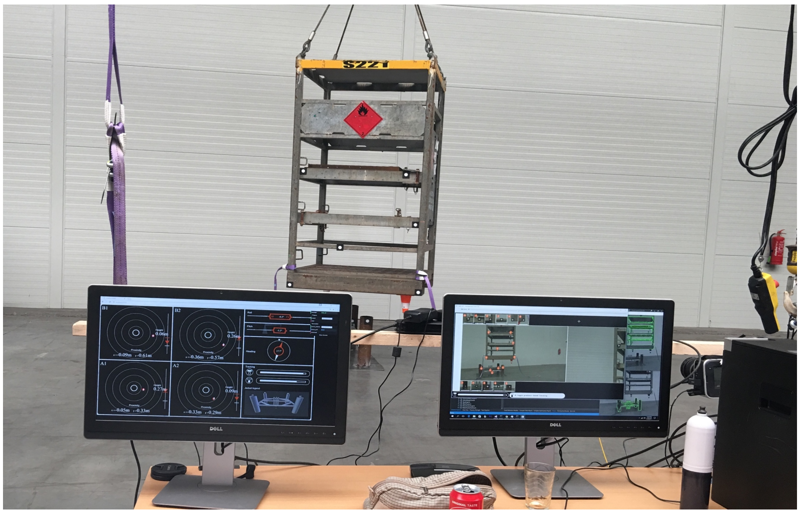


Figure 35. SME Interfaces

This simulation includes the participation of three people for both simulation scenarios, the new and the current. It is different than during the VRE that required three and two people respectively. The reason is the need of two people that hold the tugger lines during both scenarios, and the need of a superintendent. In the current process, each of the participants that hold the tugger line play also at the same time the role of crane operator (the one on the right) and assistant-superintendent (the one of the left). During the new process the one on the left just focuses on the tugger line, there is no assistant-superintendent role. The SME includes a fourth role that is common to both simulation scenarios, the system administrator (person on the right in Figure 36). Since the VRE was based on a virtual scenario, there was no need to control that the virtual and real model are aligned during the tracking phase.

Figure 36. SME Simulation Process

The process procedure is similar to the VRE, where the superintendent is responsible for the process. During the current process, he requires information to the assistant-superintendent and gives instructions to the crane operator. During the new process, the superintendent has access to the 2D UI (Figure 8) of the ARPS through a tablet (see Figure 36), and the crane operator, as it occurs during the current installation process, follows the instructions from the superintendent.

The crane operator is located close to the structures (person holding the right tugger line in Figure 36); however, its position does not allow him to see both stabbing cones and, therefore, he could not positively influence the positioning process, what would question the validity of the experiment.

As it is detailed on the section 5.5, the participants that played the role of superintendent, were asked to position the topside with the ARPS without looking at the structures, backwards to the scale model system, just using the user interface from the tablet (Figure 36). The goal is to avoid any bias related to the closeness of the participants to the scale model structures.

Since the participants are engineers familiar with offshore operations, there was no need of an intense training and the provision of the marine nomenclature instructions, as in the previous experiment, VRE.

As during the VRE, there is direct oral communication that follows the marine nomenclature (Figure 30). The crane control was adapted to the simulation case, given the offshore nomenclature and the position of the structures with respect to the scale model crane. Figure 37 shows the ordinary crane control on the left, and the adaptation of the control by adding stickers, taking into account this nomenclature and the position of the scale model simulated jacket and vessel.

Figure 37. Crane Control

5.9 Results

This section provides an overview of the results of the SME. Concerning the participants' personal data (first questions block during the interviews, Appendix G), all participants stated to be familiar with the project and with offshore operations; all of them consider that technology can be useful and reliable to improve industry processes. The participants that play the role of superintendent do not have any previous experience with AR technology, the crane operator participant does, since he has seen some TWNKLS AR projects. The quantitative measurements of the five sub experiments is depicted in Table 8. It includes the time (minutes) and the performance for the current and new process (fail or success).

Table 8. SME Quantitative Data

Experiment	Factor	Current	New
1	*Performance*	Success	Success
	Time	3	4:40
2	*Performance*	Success	Success
	Time	3:50	4
3	*Performance*	Success	Success
	Time	5:40	3.30
4	*Performance*	Success	Success
	Time	3:30	3:30
5	*Performance*	Success	Success
	Time	3:40	2:20

On the other hand, the interview results, that are included in the next paragraphs, entails six interviews results, five related to the participants that played the role of superintendent during the five simulations, and one from the crane operator participant. The detailed transcript of the six interviews is attached in the Appendix H.

<u>Participant 1</u>

"The system is useful because it allows unmanned jackets, it improves safety and fulfils clients' requirements. It also can make the process quicker and save money since there is no need of sending people to the jacket. The limitations of the technology are related to people trusting it and the robustness of the system. The system is easy to use and I will be willing to use it after offshore testing. The risks of using the system are system breakdowns and weather conditions. The simulation is not realistic but it provides a good overview of the system. This AR system has many advantages in comparison with laser positioning technology, since it does not require very precise dimension control of the structure, the time and equipment involved are lower; therefore, the process is more cost effective."

<u>Participant 2</u>

"The system is useful because it provides specific and clear information about the relative position of the structures, it avoids the need of people on the jacket, it reduces the communication to two parties and the superintendent do not depend on the assistant-superintendent instructions, he can work by himself. The system makes the process easier and probably a bit faster. The limitations of the technology are related to the 2D interface, that leads to a lower feeling of control compared with the current process. I would like to have 3D real view on the UI from a camera located in the jacket to improve the feeling of control and the user reliability on the system. The simulation is not realistic but the principles of the AR system are clear."

<u>Participant 3</u>

"The system is useful because it provides more information, it avoids the need of people under a suspended load and the SME just showed its robustness by allowing topside positioning without the superintendent view on the structures. The limitation of the system is that any technology can fail. The system is easy to use and provides a higher feeling of control is higher. The risks of using the system is people forgetting how to perform without the technology. I would include error range indications, depending on the operation conditions. This test cannot prove the robustness of the system. However, it provides a good overview of the system. I am in favour of installing the system and use it, to make it operational in few years. It is important to include back-up systems and to stablish an easy and robust installation process offshore."

Participant 4

"The system is useful because it makes the process safe for our client and avoids transportation of people to the jacket, a high-risk process heavily dependent on weather conditions. It can save time because there is no need of transporting people to the jacket. The limitations of the system are its difficult set up and operation that requires the presence of a specialist, get people to trust it, the need of a back-up system and the need of system offshore testing. The risk of using the system is that weather conditions should not interfere with the system. The feeling of control is higher and the effort lower with the system because it makes it easier. I am aware of other positioning systems that works offshore (based on the use of total stations), however they are more expensive, they require more people and equipment."

Participant 5

"The system is useful because it eliminates the need of transferring and having people on the jacket, it increases safety and decrease the process time. The limitations of the system are technical failures and the need the system to be trusted by people, it takes time. The feeling of control is higher in the current process because it is difficult to trust the system, I prefer to rely on people. I like the system, is simple and it provides an overview of all the information needed, however I would include a backup system. This test provides a good overview of the system."

Participant 6. Crane Operator

"The system is useful because it increases safety by removing the people from the jacket and allows installations under worst weather because there is no need have to transfer people to the jacket. In addition, I got more precise instructions during the simulation with the technology, the feeling of control is higher with the system. The limitations of the system are offshore weather conditions limitations and the system need to be operated by a specialist. I would improve the system setup in order to make it usable for anyone. The risk of using the system is the possible displayed of wrong information. The system should include error measurements and a backup within the system. The system is easy to use because it was developed with real superintendents' participation. Laser is other positioning system, it is very precise but it need a lot of reparations, needs of specialists in order to work."

5.10 Summary

The results of the scale model experiment include quantitative measurements on time and performance successfulness, and qualitative information from the interview process.

The quantitative data indicates that the positioning time varies depending on the participant and on the simulation. There is not any evidence on which process, current or new, has the potential to take more time. Related to the success rate, all the simulations of the SME simulations were successful.

The qualitative data collected during the interviews shows the participants perceptions on usefulness and limitations of the system, ease to use, system recommendations, behavioural intention on using the system and validity of the scale model test.

The six participants consider the system useful. The main reason of the usefulness of the system is the removal of crew standing on the jacket. The advantage of not having people on the jacket is perceived as an increase on safety, weather for HMC and the client or just for the client. Four of the participants also linked the usefulness of the system to avoid the transfer of people to the jacket, since it can reduce risks, and reduce the dependency on the weather conditions (the transfer of people is considered one of the limiting factors before deciding whether or not to start a topside positioning process). Four of the participant indicated that the AR systems provides more, and more clear information about the structures' relative position.

As a result of these advantages of using the AR system, most of the participants concluded that the system will make the process easier and probably faster. One of the participants emphasized the reduction of the communication parties with the ARPS, that allows the superintendent to work by himself. In addition, most of the participants stated that the system has the potential to lead to low costs investments.

The main perceived limitation of the system is the uncertainty concerning its robustness: would a technical failure take place? will the system work under not optimal weather conditions? The next main concern is if people will trust the system. Other limitations are related to the need of a specialist to set up and run the system and the need of implementing a 3D user interface to increase the feeling on the process. Ine participant stated that the risks of using the system is people forgetting how to perform without the technology.

All the participants considered the system as easy to use, easy to learn and they stated that it requires lower effort than the current positioning process. However, there were discrepancies concerning the feeling in control. One participant stated that the feeling of control is the same during both scenarios, two of them said that the current process made them feel more in control since they rely on people but systems can fail, and three participants affirmed that the AR systems leads to a better feeling of control due to the provision of more and more clear information.

Some of the recommendations on the system are the introduction of 3D images, error ranges, back-up systems and set up easiness. Concerning the behavioural intention, all the participants are willing to use the system.

The results related to the experiment validity show that all the participants stated that the SME is a simplification of the real OTIP, however, it provides a good overview of the system.

Is it important to mention that during the simulations one of the participants tried to position the topside without any help, neither from the assistant-superintendent nor from the augmented reality positioning system. The participant was confident about being able to position the topside by himself due to the closeness to the structures; however, he failed.

6. Expert Interviews

The main objective of the expert interviews process is to explore the impact of the introduction of an augmented reality position system in the offshore industry through interviews with experts from TWNKLS and HMC that are involved on the ARPS development. This part of the research includes a process of exploration on the innovation idea initiation and development, on users' perceptions and on the future implications of the implementation of this new system offshore.

The following sub chapters include the methodology followed during the expert interviews, the interviews structure and participants, and the results. The last sub chapter includes a summary on the main findings.

6.1 Methods

The research methodology is expert interviews with people from HMC and TWNKLS that are closely related to the augmented reality positioning system. These experts have real influence on the development of the project and are a good information source for the research purpose. The interview process involves six experts, three from each company. As it is explained later on in this chapter, every participant has a different role, area of expertise and influence on the project. The differences among participants and the explorative nature of the research indicate that a semi structure interview process is suitable for this case.

Every interview takes between 45 and 60 minutes. At the beginning of the meeting with HMC experts, there is a 15 minutes introduction of my educational background, research goal and methodology, and the current situation of the project on the ARPS. TWNKLS participants are updated of the research and project progress, therefore the 15-minutes introduction was not needed. The introduction phase (Appendix I) includes a power point and videos on the virtual reality experiment and scale model experiment. The remaining part of the meeting was used for the formulation and answer of the questionnaire based on fluent communication with the participants. At the end of the introduction phase the participants can ask questions, and at the end of the questionnaire phase the participants can add any comment that they consider relevant for the research.

6.2 Structure and Participants

The interview process is similar for both companies in terms of structure, time and type of explorative questions. However, some of the questions are different and they are adjusted to the company and participant. This sub chapter includes the structure and content of the interviews for HMC and TWNKLS respectively, and its participants. The expert interview questions related to both companies, are included in the Appendix J.

6.2.1 HMC Expert Interviews

The HMC interview process is structured in six main blocks: personal data, positioning process, usefulness of the system, system introduction, system implications and company perspective (Appendix J).

The positioning process refers to the current topside positioning procedure needs and possible solutions. The usefulness of the system block relates to the advantages and disadvantages of using an ARPS. The system introduction part includes the system requirements to be successfully implemented. It includes the factors that would make offshore people to accept it and use it.

The system implications are linked to the training requirements, organizational structure changes, OTIP demand changes and procedures modifications that are related to the introduction of the AR system. Finally, the company perspective includes insides about the potential of the technology for HMC: what is the added value that this system brings to the company?

The interviews with HMC include the participation of three experts.

- Participant 1: overall responsible for the Hermod. He is the initiator for the innovation project and is involved since the beginning.
- Participant 2: experienced Sr. Operational Manager of the Thialf.
- Participant 3: overall responsible for the Thialf.

Two of participants are the overall responsible of the two main vessels that HMC owns and are involved in the offshore topside positioning process, Hermod and Thialf. All of the participants are involved in the project but were not completely updated about the current situation of the system.

6.2.2 TWNKLS Expert Interviews

The TWNKLS interview process is also structured in six blocks, they are slightly different from the HMC's blocks, they are: personal data, ARPS, usefulness of the system, system introduction, system implications and company perspective (Appendix J).

The ARPS block refers to the initiation and evolution of the ARPS project within HMC and TWNKLS. The usefulness of the system block relates to the advantages and disadvantages of using an ARPS, its expected benefits and limitations, the added value of the system… The system introduction block includes the system requirements to be successfully implemented, it includes technical and human factors.

The system implications are linked to the offshore industry and the augmented reality industry: organizational structure modifications, training requirements, procedures changes that are related to the introduction of the AR system, future applications of the system and the impact of the successful implementation of this system in the AR industry.

Finally, the company perspective includes insides from the potential of the technology, personal expectations and challenges related to the different perspectives that involved the two developing companies.

The interviews with TWNKLS include the participation of three experts:

- Participant 1: Technical project leader. R&D team leader of TWNKLS.
- Participant 2: Project employee. Optimization of tracking algorithms project task.
- Participant 3: Previous account manager. TWNKLS founder.

All of them are involved in the project and updated about the current situation of the system and they have been involved in the project from its early beginning.

6.3 Results

This sub chapter includes the results of the expert interviews, three with HMC employees and three with TWNKLS employees, respectively, all of them involved in the ARPS project. A more detailed result report is presented in the Appendix K, that includes the transcript of the six expert interviews.

6.3.1 HMC

Heerema's participants were highly involved in the project, but had little knowledge on the ARPS recent development. This section includes the data collection of the three participants on the HMC expert interview process.

<u>Participant 1</u>

"The decision to remove people from the jacket its driven by clients' requirements on safety and HMC interests on avoiding transfer of people to the jacket. We do believe that it is a safe practice to stand on the jacket, but we want to fulfil clients' requirements and we want to eliminate the challenging and weather-sensitive process of transferring people to the jacket. In 2014, the innovation department initiates a project on removing people from the jacket. Many ideas came up: AR, drones, lasers… we are currently investing on AR and laser positioning technologies. Comparing both innovations, AR has fewer interface requirements and preparation, its cost-effectiveness potential makes it our preferable technology. Laser technology is further ahead developed, however, it is more expensive, it requires more interfaces, it is more sensitive to errors, it needs many measurements processes."

"I think the AR system is really *useful*. It should be carefully considered that the modules should be accurate enough to match with the software and it should be able to adapt its functionality to the weather conditions. I believe that there is high *acceptance to the system,* superintendents have been quite involved on the innovation process from the beginning. We have 4 vessels, 8 superintendents, it takes time to all of them get experience. Since we gather them 4 times for year, we should include the system on these meetings to involved them on the project."

"Concerning the *training* required for the introduction of the system, the system should be included on the superintendent simulation training. In addition, vessel crew should be trained on maintenance, installation and operation of the system, since we are assuming that anybody from TWNKLS will be there and any IT worker will be specifically hired for this system implementation."

"We do around 15-20 topside installations per year. The fact of implementing this technology will not affect *the demand* of topside positioning processes, however, it will position HMC a small step ahead from competition. We expect no changes on the *organizational structure* of the vessel, just extra training and some procedure changes."

"This AR system could be implemented *in other offshore processes*, such as pile positioning, structures measurements and structures positioning. We currently perform pile positioning on the jackets through under water cameras, that provide low quality visibility of the structures, AR could improve this process by using its tracking system on the part of the pile that is above water. Structures measurements applications can be extremely useful for decommissioning of structures, where we need to measure how accurate is it cut, its shape, in order to be able to settle structures down on the deck. Nowadays this measurement process is not precise, it takes place under water and lasts for a long time. AR could make this process faster and more economic."

"The added value of an ARPS for OTIP is not related to sales increase or lower labour/equipment cost. It is about satisfying client's requirements in a cost-effective way and reducing the complexity and risk of topside operation processes. An additional expected benefit of the system is the reduction of installations items (those that facilitate the transfer and access of people to the jacket). The process time is not expected to be reduced because the *crew transfer to the jacket takes place while the topside is starting to be moved by the cranes*."

"It takes time before you can implement technology. Most of the time difficulties come up from the technology, when you want to implement it in a specific process it is needed to *adapt the technology to the case*. Most of the times technology is not directly applicable and it needs some changes, that's where the successfulness of the system comes up. The system successful implementation depends on how much priority people give to it. One of the advantages of the implementation of this system is that HMC has assigned *one specific team to develop and work ARPS,* and it is not an extra task within an existing team."

<u>Participant 2</u>

"The current process for topside positioning need to be improved in terms of *safety.* The system can benefit the topside installation process by no sending people to the jacket that need to climb and stand under the load. The trip and climbing on the jacket is more dangerous than standing under the engineering load. A possible disadvantage is the chance of technical failure. We should be ready to send people to the jacket in case of failure and/or install a back-up system. The system should be firstly tested still having people on the jacket. To be successful implemented, the systems needs to be: easy to install, 100% reliable and every time successful. If the system fulfils these requirements, then people will trust it and use it."

"The system will not affect the *demand* of topside installation nor *the organizational structure.* Well it depends if we buy the system ourselves or if we keep renting it, but probably we will buy it. HMC is also investing on another technology system to eliminate the need of people on the jacket, laser positioning technologies. It is a system that it is much more expensive and complicated to install and maintain than the augmented reality system. Our preference is TWNKLS system, mainly for economic reasons."

<u>Participant 3</u>

"The current process should be implemented by *eliminating people from the jacket*. We established this goal 10 years ago, however by that time the technology was not ready. Two years and a half ago we decided to try it again, since technology was already available. AR looks like a suitable and simple technology that can achieve our goal. I have to say that I was impress by the AR system. It comes from a theoretical environment and TWNKLS is really different from HMC, understanding among parties took a bit longer that with people that work on our industry. I think that if you want a *great innovation in technology, you cannot take it from the traditional industry*, you need to take people from another industry involved. ARPS is completely new technology in a very traditional environment."

"The *advantages* of implementing the system are *safety*, elimination of some equipment (such as ladders to access the jacket). Maybe the system can allow the topside positioning process on a bit worst weather conditions since there is no need to transfer people to the jacket. The *disadvantages* are mainly related to *reliability issues*. Our industry is really traditional, we do have many risks already, we don't want to introduce new risks. Introducing something completely new requires the slowly introduction and early involvement of the users on the process. We already run the system in parallel with the current positioning process methods, therefore, the crew are familiar with the system. We think that the right system should be *gradually implemented* to get users reliability, the system needs to prove to be accurate and stable all the time."

"A *robust* system is essential, it should include a backup system, Moreover, the system needs to be *simple to set up*, since crew should be able to do it. Here is the challenge between TWNKLS and HMC: a technical very complicated system should be operated by not technical people. We have few IT, software people on the vessel and we don't want to include more. It the systems needs to be modified and adjust it every time before we use it, then it would not be user friendly, we don't want it."

"Concerning the topside installation *demand***,** I think it will not change. There will not be so much changes on *procedures* or protocols. It is important to define who will operate it and which training it will need. The answer to this question heavily depends on the user interface. *How much training people need depends on how user-friendly end up making the system HMC and TWNKLS."*

"The *added value* of the AR system for HMC is safety improvement. It will *not reduce the process time* (the lift of heavy modules requires slow movements) and *it will not reduce the cost of the process.* HMC invested in AR because we wanted unhuman positioning, and AR could do it. We had already a solution, laser positioning technologies, but it is very expensive. This AR system could maybe be operated by our own crew, this is a big step we were looking for."

6.3.2 TWNKLS

TWNKLS's participants were involved in the ARPS project and they are AR experts. They have been involved in the project for a long period (1-2 years) and are already familiar with offshore processes and topside installation operations. The answers are collected following the same structure as in the HMC expert interviews: ARPS, system usefulness, system introduction, system implications for the offshore and AR industry, and TWNKLS perspective (Appendix J).

<u>Participant 1</u>

"The ARPS fulfils HMC *clients' requirements* on safety. In addition, this system *can make the process faster; not for topside installations* because it takes long times due to the heaviness of the structures, but windmills structures installations, that require thousands of installations processes, could be done in less time. So right now, the main advantage of using the system is safety, maybe in the future it saves time, that translates into monetary savings."

"Compared to laser positioning system, ARPS allows Heerema to *run the system by themselves* instead of renting a laser technology service for every offshore operation. The main disadvantage is that it is a vision system, so it highly *depends on the weather conditions*."

"Nowadays, the system has a difficult set up process that involves *technical knowledge*. We are working on making a simpler set up process. The goal is that in the near future, TWNKLS will not be offshore anymore and it will become a second line support through remote assistant-superintendent. The introduction of the system requires the system to work and to build trust from people offshore. *Trust come from testing the system, but it is difficult because you can just test it a couple of times per year per vessel*. Other way to get trust is to have people abroad convince about the validity of the system, that it will be effective."

"Offshore people should be *trained* on the system. Standard checks procedures on both, the user and system level should be established. User level requires training by simulating the system and possible scenarios in the simulation center. The management interface and hardware set up needs specialized training, a real engineer. In this case, new people or training of one IT engineer from the vessel."

"Concerning *future applications*, there are many possibilities: movement of structures from one vessel to another, jacket placements. The successful implementation of the system really useful for the offshore industry, since other applications can follow. In addition, other industries can benefit by implementing outdoor tracking such as on the *construction or steel industry*."

"HMC is investing on this AR application for topside positioning processes, however, at R&D level, *AR can have many other applications*. There are some offshore applications easier to do than topside installations, they could be further research"

Participant 2

"The idea generation of the project is the result of a *Heerema request* given the AR capability on tracking indoor environments. The initial expectations on the project were to achieve precise edge base video tracking and real-time feedback."

"The system allows *unmanned topside positioning, it fulfills clients' requirements* and it provides more precise results than current methods. Compared to laser positioning technologies, this system is more robust, lasers can be interrupted by any drop of rain, they have higher visibility constrains, and equipment requirements. The only limitation of the AR system is to assure a correct *match of the 3D model* and the real image. Weather is not a limitation for using the system, if the weather conditions allow the process, the system will also allow it. The eliminates the need of sending people to the jacket, what can lead in a shorter time of operation and less restrictive weather limitations. Concerning future developments of the system, first the system will automatically track the markers, then the system will be able to track the structures without markers."

"Concerning the *organizational structure,* the introduction of the system implies the creation of one extra position, the one who operated the computer system. This extra position can be overtaken by one guy from the vessel. There is a need of establishing *protocols for each possible scenario.* The system works or not, *operate it does not require high skill worker*. TWNKLS is not needed during day to day operations, just during the first offshore trials. Heerema should include the system in the *simulation center* and train the crew on worst case scenarios. In collaboration with us, we should come up with suitable cameras positioning locations taking into account the process and positioning conditions."

"This is the *first time that AR* is used with such a *big and complex 3D models.* Topsides and jackets are structures with a lot of features that needs to be tracked. It can be considered as a big step forward for the AR industry, that is usually involved on the tracking of simple and small objects."

Participant 3

“The *benefits* of the system are linked to safety for oil and gas companies, HMC’s clients; and cost reduction, this system requires low preparation and can make the process faster, saving a bit of time saves a lot of money.”

“A *successful system introduction* requires system robustness and user friendliness. We do not know if it works, we assume it will work, however, the behavior of the system on different weather conditions is unknown. The *training* on the system should ideally take place in the VR training center of HMC.”

“The ideal situation is that TWNKLS will not be offshore during OTIP, we will send a box with the equipment and they will use it. The next two times we will go offshore to test the system and show how it works, then the idea is to HMC to do it by themselves. Remote assistance from TWNKLS is the goal.”

“I think that this system can have *many other applications,* such as windmill installation, bridges placements, more generally any structure placement. Is the first time that the AR industry deals which such as a big dimension project. *The combination of the measurements and AR technology makes this project really powerful*. There is a high interest of this technology in the marine industry market because they want to achieve unmanned OTIP. This is a project that has a huge R&D part, we create algorithms, we cannot test the system in house, as usual.”

“There are few OTIP per year, how would you proof its robustness? We have *video footage of previous installations*, we can test the system with different algorithm over and over. In addition, we can test it offshore a few times, like we are currently doing.”

6.4 Summary

This sub chapter summarizes the results of the main finding of the expert interviews. It includes the results of HMC and TWNKLS expert interview process related to the augmented reality positioning system.

HMC is looking for a positioning system that allows topside installations on unmanned jackets. They are currently investing on laser positioning systems and ARPS. HMC has preference on the ARPS over laser technology because it requires lower equipment costs and allows HMC to keep doing the positioning process by themselves, without bringing a new technical team offshore.

Other *ARPS applications* suggested by the experts are pile positioning on jackets, measurement of structures during decommissioning process, jacket placements and windmill installations. In addition, other industries can benefit by implementing ARPS for outdoor tracking, such as the *construction or steel industry.*

Experts agree on the few or *the lack of impact of the ARPS in the topside positioning time*. The system will most likely not decrease the operational time because OTIP are slow and long processes, and the removal of transfer of people to the jacket does not speed up the process because these transfer takes place when the topside is already being lifted. However, as one of the TWNKLS experts stated, *ARPS can make positioning process faster*, maybe not for topside installation processes, that are characterized for long times and slow movements, but it could speed *other positioning processes* (such as windmill installation processes).

The expected benefits of the introduction *of ARPS for OTIP* are not related to cost or time saving in comparison with the current positioning process, they are related *to solve the current safety concerns* related to offshore crew standing on the jacket under the suspended topside in the most economical possible way.

The main uncertainties of the ARPS are its *accuracy, robustness, weather conditions workability and effective tracking capacity*. Additionally, as one of the experts from TWNKLS mentioned, it should be taken into account that the introduction of the system implies the *creation of a communication* process between the system administrator and superintendent concerning the tracking quality.

The use of ARPS for OTIP implies the introduction of a completely new technology in a traditional environment, the offshore industry. But, as one of the participants stated, “if you look for a great innovation in technology, you cannot take it from the traditional industry, you need to take people from another industry involved”. The new technology should be adapted to the specific process, OTIP in this case, and it should be *gradually introduced* to be successful and user friendly (simple set up and operation). It requires fluent collaboration among the technical and the marine companies. One successful factor on the ARPS development is the designation of one specific team at HMC to carry this project.

OTIP *are not frequent*, they take place few time per year, what implies a low technology-testing chances. As a consequence, the use of ARPS requires a robust and gradual introduction process that involves offshore users in order to build the technology trust. The *superintendents*, that are *gathered* four times per year, are planned to be further introduced to ARPS during these meetings. The fact that there are few OTIP per year, makes difficult to proof the ARPS robustness. However, the system can be tested over *video footage* of previous installations. The combination of this testing and offshore testing can lead to the validation of the system reliability and lead to users trust on the system.

Introducing the ARPS is *not expected to change the OTIP demand, neither to change the current organisational structure of the vessel* because the ARPS is expected to be handled by the crew members. However, the *training process and the current protocols should be modified*. The *system should be standardized* to allow the creation of protocols that described step by steps checking, set up, operation and maintaining processes. Protocols should include action plans on worst case scenarios, such as system failure or tracking errors. The superintendent should be trained about the user interface and several possible scenarios in the simulation centre. In addition, one of the IT engineers from the vessel crew has to be instructed on how to install, operate and maintain the system, also in the simulation centre including different scenarios. As one of the experts from HMC stated: “*How much training people need depends on how user-friendly end up making the system HMC and TWNKLS*”.

The main discrepancies between the participants are different perspectives on whether the system will require TWNKLS support during day to day operations and how much can the system be simplified and adapted in order to be *used by offshore crew*. There is also uncertainty and discrepancies about the performance of the system under non-optimal weather conditions. The final goal of the ARPS is to be operated by HMC. TWNKLS plan to send “a box” with the equipment needed and the instructions, and HMC would install and operate the system. TWNKLS experts highlight the importance of *remote assistance* by TWNKLS during OTIP to assure the successfulness of the process.

As one the experts from TWNKLS indicated, at R&D level, *AR* can have many other *applications in the offshore industry* apart from offshore topside positioning processes. There are some offshore applications easier to do than topside installations, that could be further researched.

The success of this ARPS would mean *a big step forward for the AR industry*, which is currently mainly focused on the tracking of small and simple objects and no on big and complex structures. All the experts showed enthusiasm about the ARPS and were optimistic about the success and implementation of the system for OTIP and for other processes in the future.

7. Conclusions

Oil and gas industry is seeking to improve safety on its current operation procedures. Installation of topsides is considered one of the most challenging offshore installation activities (Hee et al., 2007), it is a long process that requires the lifting of heavy and big structures on an uncontrolled offshore environment (Breidablikk, 2010). Nowadays, it is based on visual measurements assessment from offshore crew positioned on the jacket during the installation, what counters to one of the golden safety rules, “do not stand or walk under suspended loads” (Peuscher & Groeneweg, 2012).

Since the safety requirements in the oil and gas industry have become more stringent, the safety concerns related to manned platforms during topside installations are driving the offshore oil and gas industry to explore different methods to allow topside installations on unmanned jackets. On the other hand, augmented reality is a technology that is increasingly receiving attention (Cheng, 2017), and it can allow the position of objects measurements by tracking and augmentation techniques (Daponte et al., 2014), and therefore structures positioning processes. This technology would not require the presence of crew members under a suspended load and could solve the safety issues for topside installation processes.

This research explores the potential expected benefits of the use of an augmented reality positioning system during offshore topside installation processes, and it investigates the system usefulness and the users’ perception on its usability. Moreover, the research examines the implications of the implementation of an ARPS in these types of processes. The research is mainly based on the project that relates to the development of an augmented reality positioning system that TWNKLS and HMC are developing for topside installation processes.

The following first chapters provides an answer to the research questions. The second one includes reflection and discussion on the main findings of the research and includes the limitation of the research process. The third sub chapter drives recommendations for the companies that participate on the development of the first ARPS. The last sub chapter addresses future research steps for AR as a positioning system and its introduction in offshore topside installation processes.

7.1 Recap of the Research Questions

This sub chapter makes use of the research process based on desk research, a virtual reality experiment, a scale model experiment and expert interviews, and of tits findings in order to answer the main research question by answering the three research sub questions.

RQ.1. Which are the potential expected benefits of ARPS for offshore topside installations in terms of safety and cost?

The main expected benefit of the use of ARPS is the topside positioning on unmanned jackets, that is perceived as a *safety* improvement by gas and oil companies (HMC's clients). In addition, since people do not need to stand on the jacket, they do not need to be transferred there, what is considered a risky process heavily dependent on weather conditions.

ARPS has the potential perceived benefit of allowing low-*cost* unmanned topside positioning process due to its possibility of being run by the current offshore crew and due to the low equipment and cost of the system. This fact positively differentiates ARPS from other positioning technologies such as laser. The positioning system based on augmented reality has been designed to be operated by non-AR specialist person. Moreover, the hardware required for this system is relatively cheap, especially when it is compared with the hardware needed for other potential positioning tools. In addition, the use of ARPS does not require equipment in the jacket and topside, and therefore, crew members do not have to stand or travel to the structures. As an example, laser systems require the offshore intervention of a specialist team in OTIP and numerous total stations located in the vessel and several number of prisms located in the jacket and topside.

Apart from the potential expected benefits already mentioned, the virtual reality experiments' qualitative data indicates that the *ARPS* could potentially reduce the *number of operations* (Table 7). The decrease on the number of operations could be the result of the provision of more and more precise data that allows the superintendent to better and more efficiently instruct the crane operator about the movements needed to position the topside. Moreover, another expected benefit is the provision of more, and more accurate data of the relative position of the jacket and the topside. It can lead to better and more accurate information to position the topside.

The quantitative data collected during the VRE indicates that the new positioning process (using the AR system) could reduce the positioning process *time*. However, the data is biased by the nature of the simulation process. Virtual reality simulations allow the restart of the process for unlimited times, what causes the user to tend to execute the process fast rather than right (as one of the participants indicated). In addition, the fact that during the simulation of the new process there were just two people involved, instead of three, made stronger the tendency to hurry and led to lower positioning times. On the other hand, the quantitative data collected during the SME indicates that there is not a clear conclusion on the time effect of ARPS in OTIP. On the other side, the qualitative data collected from the interview period suggests that the system could make the process faster because it avoids the process that entails the transfer of the people to the jacket. However, the results of the expert interviews, where offshore experts participated, reveals that the transfer of people takes place at the same time as the topside is being lifted. Therefore, the elimination of the transfer of people to the jacket will not alter the total operational time.

Four of the participants of the VRE and SME, pointed out that the elimination of the role of the assistant-superintendent, and therefore the elimination of the communication process, can lead to lower positioning times. However, the system eliminates the superintendent and assistant superintendent communication process but includes a communication process between the superintendent and the system administrator about the ARPS. Therefore, the introduction of the ARPS is not expected to significantly reduce time of offshore topside positioning processes.

However, the ARPS should be proved to work on offshore real conditions in order to accomplish all these expected benefits. In addition, nowadays, the system requires the presence of a specialist from TWNKLS during the offshore process. As a consequence, the potential safety and economic benefits of the AR system are constrained by the *system robustness and near-future system simplification.* The system should ensure a continuous and accurate tracking process that provides on-time accurate information about the structures' relative position under acceptable weather conditions (weather conditions that are good enough to allow topside positioning). In addition, it should be further simplified to allow its operation by crew members.

The main expected benefit of ARPS in OTIP is the allowance of unmanned jacket topside positioning in an economic way. Therefore, at the end, the goal is to achieve clients' requirements of not having people under suspended loads in the most economical way as possible. It implies that the system will not reduce the costs of topside positioning processes, it will provide an increase of safety perception by investing a low amount of money compared with current technology procedures.

ARPS could be applied to other processes in the offshore industry such as jacket piles positioning, windmill positioning, structures measurements and general relative positioning measurements. It could lead to different potential benefits for other offshore processes. For example, ARPS applied to wind mill installation processes could imply an increase on installation speed; given the high volume of these structures offshore, a small increase in speed can lead to large total time and economic benefits. ARPS for OTIP does not have this potential benefit because this kind of processes are highly time consuming and involve the movement of extremely heavy structures during severely weather conditioning limiting processes.

RQ.2. Which is the perceived usability and usefulness of ARPS in the offshore industry?

Apart from technical benefits, the successful introduction of the system requires *users' acceptance*. The users should accept the system and be willing to use it. As it was developed on the section 4.1 and 5.1, related to the methodology of the experiments, it mainly depends on three factors (see Figure 38).

The *performance expectancy* relates to the system unmanned topside positioning expected benefits that have been already mentioned. The effort expectancy is linked to the perceived ease of use of the AR system for both, the superintendent and the system administrator. Facilitating conditions on the system are a complete training on the system that enhances a high perceived behavioural control of the situation.

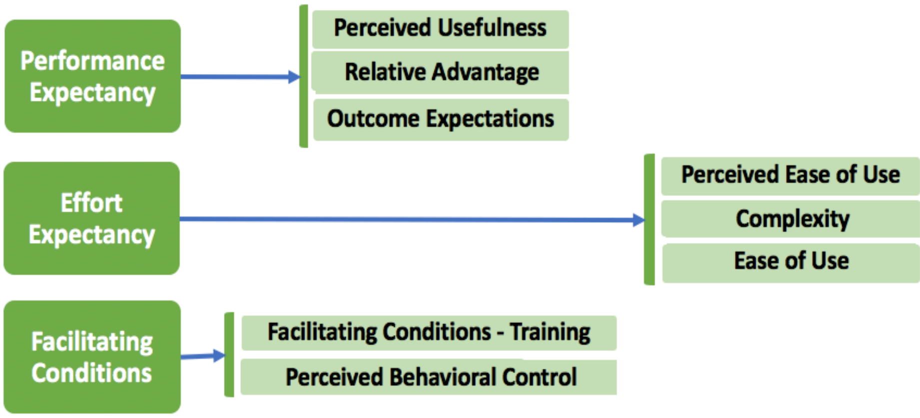


Figure 38. User Acceptance Factors

The *effort expectancy* of the ARPS is perceived on different ways, while the user interface is considered as easy to understand, the management interface and the system set up are perceived as complex. The system should be further simplified in order to achieve a successful technology implementation. The perceived *ease of use* of the user interface has been achieved through the inclusion of superintendent's opinion and preferences on its design. This fact suggests that in order to achieve a perceived ease to use management interface, the IT people from the vessel that will run the system should be involved in the design and modification process of the interface.

Concerning the *facilitating conditions*, the introduction of the system is expected to require some additional training: the training of the superintendent on the user interface and the training of the system administrator. This training needed is perceived as non-complex since, since, as one of the participants indicated," the system comes naturally to understand". The present research results show discrepancies concerning the perceived *feeling of control* using the system. Some people rely more on human measurements and consider the system as a reduction on the control of the situation, on the other hand, other participants consider the system a better source of information that human estimations. Therefore, the feeling of control depends on the participant perception about the system robustness. Nonetheless, all participants agreed on the need of *visual check* independently of the positioning methodology used, either by sight or by camera.

As it was mentioned in the first sub question results, the system has the potential to provide more, and more accurate data of the relative position of the jacket and the topside. It is clear that the system will provide more data about the process, however, the accuracy is subject to be tested under different offshore conditions. While some users considered accuracy as a system advantage, some of them considered it a limitation. The research process indicates that users can increase their confidence on the system if it includes an error range measurements accuracy according to the weather conditions. Moreover, the introduction of the error range is also a way to increase users' reliability on the system. The fact that nowadays the system just provides exact figures makes some users to wonder about the preciseness of these measurements.

RQ.3. What are the implications of the introduction of ARPS in the offshore industry?

Concerning the implications of the introduction of ARPS, several factors have been analysed, the main ones are: demand effect, potential changes on the organizational structure and required training.

All experts agree on the *lack of impact of the system on the demand* of topside positioning process. The implementation of the system is considered as a competitive advantage respect to the current positioning process in terms of perceived safety and a competitive advantage respect to laser positioning systems in terms of cost. However, since the demand is mostly considered as static, it is not considered to have the potential to increase the number of OTIP.

The system is *expected to influence as little as possible the organizational structure* of the vessel during OTIP. The expected simplification of the system lead to few changes expectations on the crew structure. The number of workers it is not expected to change because the system design established that crew members will be able to initialized and operate the system.

The introduction of the system requires the training of the superintendent on the user interface and the training of the system administrator, the worker responsible of the management interface. This worker is not expected to need high technical skills; however, he should be an engineer from the IT vessel department that should be instructed on the system set up, operation, control and maintenance.

The *training* should take place in the simulation centre, as it occurs nowadays for the current process. The system, user interfaces and camera tracking system should be implemented in the simulation centre. The training should also include simulation on different possible scenarios such as system failure, bad weather conditions or any other possible problem. As the results of the VRE indicated, *training heavily determines the user perception on the system*. An incomplete training process could lead to user rejection to the system given a complex perception of the system usability. Furthermore, another implication of the system introduction is the modification and creation of *protocols*. Protocols should be modified to include action plans for each scenario. Moreover, the system should be standardized to allow the creation of protocols that describe step by step checking, set up, operation and maintaining processes.

The implications of the use of ARPS for OTIP considered little organizational and protocol's modifications, and non-complex training introduction. However, these expected changes heavily depend on the final design of the ARPS.

7.2 Reflection and Limitations.

This thesis reports an explorative research based on an innovative AR positioning technology for offshore topside positioning processes. The research is mainly based on the ARPS that is being developed by TWNKLS and HMC. Since this is the first AR positioning system that is being developed, it constitutes a suitable foundation to drive conclusions on the potential benefits and implications of ARPS in OTIP. The research provides qualitative results based on a virtual reality experiment, a scale model experiments and experts' interviews.

Concerning the VRE, there are two main limitations, the *lack of the skipper role* in the simulations and the tendency to rush the process. On the one hand, the lack of the skipper is common for both processes, current and new, and therefore, the comparison among these two processes keeps its validity. Moreover, the experiments explore the users' interaction with the system and the system usefulness, which is not directly affected by the role of the skipper. On the other hand, the tendency to rush makes invalid que quantitative data related to the process time and the failure rate.

Even though the SME was carefully designed, at the beginning of the test the validity of the *simulation* was questioned. One of the participants was sceptic about the validity of the simulation since the vessel and the jacket were relatively close to each other (few meters). He believed that he could position the topside without the assistant-superintendent or the AR system support. His failure during this trial process proved the validity of the simulation. Moreover, the research process indicates that the validity of the c*omplete scale model experiment* is suitable given the goal of the research. The results indicate that scale model experiment does not realistically simulate OTIP since offshore conditions are challenging to simulate. However, according to the qualitative data collected, the experiment provides a good overview of the AR system and its capabilities, and allows a reliable interaction user-system, what meets the research goal.

The experts' interviews are considered a valid explorative research method because the participants include experts from HMC and TWNKLS with different roles and perspectives on the project. A possible improvement of this research process would have been the *participation of real superintendents* throughout the research process. This was one initial goal of the research; a superintendent was planned to assist to the SME. However, they usually either work on the vessel or are off, so the probability of having them as part of the experiment was low; his tight agenda made impossible his assistance to the experiment.

As this research indicates, the ARPS is considered useful since it enhances an increase of safety feeling by oil and gas companies. This safety factor is still subject of testing. Until now, no accidents on OTIP have taken place, however there is uncertainty about the relation of the ARPS for OTIP and safety.

This research denotes that the perceived cost of the ARPS are low since the system is designed to require low equipment and low installation and operational cost in comparison with other unmanned jacket positioning techniques. However, the cost of the systems directly depends on the system meeting its initial expectations in terms of simplicity and operation: Will the system reach the expected level of simplicity and robustness to such extent that no AR experts are required offshore? How much support from AR experts will be needed during operation? How many software modifications are required within different topside positioning process? Can the system be operated without the support or intervention of technical experts from the software development company?

The scale model experiment was an initial proof of the efficiency of the system allowing OTIP without the need of crew members on the jacket. In addition, the interview process that took place during the VRE and SME indicates that the system is easy to use by the superintendent, while the system administrator part needs to be further simplified (system set up, management interface, operation…). The experiments show that users expect that the system will not require complex training. Once the system proves its robustness in the offshore environment, all participants agree on be willing to use the system.

The perceived implications of the use of ARPS in OTIP are considered little organizational and protocol's modifications, and non-complex training introduction. However, most of the times the introduction of new technology on new setting conditions are perceived simpler than they are. The introduction of an ARPS in OTIP requires a new emergency case protocol, new roles on the vessel crew structure, new procedures and further testing to allow a safety implementation of the technology, that is the main goal of its introduction. As an example of these procedure modifications, the system could lead to changes on the decision on the optimal time to install the topside. Nowadays, the installation is carried when the weather conditions are considered good enough for installation, the point in time when the environmental conditions are better is chosen (green point in Figure 39). Therefore, the topside installation would take place at the time corresponding to the green circle situation. However, if at that time the sun is facing the cameras that track the structure, maybe it is better to position the topside at the time corresponding to the orange circle situation.

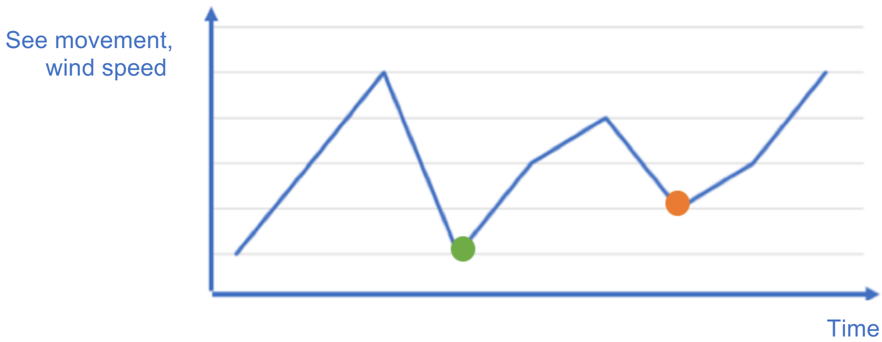


Figure 39. Weather conditions' graph

Furthermore, it is important to consider that the training heavily determines the user perception on the system. A good and appropriate training process would lead to well-prepared workers able to understand the system and control it. An uncomplete training can lead to unsafety and users' reluctance to the technology. An example of the importance of training took place during the VRE, where one of the participants was not well trained about the UI features. When the simulation started he did not expect the UI to sudden zoom in during the process. The fact that he was not aware about all the features and actions of the interface, made him not to be prepared for the UI changes during the positioning process and to consider it as something negative. Implementation of new technology requires users to be aware of what it does, when it does it and how it does it.

One of the main *challenges* of the introduction of an ARPS in the offshore industry is the combination of such an innovative technology in a traditional industry not used to the integration of disruptive innovations. The inherent high risk involved on offshore operations makes the offshore industry reluctant to include more perceived risks such as innovations. In addition, the combination and required collaboration of a technical company, such as TWNKLS, and an offshore company, such as HMC, requires flexibility and high comprehension among parties. This challenge is successfully being managed by HMC and TWNKLS since both companies have a specific team full time dedicated to the ARPS project.

Another challenge for ARPS offshore introduction is the low frequency of OTIP, few topsides are positioned per year since the demand is limited. The complexity of the introduction of the AR system in the offshore industry should be balanced by a gradual system introduction that involves all the stakeholders on the project development. These challenges do not make possible the trial of the ARPS in real offshore conditions given the scope of this research.

Despite the described challenges related to the introduction of AR as an innovative positioning tool for OTIP, the research shows that all the participants of the project are optimistic about the successful implementation of the system and are willing to use it. There is a positive feeling about the further successful development of this system. As one of the participants stated, “if you look for a great innovation in technology, you cannot take it from the traditional industry, you need to take people from another industry involved”.

7.3 Recommendations

The development of the augmented reality positioning system is following a successful development path. This sub chapter drives some recommendations to further implement this system in offshore topside positioning processes.

The first recommendation is to further simplify the system in order to achieve the expected benefits of the technology implementation, especially the part related to the system set up and management interface. The system set up and operation should be understandable and managed by an IT engineer of the vessel crew. In order to achieve a perceived ease of use of the management interface, these engineers that are planned to run the system should be involved in its design process, in the same way that superintendents participated in the design process of the user interface. Moreover, as it was mentioned on the section related to the limitations of augmented reality, the system should deliver straightforward information to the end user that does not lead to misinterpretation of data or to the user distraction while also preventing the user to overly rely on the AR system such that important cues from the environment are missed. As one of the participants of the SME indicated, the use of the system can make the people to over rely on it and forget on how to act or not pay enough attention to the environment.

One of the perceived benefits of using ARPS for OTIP is that it could be run by the offshore crew. However, as the expert interview process reveals, remote support from a technical company will most probably be required. Remote assistance requires high quality Wi-Fi connection. However, current offshore conditions lack suitable connections. It is recommended to further investigate and test the offshore Wi-Fi workability when the time to use remote assistance comes.

This research indicates the importance of including the ARPS in the current trainings, that take place on a virtual reality centre. Furthermore, the implementation of this system in the training process should include the simulation of all the possible scenarios related to the system behaviour and the offshore conditions.

All participants agreed on the need of visual check independently of the positioning methodology used, either by sight or by camera. Nowadays, the user 2D interface (Figure 8) does not display the real structures, just the management interface does (Figure 7). It is recommendable to introduce a view of the process in the UI in order to increase users' reliability on the system and avoid errors. For example, it is essential that the user correctly interprets the information related to the position of each stabbing cone and its corresponding bird view. As Figure 8 shows, it is currently indicated through a 3D model that indicates the position of each stabbing cone and its related view by assigning figures, A2, A2, B1 and B2, to each cone. However, the possible change of orientation and position of the superintendent in the vessel; and an unfortunate misinterpretation of the reference system can have disastrous consequences.

In addition, this research indicates that the ARPS should be further improved by integrating error range measurements in the user interface according to the system preciseness depending on the weather conditions. It would lead to more efficient process and an increase on users' reliability on the system and their feeling of control.

As it has been mentioned before, OTIP take place few times per year and therefore new positioning systems can be infrequently tested offshore. Moreover, offshore crew have tight schedules and they are rarely gathered. Therefore, the system should be introduced to all the stakeholders during the collective meetings that take place during the year. The next ARPS testing should involve the real potential users of the system, superintendents and IT vessel engineers. As one of the TWNKLS experts indicated, a useful method to test the system on realistically offshore conditions onshore is to use video footage of previous installations. Thus, a suitable method to test the ARPS in offshore simulation conditions is to use *video footage* of OTIP to run the system with different algorithms and check the system behaviour. Apart from video footage testing, it is recommendable to test the system on big scale models on outdoors environment and to try to use the system as a back-up system during real OTIP.

More importantly, it is essential to be aware of the possible difficulties and modifications that the introduction of an ARPS in offshore operations requires. Underestimation of the effort needed to introduce the system can lead to the failure of the ARPS introduction in the offshore industry.

7.4 Future Research

Concerning the use of ARPS for OTIP, nowadays, the ARPS uses AR video mixing tracking techniques for the initialization and monitoring of the structures. However, AR can be further implemented in this system by including AR visualization techniques. The visualization of the positioning information that is currently displayed in the 2D user interface could be directly displayed on the real offshore environment through optical combination. This would solve the current issues concerning the lack of real visual information of the user interface, that prevent the superintendent to visualize the real process situation. Smart glasses could be the new display device that substitutes the current tablet and 2D user interface. However, safety issues related to the use of smart glasses in uncontrolled and unpredictable environments should be considered before its implementation. As an example, the glasses could limit the field of vision of the superintendent during the process and he could miss important cues from the environment.

The success of an ARPS in OTIP could imply a great advantage in the offshore industry since ARPS could be applied to other processes such as windmill positioning, measurement of structures for decommissioning processes and jacket placements. Moreover, augmented reality has a great potential as a positioning tool, not just in the offshore industry also on other sectors such as the construction or steel industry, that can benefit from the outdoor tracking capabilities of AR systems. Therefore, AR has the potential to be applied in diverse engineering projects that require measurements and positioning calculations. However, it is important to consider that introducing new AR application technologies in industrial settings requires a deep understanding of the applying industrial process and its requirements.

The introduction of an ARPS for OTIP represents a great step forward for the AR industry, which is mainly applied on the tracking of relatively small and simple objects and no on big and complex structures such as topsides and jackets. However, the potential benefits of an augmented reality position tool for complex and big structures on diverse environments heavily depends on the quality and tracking capabilities of the system. As the literature review indicates and the expert on this technology mentioned during the interviews, tracking in unprepared environments, such as offshore conditions, remains a challenge. Further research on AR tracking should keep going during the next years to assure correct match of 3D models and real structures in order to provide reliable measurements information.

To sum up, the main determinants of the successful introduction of ARPS in OTIP is whether the system will work on offshore conditions and whether it can be fully automatic or if it would require continued technical assistance and specialized IT workers to run it. The successful introduction of ARPS in topside positioning processes would introduce structures positioning as a new AR application. As a consequence, AR could be used to positon and measure structures in diverse engineering fields.

References

Akers, P. (2003). Laser Leveling System, Apparatus And Method For Building Construction, *2*(16).

Ali, I. A. (2014). Structural modelling of offshore module for loadout, transportation and installation, (June). https://doi.org/10.1177/0739456X9401300405

Amir H. Behzadan, Suyang Dong, and V. R. K. (2015). Recent Advances in Augmented Reality for Architecture, Engineering, and Construction Applications.

Azuma, R., Behringer, R., Feiner, S., Julier, S., & Macintyre, B. (2001). Recent Advances in Augmented Reality, (December).

Bakker, F. C. (2015). A conceptual solution to in- stable dynamic positioning during offshore heavy lift operations.

Barlow, J. (2000). Innovation and learning in complex offshore construction projects.

Beglov, V. (2013). Object information based on marker recognition.

Borsci, S., Lawson, G., & Broome, S. (2015). Empirical evidence, evaluation criteria and challenges for the effectiveness of virtual and mixed reality tools for training operators of car service maintenance. *Computers in Industry*, *67*, 17–26. https://doi.org/10.1016/j.compind.2014.12.002

Breidablikk, L. S. (2010). Heavy Lift Methods in Decommissioning of Installations, 70.

Brooke, J. (2000). SUS - A quick and dirty usability scale.

Caudell, P., & Mizell, D. W. (1992). Augmented Reality : An Application of Heads-Up Display Technology to Manual Manufacturing Processes.

Chakrabarti, S. K. (2005). *Handbook of Offshore Engineering, Chapter 4 - Loads and Responses*. *Plainfield, IL, USA* (Vol. I). https://doi.org/10.1016/B978-0-08-044381-2.50006-0

Chen, P., Liu, X., Cheng, W., & Huang, R. (2017). A review of using Augmented Reality in Education from 2011 to 2016, 13–19. https://doi.org/10.1007/978-981-10-2419-1

Cheng, K. (2017). Reading an augmented reality book : An exploration of learners ' cognitive load , motivation , and attitudes, *33*(4), 53–69. https://doi.org/10.14742/AJET.2820

Cheng, K., & Tsai, C. (2013). Affordances of augmented reality in science learning: suggestions for future research. *Journal of Science Education and Technology*, *22*(4), 449–462. https://doi.org/10.1007/s10956-012-9405-9

Cherian, L. D., & Suresh, P. K. (2013). Installation Engineering for Heavy Float Over Topsides- A case narrative, 3–16.

Chuttur, M. (2009). Overview of the Technology Acceptance Model : Origins , Developments and Future Directions.

Daponte, P., Vito, L. De, Picariello, F., & Riccio, M. (2014). State of the art and future developments of the Augmented Reality for measurement applications. *MEASUREMENT*, *57*, 53–70. https://doi.org/10.1016/j.measurement.2014.07.009

Davis, F. D. (2008). Perceived Usefulness, Perceived Ease of Use, and User Acceptance of Information Technology, *13*(3), 319–340.

Dillon, A. (2001). User acceptance of information technology, (August).

Dini, G., & Mura, M. D. (2015). Application of Augmented Reality Techniques in Through-life Engineering Services. *Procedia CIRP*, *38*, 14–23. https://doi.org/10.1016/j.procir.2015.07.044

Dunleavy, M., & Dede, C. (2014). Augmented reality teaching and learning. *… of Research on Educational Communications and …*, 1–34. https://doi.org/10.1007/978-1-4614-3185-5

Fred D. Davis, Richard P. Bagozzi, P. R. W. (1989). User acceptance of comuper technology: a comparison of two theoretical models.

G. Liu and H. Li. (2017). *Offshore Platform Topsides and Substructure*. https://doi.org/10.1007/978-981-10-3617-0

Gavish, N., Gutierrez, T., Webel, S., & Rodriguez, J. (2011). Design Guidelines for the Development of Virtual Reality and Augmented Reality Training Systems for Maintenance and Assembly Tasks. *The International Conference SKILLS*, *29*, 1–4. https://doi.org/10.1051/bioconf/201101000

Gavish, N., Gutiérrez, T., Webel, S., Rodríguez, J., Peveri, M., Bockholt, U., & Tecchia, F. (2013). Evaluating virtual reality and augmented reality training for industrial maintenance and assembly tasks. *Interactive Learning Environments*, *4820*(November 2014), 1–21. https://doi.org/10.1080/10494820.2013.815221

Greaves, T., & Hohner, L. N. (2015). 3D Laser Scanning : Benefits and Paybacks for Industrial Plant Design , Construction and Operation.

Hee, D. D., Pickrell, B. D., Bea, R. G., Roberts, K. H., & Williamson, R. B. (2007). Safety Management Assessment System (SMAS): A process for identifying and evaluating human and organization factors in marine system operations with field test results. *Reliability Engineering and System Safety*, *65*(2), 125–140. https://doi.org/10.1016/S0951-8320(98)00095-7

Heerema Marine Contractors. (2014). DEV80780 Topside set down monitoring Functional specifications of the system to be developed.

Jarvis, S. (2015). Installing Off-Shore Oil Platforms with SpatialAnalyzer. New River Kinematics.

Jonathan Lazar, Jinjuan Heidi Feng, H. H. (2017). Research Methods for Human Computer Interaction, 25–44. https://doi.org/10.1016/B978-0-12-805390-4.00002-

Jong, M. D. T. De, & Angles, T. T. (2014). The Quest for a Usability Theory, *61*(3).

Krevelen, D. W. F. Van, & Poelman, R. (2010). A Survey of Augmented Reality Technologies , Applications and Limitations, *9*(2).

Langley, A., Lawson, G., Hermawati, S., & Apold, J. (2016). Establishing the Usability of a Virtual Training System for Assembly Operations within the Automotive Industry. *Human Factors and Ergonomics in Manufacturing*, *16*(1), 61–81. https://doi.org/10.1002/hfm

Lee, K. (2011). The Future of Learning and Training in Augmented Reality. *InSight: A Journal of Scholarly Teaching*, *7*, 31–42. Retrieved from http://eric.ed.gov/?id=EJ980168

Lee, K. (2012). Augmented Reality in Education and Training. *TechTrends*, *56*(2), 13–21. https://doi.org/10.1007/s11528-012-0559-3

Lemmes, M. (2015). Features, status and trens Tontal Stations, 2009–2011.

Lin, C. C. (2013). Exploring the relationship between technology acceptance model and usability test. *Information Technology and Management*, *14*(3), 243–255. https://doi.org/10.1007/s10799-013-0162-0

Lin, H.-C. K., Chen, M.-C., & Chang, C.-K. (2013). Assessing the effectiveness of learning solid geometry by using an augmented reality-assisted learning system. *Interactive Learning Environments*, *0*(January 2015), 1–12. https://doi.org/10.1080/10494820.2013.817435

Louho, R., Kallioja, M., Oittinen, P. (2006). Factors Affecting the Use of Hybrid Media Applications, *35*, 11–21.

Lret, T. (2011). Installation Engineering and Execution of Offshore Projects, (September).

Markham, S. K., Ward, S. J., Aiman-smith, L., & Kingon, A. I. (2010). The Valley of Death as Context for Role Theory in Product Innovation, 402–417.

Mendes, P. A. S., Hall, J., Matos, S., & Silvestre, B. (2014). Reforming Brazil ' s offshore oil and gas safety regulatory framework : Lessons from Norway , the United Kingdom and the United States. *Energy Policy*, *74*, 443–453. https://doi.org/10.1016/j.enpol.2014.08.014

Nassir Navab, Echeyde Cubillo, Benedicte Bade ' Jurgen Lockau, Klaus-D. Kamsties, M. N. (2000). Cylicon : A Software Platform : For The Creation & Update, *0*.

Navab, N. (2004). Projects in VR Developing Killer Apps for Industrial Augmented Reality, (June), 16–20.

Oye, N. D., Iahad, N. A., & Rahim, N. A. (2014). The history of UTAUT model and its impact on ICT acceptance and usage by academicians, 251–270. https://doi.org/10.1007/s10639-012-9189-9

Peuscher, W., & Groeneweg, J. (2012). A Big Oil Company ' s Approach to Significantly Reduce Fatal Incidents.

Rauschnabel, P. A., & Ro, Y. K. (2016). Augmented reality smart glasses : an investigation of technology acceptance drivers, *X*, 1–26.

Sadeghi, K. (2007). An Overview of Design, Analysis, Construction and Installation of Offshore Petroleum Platforms Suitable for Cyprus Oil/Gas Fields. *Soc. & Appl. Sci*, *2*(4), 1–16.

Samaradiwakara, G. D. M. N., & C G Gunawardena. (2014). Comparison Of Existing Technology Acceptance Theories And Models To Suggest A Well Improved Theory / Model, *1*(1), 21–36.

Shafy, A. (2004). General Introduction on offshore structures.

Siltanen, S. (2012). *Theory and applications of marker-based augmented reality*.

Singh, S. (2016). An Overview of Augmented Reality in Various Fields In Various Fields Of Mechanical EngineerinG, (November), 163–168.

Stricker, D., Christou, I. T., & Ioannidis, N. (2001). ARCHEOGUIDE : first results of an augmented reality , mobile computing system in cultural heritage sites, (July 2017). https://doi.org/10.1145/584993.585015

Tseng, C.-M., Chau, C.-K., Elbassioni, K., & Khonji, M. (2017). Flight Tour Planning with Recharging Optimization for Battery-operated Autonomous Drones, 1–10.

Vasilijević, A., & Borović, B. (2011). Augmented Reality in Marine Applications. *Electrical Engineering*, *62*, 136–142.

Venkatesh, V., Morris, M. G., Davis, G. B., & Davis, F. D. (2017). User Acceptance of Information Technology: Towards a Unified View, *27*(3), 425–478.

Veritas, D. N. (2014). DNV-OS-H206 Loadout , transport and installation of subsea objects (VMO Standard - Part 2-6), (September).

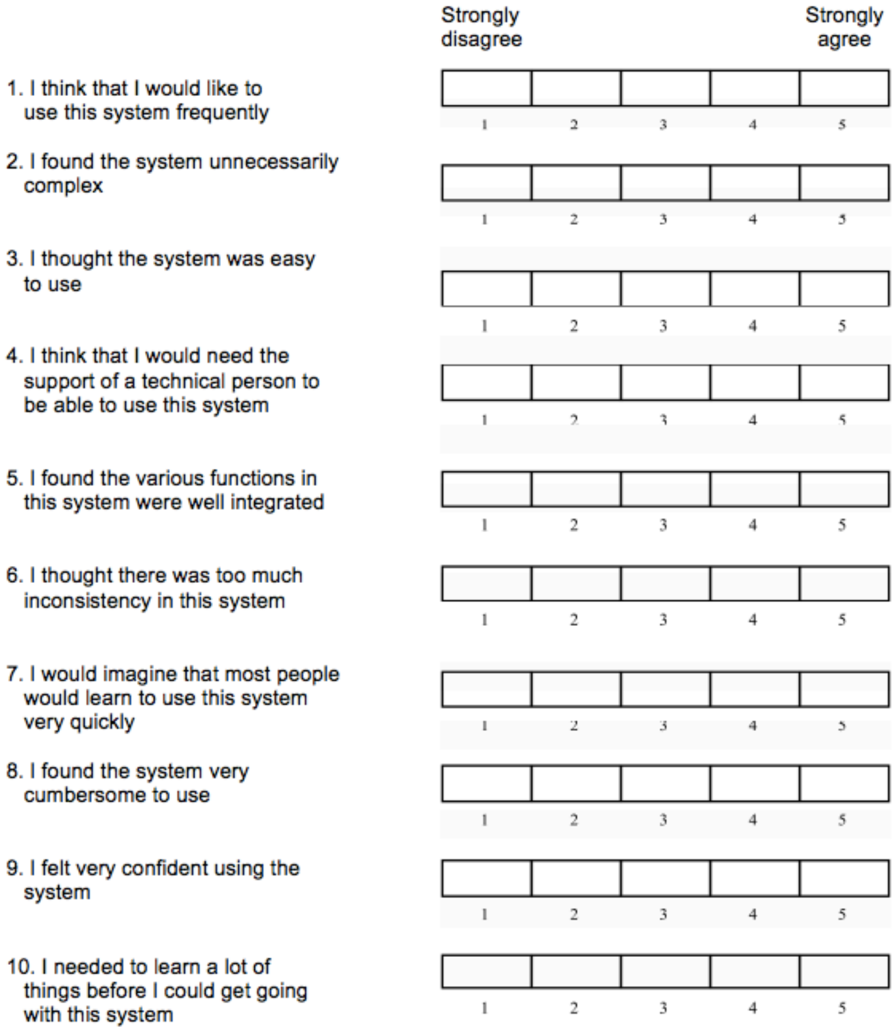
Verschuren, P., & Doorewaard, H. (2010). Designing a Research Project: Project Design. *Designing a Research Project*, 1–25. https://doi.org/10.1007/s13398-014-0173-7.2

Wojciechowski, R., & Cellary, W. (2013). Evaluation of learners' attitude toward learning in ARIES augmented reality environments. *Computers and Education*, *68*, 570–585. https://doi.org/10.1016/j.compedu.2013.02.014

Appendix

Appendix A. System Usability Scale

The instructions for the use of this questionnaire scale are to mark one only box that describes bests your reactions to the technology system (Brooke, 2000).



	Strongly disagree				Strongly agree
1. I think that I would like to use this system frequently	1	2	3	4	5
2. I found the system unnecessarily complex	1	2	3	4	5
3. I thought the system was easy to use	1	2	3	4	5
4. I think that I would need the support of a technical person to be able to use this system	1	2	3	4	5
5. I found the various functions in this system were well integrated	1	2	3	4	5
6. I thought there was too much inconsistency in this system	1	2	3	4	5
7. I would imagine that most people would learn to use this system very quickly	1	2	3	4	5
8. I found the system very cumbersome to use	1	2	3	4	5
9. I felt very confident using the system	1	2	3	4	5
10. I needed to learn a lot of things before I could get going with this system	1	2	3	4	5

Figure 40. SUS
Source: Brooke, 2000

Appendix B. VRE Training

During the virtual reality experiment training ach sub experimental group had the same training. John and me introduced the experiment goal, structure and positioning process. The training includes the familiarization of the participants with the VRE, the user interface and the software. It includes a question solving and trial process.

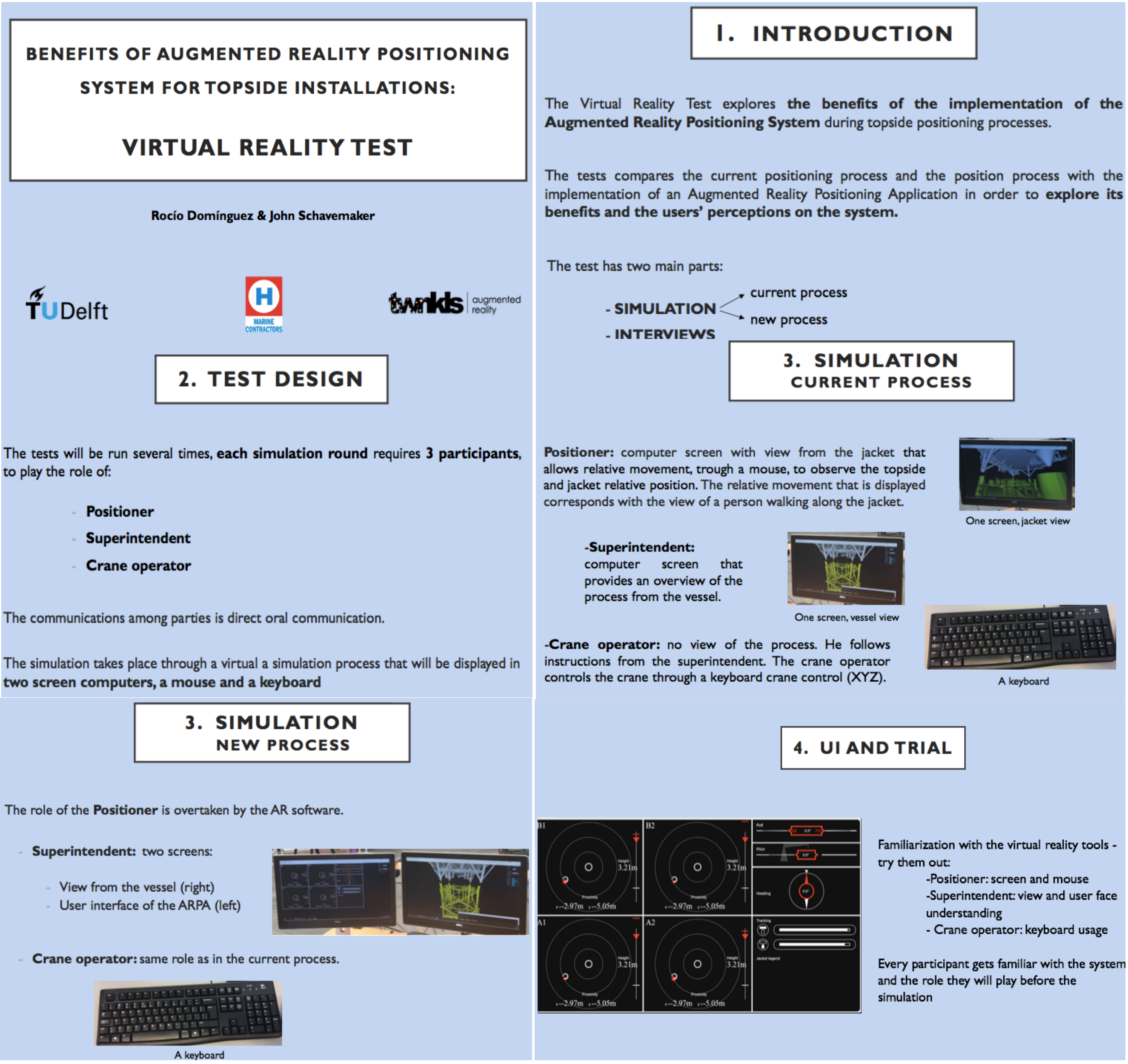


Figure 41. PPT VRE Training

Appendix C. VRE Interview Questions

The virtual reality experiment interview questions are divided in six main blocks:

PERSONAL DATA

Name and mail.
Background
Experience on topside installation processes
Experience with AR technology

PERFORMANCE EXPENTANCY

Do you find the system useful? How? Why?
Which are the benefits/ advantages and disadvantages of using the system?

- How does the system affect the process time?
- What about the quality of performance?
- How does the new system affect the process difficulty?
- How do you compare the current and new process? What is the added value of the system?

EFFORT EXPECTANCY

Is the system easy to use?

- Do you find the system Understandable or complex?
- Do you think it is easy to learn how to use the system?
- What about the feeling of control? When was its higher?
- How would you compare the effort made compared with the current process?

FACILITATING CONDITIONS

How do you think that the users should be trained for the use of the system?
Would you improve something on the system?

- What about the user interface?
- And the functionality of the system?

ATTITUDE AND BEHAVIORAL INTENTION

Do you think that is it a good idea to use the ARPS? Why?
Are you willing to use the system?

LIMITATIONS ON THE SIMULATION

Does the virtual reality test realistically simulate the real topside positioning process?
Does the virtual reality test provide a good overview of the benefits and limitations of the use of the new augmented reality positioning system?

Is there something else that you would like to add?

Appendix D. VRE Qualitative Data

The virtual reality simulation was designed to keep count of each operation carried by the crane operator and the relative position of the structure. This Appendix contains a summary of the results during the first and second sub experiment.

This data includes the time of the simulation (HH and MM), the number of crane movements through each direction (a, d, l, p, s, w), the total number of operations (defined as the sum of the operations on all directions) and the relative structures' position through the indications of XYZ of the topside respect to the jacket.

This table follows the nomenclature used during the VRE (Chapter 4). Six keys from the keyboard drove the movement of the crane on the six directions of XYZ during the VRE: left, right, forward, background, up and down (see Figure 27). XYZ follow the system used by the ARPS (see Figures 7 and 8).

Table 9. Quantitative Data VRE Sub Experiment 1

HH	MM	a	d	l	p	s	w	total	X	Y	Z	
11	38	0	0	0	0	0	0	0	3,97	3,86	-0,28	
11	39	67	21	40	1	21	23	173	-0,62	0,26	-0,41	
11	40	28	33	46	66	28	27	228	0,34	0,56	-0,53	
11	41	28	0	19	24	30	0	101	0,65	0,46	-0,28	END TEST
TOTAL		123	54	105	91	79	50	502				
11	50	0	5	0	0	0	22	27	-1,23	2,46	0,32	
11	51	0	16	7	0	0	7	30	-0,54	1,76	-0,14	
11	52	0	0	6	0	0	0	6	0,03	1,16	0,04	
11	53	0	0	0	33	0	0	33	0,02	1,16	0,05	
11	54	41	18	0	0	17	14	90	-0,15	4,46	-0,28	
11	55	0	22	10	0	0	1	33	0,22	3,46	0,1	
11	56	0	4	14	0	0	1	19	-0,04	2,06	0,12	END TRIAL 1 WITHOUT UI
TOTAL		41	65	37	33	17	45	238				
11	59	0	0	0	0	0	0	0	-2,57	2,41	-2,77	
12	0	12	0	0	17	40	19	88	-2,47	2,41	-2,93	
12	1	0	42	0	0	9	0	51	-0,32	4,11	-0,14	
12	2	0	0	41	2	4	0	47	0,51	0,31	0,04	END TRIAL 1 WITH UI
TOTAL		12	42	41	19	53	19	186				
12	32	0	0	0	0	0	0	0	3,88	3,78	2,3	
12	33	0	0	0	1	0	0	1	3,86	3,88	2,33	
12	34	40	0	0	6	0	0	46	0,83	4,48	2,14	
12	35	0	0	14	0	8	32	54	-0,12	3,08	-0,1	
12	36	42	0	27	28	31	0	128	0,15	0,38	0,66	END TRIAL 2 WITHOUT UI
TOTAL		82	0	41	35	39	32	229				
12	37	4	0	0	0	0	0	4	-3,51	3,18	2,97	
12	38	0	39	0	0	0	34	73	-0,82	3,18	0,24	
12	39	21	27	0	0	26	11	85	-0,06	3,18	-0,44	
12	40	0	0	24	0	0	5	29	0,08	0,78	0,44	END TRIAL 2 WITH UI
TOTAL		25	66	41	0	26	45	162				
12	48	0	0	0	39	0	0	39	-0,82	2,53	1,9	
12	49	0	7	30	0	0	12	49	-0,81	3,53	1,01	
12	50	0	8	7	0	0	14	29	0,15	2,73	0,24	
12	51	0	0	9	0	7	6	22	0,45	1,83	-0,65	
12	52	3	0	4	0	0	0	7	-0,31	1,43	0,01	
12	53	0	0	15	0	0	0	15	-0,22	-0,07	0,17	END TRIAL 3 WITHOUT UI
TOTAL		3	15	65	39	7	32	161				
12	55	23	0	0	19	0	0	42	-1,97	2,23	-2,16	
12	56	0	46	20	0	18	0	84	-0,45	2,13	-0,99	END TRIAL 3 WITH UI
TOTAL		23	46	20	19	18	0	126				

Table 10. Quantitative Data VRE Sub Experiment 2

HH	MM	a	d	l	p	s	w	total	X	Y	Z	
15	37	0	0	0	0	0	0	0	0,65	3,95	-0,47	
15	38	7	0	0	0	0	0	7	0,65	3,95	-0,48	
15	39	17	20	9	8	16	11	81	0,15	3,85	-0,23	
15	40	20	15	0	0	9	23	67	0,02	3,85	-0,01	
15	41	0	0	16	18	0	0	34	0,41	3,75	-1,25	
15	42	0	0	0	0	0	0	0	0,11	4,05	-1,18	
15	43	4	0	18	0	13	0	35	0,22	2,25	-0,53	
15	44	2	2	7	0	0	0	11	-0,64	1,55	-0,69	
15	45	0	5	2	0	0	5	12	0	1,35	-0,05	
15	46	2	0	0	0	2	0	4	0,05	1,35	-0,22	
15	47	0	0	16	0	0	0	16	0,03	-0,25	-0,18	
15	48	17	0	13	65	13	0	108	-0,02	-0,25	-0,16	END TRIAL 1 WITHOUT UI
TOTAL		69	42	81	91	53	39	375				
15	49	0	0	0	0	0	0	0	-1,22	4,95	0,48	
15	50	0	0	0	0	0	0	0	-1,23	4,95	0,46	
15	51	0	18	20	0	0	0	38	0,21	3,05	1,13	
15	52	0	0	36	0	0	4	40	0,47	0,15	-0,09	END TRIAL 1 WITH UI
TOTAL		0	18	56	0	0	4	78				
15	57	0	0	0	0	0	0	0	-3,71	2,48	3,43	
15	58	0	0	0	0	0	0	0	-3,7	2,48	3,43	
15	59	0	10	0	6	0	6	22	-3,95	2,48	3,28	
16	0	0	26	9	0	0	47	82	-0,46	2,18	-2,03	
16	1	0	0	22	0	10	0	32	-0,62	0,28	-0,05	END TRIAL 2 WITHOUT UI
TOTAL		0	36	31	6	10	53	136				
16	2	0	0	0	48	0	0	48	-0,15	-0,02	-0,15	
16	3	20	30	0	11	2	9	72	0,02	4,78	-0,52	
16	4	16	11	54	0	17	0	98	0,49	0,58	0,57	END TRIAL 2 WITH UI
TOTAL		36	41	54	59	19	9	218				
16	11	0	0	0	0	0	0	0	2,85	3,27	-3,17	
16	12	20	0	0	0	0	5	25	1,06	3,27	-3,56	
16	13	0	0	18	0	12	0	30	0,95	-2,41	-2,41	
15	52	0	0	36	0	0	4	40	0,47	0,15	-0,09	END TRIAL 3 WITHOUT UI
TOTAL		20	0	54	0	12	9	95				
16	15	32	0	0	46	0	7	85	0,43	-0,33	-0,66	
15	52	0	0	36	0	0	4	40	0,47	0,15	-0,09	END TRIAL 3 WITH UI
TOTAL		32	0	36	46	0	11	125				

The white rows indicate the initialization of a simulation, the green rows the crane movements during the simulation process and the yellow rows the different operations during the last minute of the simulation. The orange cells indicate the total number of operations for each direction per simulation, and the total.

The XYZ columns show the topside relative position every minute. The last column of the table indicates the end of each simulation through pink cells. As it can be observed in the sub experiment one, there is a trial period that finishes before the initialization of the first experiment. Its end is indicated in the last column of the table by “end test” (first pink cell).

Appendix E. VRE Interview Detailed Results

This Appendix includes the transcript of the interviews with the VRE participants. It includes data on the two sub experiments, therefore, there are six participants interview results.

Participant 1

Usefulness: "if the system is accurate, it can be very useful because it gives good information, better than the one from the assistant-superintendent located on the jacket, that are based on estimations."

Easy to use: "The system is easy to use and to control and there is a need of a training before the actual use of the system (training on the system for the superintendent) …"

Things to improve: "the system zoom in, you did not expect it and I would prefer it to be smoother."

Intention to use: "Yes. However, it should be previously tested and include a warning system in case of failure (back-up system)"

Limitations VRE: "It is a simplification of the process so accuracy is not guarantee, however the tests is able to give a correct impression about the system to the user. The limitations of the simplification refer to the movement of the topside: the simulation does not include rotation, it moves faster than in reality, the movements simulated are just circular and the simulation does not detect collision. "

Future steps: "real simulation on scale models, interviews with offshore workers"

Participant 2

Usefulness: "Yes, because it provides accurate measurements. It also leads to a better feel of control of the process and you feel more confident. In addition, the system eliminates the need of communication with the assistant-superintendent on the jacket, and there is just need of communication with the crane operator. So, you consider that the system can make the process quicker".

Easy to use: "The system is easy to use and understandable, the view is good and clear."

T*hings to improve: "*I suggest a system prediction of the topside movement (given the history of movement) as a future improvement."

Intention to use: "If it is accurate, yes."

Limitations VRE: "The test provides a good overview of the process and the what the system can do. It would be more realistic with different viewpoints from the jacket, and slower movement of topside. "

Future steps: "It would be great if the user interface can slightly be modified depending on the case, such as the number and size of the legs."

Participant 3

*Usefulness: "*The system is very useful because you can easily view from the topside where the cones are. However, you will use it as a backup system since you feel instructions from real people are more reliable. I consider that the system makes the process easier, it gives a better feeling of control, but I do not completely rely on a 2D screen."

Easy to use: “The system is easy to use and to learn. I had to get familiar with the marine positioning language and my virtual position on the jacket. I guess marine engineers will not struggle with it.”

Intention to use: “I will be willing to use the system if it is tested and trustable”

Limitations VRE: “No experience on this but from my point of view it seems really complete.”

Future steps: “A good training for the users in order to guarantee safety (a certain number of experience using the technology should be required.”

Participant 4

Usefulness: “the system is useful because it makes the process easier, it provides better view, it makes the process faster and it reduces the communication parties from between three people to two.”

Easy to use: “the system is easy to use and understandable, it provides you a better feeling of control. It is easy to get familiar with the system.”

Intention to use: “Yes.”

Limitations VRE: “It is a simplification of the process so the movement of the topside is not completely realistic.”

Participant 5

Usefulness: “The system is useful because it improves safety and gives good feedback. Replacing a human with sense is very challenging since human learn and get experience (may the can foresee a problem or know what is going on). You think the system will make the process faster. the system is easy to use and understandable, easy to learn, it gives more feedback and better feeling of control.”

Easy to use:” the system is easy to use and understandable, easy to learn, it gives more feedback and better feeling of control.”

Intention to use: “Yes, after a real camera-tracking test.”

Limitations: “The virtual simulation has the option to restart, it creates a tendency to rush, to make things quicker, unlike in offshore operations, where you do it right rather than quickly.”

Participant 6

Usefulness: “The system is useful because it gives you an extra pair of eyes, a better perspective. It eliminates the need of a person on the jacket and improves safety. It makes the process easier because there is less communication parties. It could decrease the time.”

Easy to use: “The system is easy to use and to learn, it comes naturally to understand. It gives you a better feeling of control.”

Intention to use: “If its fully tested, yes.”

Limitations: “Limitations of the simulation is the lack of rotation and the difficulty of simulate the hard-offshore conditions.”

Appendix F. SME Training

Each of the seven participants of the Scale Model Experiment was instructed about the simulation process: the five engineers that played the role of superintendent, the one playing the role of crane operator and rotation controller, and the one who played the role of assistant-superintendent and/or rotation controller.

The training includes information about the thesis research and the SME. It includes the research goal and methodology, and instructions on the simulation process: test design and parts, number of participants, role of each participants, general overview of the current and new positioning process simulation, ARPS explanation and trial period.

The training was given by John Schavemaker and me. The training had several rounds because the participants playing the role of superintendent were coming at different timings. The SME training process was easier than the VRE one because the participants were familiar with OTIP and marine nomenclature. In addition, after the VRE, we were more experienced about how to train them and possible emerging questions. As in the VRE training, the SME training included a PPT.

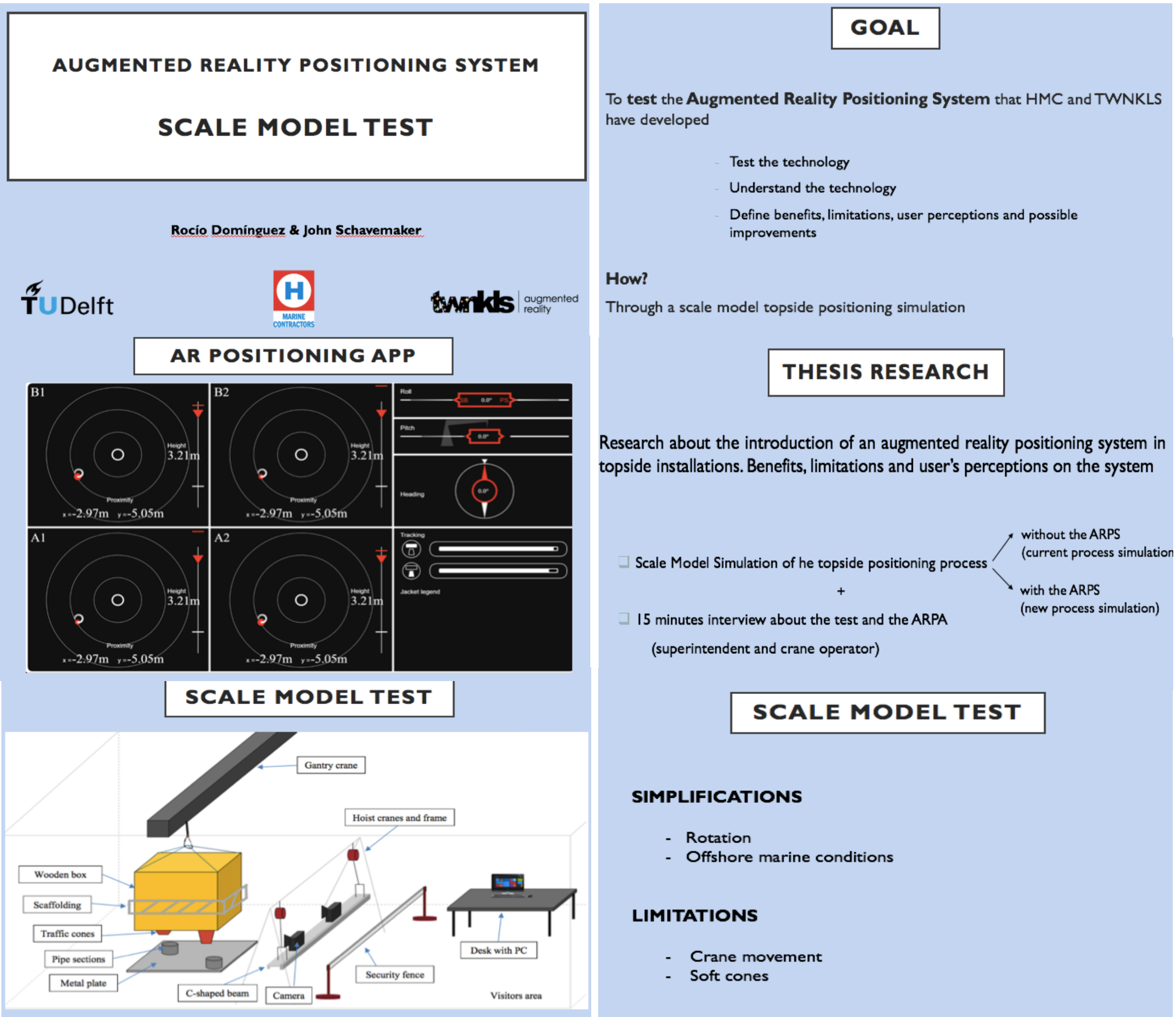


Figure 42. PPT SME Training

Appendix G. SME Interview Questions

This Appendix includes the interview questions for the SME for the participants that played the role of superintendent and crane operator.

Superintendent Questions

PERSONAL DATA

Name and mail, Background
Offshore Experience, OTIP experience
Experience with AR technology
Role in the project (HMC-TWNKLS)
Technology experience:

- Do you think that humans can rely on technology? Do you think that technology can improve industry processes?

PERFORMANCE EXPENTANCY

Do you find the system useful? How?
Which are the benefits/ advantages and disadvantages of using the system?

- How does the system affect the process time?
- What about the quality of performance?
- How does the new system affect the process difficulty?
- How do you compare the current and new process? What is the added value of the system?

Which are the limitations of the system?

EFFORT EXPECTANCY

Is the system easy to use?

- Do you find the system Understandable or complex? (numbers, figures...)
- Do you think it is easy to learn how to use the system?
- What about the feeling of control? When was its higher?
- How would you compare the effort made compared with the current process?

FACILITATING CONDITIONS

How do you think that the users should be trained for the use of the system?
Would you improve something on the system?

- What about the user interface?
- And the functionality of the system?

ATTITUDE AND BEHAVIORAL INTENTION

Are you willing to use the system? Why?

- What would change your mind?

Which are the risks of using the system? How would you avoid them?

LIMITATIONS ON THE SIMULATION

Does the scale model test realistically simulate the real topside positioning process? Which is the potential and limitations of the simulation?
Does the scale model test provide a good overview of the system? (how it works, what can it do...)

Do you think that the simulation gives you an adequate perception of the ARPS (in a way that you understand the technology and you could use it in a real process)?

Is there something else that you would like to add?

Crane Operator Questions

PERSONAL DATA

Name and mail, Background
Offshore Experience, OTIP Experience,
Experience with AR technology
Role in the project (HMC-TWNKLS)
Technology experience:

- Do you think that humans can rely on technology? Do you think that technology can improve industry processes?

PERCEIVED DIFFERENCES

Did you feel any difference among the two scenarios?

PERFORMANCE EXPENTANCY

Do you find the system useful? How?
Which are the benefits/ advantages and disadvantages of using the system?

- How does the system affect the process time?
- What about the quality of performance?
- How does the new system affect the process difficulty?
- How do you compare the current and new process? What is the added value of the system?

Which are the limitations of the system?

IMPROVEMENTS

Would you improve something on the system?

- What about the user interface?
- And the functionality of the system?

ATTITUDE AND BEHAVIORAL INTENTION

Are you willing to use the system? Why?

- What would change your mind?

Which are the risks of using the system? How would you avoid them?

LIMITATIONS ON THE SIMULATION

Does the scale model test realistically simulate the real topside positioning process?

- Which is the potential and limitations of the simulation?

Does the scale model test provide a good overview of the system?
Do you think that the simulation gives you an adequate perception of the ARPS (in a way that you understand the technology)?

Is there something else that you would like to add?

Appendix H. SME Interview Detailed Results

This Appendix includes the transcript of the interviews with the SME participants. It presents data from the five participants that played the role of superintendent in each round and the participant that played the role of crane operator during all the rounds.

Participant 1

*Usefulness: "*the system is useful because it removes the need of having people on the jacket, therefore it improves safety and it fulfils client's requirements. It also can make the process quicker and save money since there is no need of sending people to the jacket.

The *limitations* of the technology are related to people trusting it (since it requires time) and the robustness of the system (since it should be tested and work under all weather conditions). "

Easy to use: "the system is easy to use. The feeling of control and effort are the same in both scenarios (with and without the system)."

Intention to use: "Yes, after offshore testing. The *risks* of using the system are system breakdowns and weather conditions. "

Limitations SME: "The simulation does not realistically simulate the real process because the environment is really easy and controlled during the SME. However, it provides a good overview of the system."

Extra Information. "I have experience with laser positioning systems, I used it 20 years ago. I would say that this AR system has many advantage in comparison with laser technology, since it does not require very precise dimension control of the structure, the time and equipment involved are lower; therefore, the process is more cost effective."

Participant 2

*Usefulness: "*the system is useful because it provides specific and clear information about the relative position of the structures, it avoids the need of people on the jacket, it reduces the communication to two parties, and the superintendent do not depend on the assistant-superintendent instructions, he can work by himself. It makes the process easier and probably a bit faster.

The *limitations* of the technology are related to the 2D interface, it does not provide information about all the motions, so the feeling about the structures' position is lower."

Easy to use: "the system is easy to use and learn. The feeling of control is higher in the current process since there are human eyes that really see the structures and can quickly turn on the alarm in case of emergency or problems. The effort was lower in the new process because the system makes the process easier."

Recommendations: "I would like to have 3D real view from a camera located in the jacket. I would include this 3D view of the structures in the UI. It will improve the feeling of control and the user reliability on the system (more direct, not dependency on assistant-superintendent's instructions, quicker)."

Intention to use: "Yes. The *risks* of using the system is the lack of a real 3D view."

Limitations SME: "The simulation does not realistically simulate the real process because the real process is more difficult, there are more motion and movements. However, it provides a good overview of the system, the principles are clear."

Participant 3

Usefulness:" the system is useful because it provides more information about the relative position of the structure and it avoids the need of people under a suspended load. The new system is more robust and the SME showed that the superintendent can place the topside without looking at the structures. There is no certainty about the effect of this technology on the process time, but it could help inexperience crew to do it quicker. I believe that the process become easier with the system since the superintendent get more information."

"The *limitation* of the system is that any technology has computer code written by people and people make mistakes. This maybe comes up offshore and it is difficult to correct. So, how do we ensure that with every software update no bugs are introduced?"

Easy to use: "the system is easy to use, understandable and easy to learn. The feeling of control is higher and the effort lower with the system because it makes it easier. There is need of a training period in order to get full advantage of the system."

Recommendations: "I would include error range indications, depending on the operation conditions. If there is fog or sunlight which makes the system less reliable, this should be clearly visible in the display"

Intention to use: "Yes, after it is tested in the simulation centre. It is a process improvement. The *risks* of using the system is people forgetting how to perform without the technology."

Limitations SME: "The simulation does not completely realistically simulate the real process because the real process is more complex and it is dependent on the weather conditions (day/night conditions, rain/fog, etc). This test cannot prove the robustness of the system. However, it provides a good overview of the system."

Extra Information: "I am in favour of installing the system and use it, to make it operational in few years. Start using it, in order to build up experience and confidence. It is important to include back-up systems and to stablish an easy and robust installation process offshore."

Participant 4

Usefulness:" the system is useful because it makes the process safe for our client (it is a safe process as all heavy lifts are engineered with safety factors; however, our clients perceive as unsafe to have people under suspended load). In addition, the system avoids transportation of people, it avoids risks, high dependency on weather conditions… The system makes the process easier because there is no need to transfer and position people on the jacket. It can save time because there is no need of transporting people to the jacket, and this in practice is potentially a weather sensitive operation."

"The *limitations* of the system are:

- difficult initialization: need of markers and manually assignation of points.
- people should be convinced about the system reliability
- need of a plan B in case of system failure.
- the system needs to be operated by a specialist.
- the system needs to be proven to also work reliable under all weather conditions (night time, heavy rain, fog, ….)"

Easy to use: "the system is easy to use, understandable and easy to learn. However, the system set up is difficult. The feeling of control is higher and the effort lower with the system because it makes it easier. "

Recommendations: “To try the system offshore, including the tablet device.”

Intention to use: “Yes, it gives you in one view all the information that you need for an installation process. The *risk* of using the system is that weather conditions should not interfere with the system. Include solutions such as extra markers and lighting.”

Limitations SME: “The simulation does not completely realistically simulate the real process because the real process is more complex and there are more movements. This test provides a good overview of the system.”

Extra Information: “I am aware of other positioning systems that works offshore (based on the use of total stations), however they are more expensive, they require more people and equipment. “

Participant 5

Usefulness: “the system is useful because it eliminates the need of transferring and having people on the jacket, it increases safety and decrease the process time.”

“The *limitations* of the system are technical failures, since there is no buck up system; and the need the system to be trusted by people, it takes time.”

Easy to use: “the system is easy to use, understandable and easy to learn. The feeling of control is higher in the current process because it is difficult to trust the system, I prefer to rely on people.”

Recommendations: “To include a backup system”.

Limitations SME: “This test provides a good overview of the system.”

Extra Information: “Some of the questions, such as the one related to the willingness of using the system, should be answered by a real superintendent. I like the system, is simple and it provides an overview of all the information needed.”

Participant 6. Crane Operator

Usefulness: “the system is useful because it increases safety by removing the people from the jacket. It also allows installations with worst weather because there is no need have to transfer people to the jacket. I got more precise instructions during the simulation with the technology, based on distances, not on orders that require me to move till the superintendent says stops”

“The *limitations* of the system are the system needs to be operated by a specialist, and the system should be tested offshore, because it should work on different weather conditions.”

Differences on the two scenarios: “The feeling of control is higher with the system. I got more clear instructions. “

Recommendations: “Improve the system setup in order to make it usable for anyone. Install and start tracking should be very straightforward.”

Intention to use: “Yes. The system will be tested offshore within a month. The *risk* of using the system is the possible displayed of wrong information. The system should include error measurements and a backup within the system, (a new same equipment as a backup is useful because usually there is 100% redundancy). “

Limitations SME: “The simulation does not completely realistically simulate the real process because the real process is more complex and there is much more to track. This test provides a good overview of the system.”

Extra Information:

- “The system is easy to use, understandable and easy to learn. It was developed with real superintendents’ participation.
- Superintendents like the AR system, they want to see it working offshore.
- Laser is other positioning system, it is very precise but it need a lot of reparations, needs of specialists in order to work.
- Other future applications of the system are: positioning any object offshore and looking at motions of objects without having sensors of them. “

Appendix I. HMC Expert Interviews Introduction

The expert interview introduction process to HMC experts took around 15 minutes. The first part of the process is the introduction of myself, my research and the AR system, including the progress done on the field till the moment. This Appendix includes the introductory PPT used during the questions period with HMC experts. The expert interviews' participants are continuously updated about the ARPS and its progress, and about the present research, therefore there was not need of an introductory process.

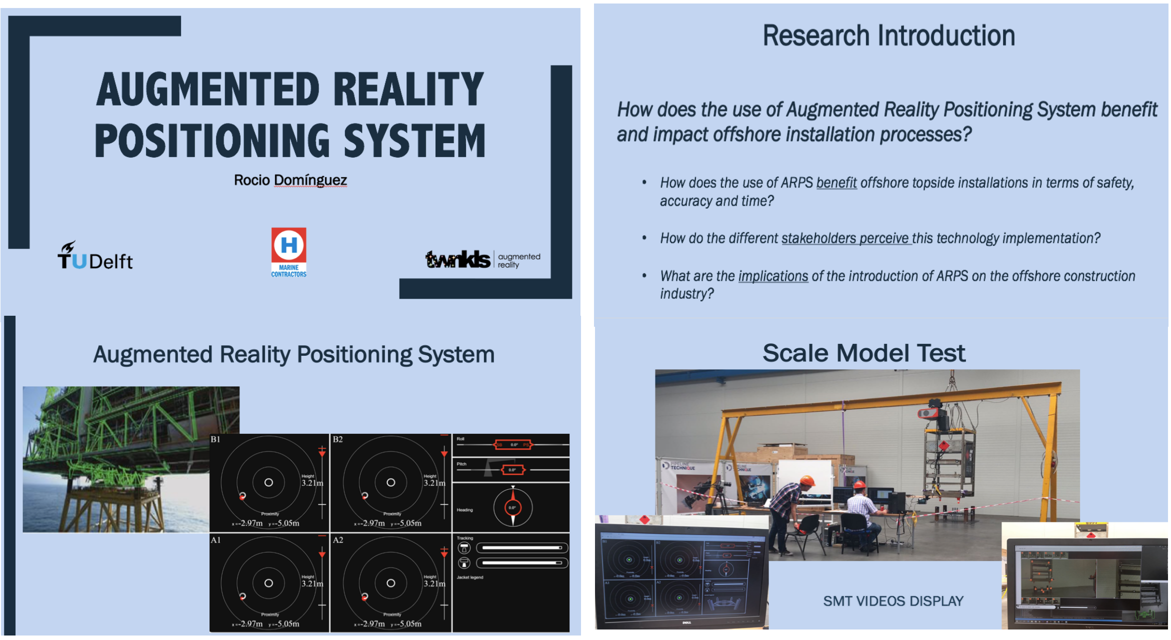


Figure 43. Experts Interviews Introduction

In addition to the PPT pictures, process explanation and videos recorded form the SME were played and explained.

Appendix J. Expert Interviews Questions

These Appendix includes the questions that constitutes the semi structure interview process that took place with HMC and TWNKLS experts

HMC Questions

PERSONAL DATA

Introduce yourself

Name and mail

Background

Experience with AR technology?

POSITIONING PROCESS

How can the current process be improved? How innovation is related to these improvements?

Which improvements and innovations has been developed in the future in this process? And in other offshore processes or projects?

How do you envision future developments? Are you willing to change, to invest on innovation? How do u see AR as an innovation?

How often do HMC position topsides? Is there a growing demand? Is the demand fixed or is it constrained by the difficulty and expensiveness of these processes?

USEFULNESS OF THE SYSTEM

Do you find the system useful? How (can it improve the current process)? Why?

Which are the benefits/ advantages and disadvantages of using the system?

Does the AR system accomplish all the requirements to improve the positioning?

SYSTEM INTRODUCTION

Would you improve something on the system?

What does the systems require to be successfully implemented?

What is necessary to make offshore people to accept the system?

SYSTEM IMPLICATIONS - <u>changes</u>

Do you think that the organizational structure should be changed?

New people hired? People fired?

New managers? New departments?

New knowledge/skills required?

How do you think that the users should be trained for the use of the system?

How would the positioning process change?

Protocol, steps, operational procedure (initialization, loose of track ...)

How could this technology affect the market?

With might be future applications domains of this technology?

Topside, wind mill installation, general operations (supply ship to deck…)

HMC PERSPECTIVE

Which are your expectations on the system?

How far is HMC willing to invest in this technology?

How did u decide to invest on this and explore it?

How could you compare ARPS with other innovations you are familiar with?

Is there something else that you would like to add?

TWNKLS Questions

PERSONAL DATA

Introduce yourself

Name and mail

Background

Experience with offshore topside positioning processes?

ARPS

How did the idea of developing an ARPS come up?

Which were the initial expectations?

How has the project evolved?

Which improvements and innovations has been implemented during the development process?

How do you envision future developments?

USEFULNESS OF THE SYSTEM

Which are the expected potential benefits of using the system for topside installation processes?

Do you find the system useful? What do you think about its efficiency?

What can the system do now and what will it do once it is implemented?

SYSTEM INTRODUCTION

What does the *systems require* to be successfully implemented?

What is necessary to make offshore people to accept the system?

SYSTEM IMPLICATIONS – Changes in marine industry and AR industry

Do you think that the *organizational structure* should be changed?

New people hired? People fired?

New managers?

New departments?

New knowledge/skills required?

How do you think that the users should be t**rained** for the use of the system?

How would the positioning process change?

Protocol, steps, operational procedure (initialization, loose of track ...)

How could this technology affect the *market?*

With might be *future applications* domains of this technology?

Topside, wind mill installation, general operations (supply ship to deck…)

What is the impact of the successful introduction of this technology in the *AR industry?*

TWNKLS PERSPECTIVE

Which are your expectations on the system?

Why would you recommend a company, such as HMC, to invest in this system?

How could you compare this technology with other AR applications?

How do Heerema have to act in order to achieve a successful implementation of the AR system offshore? Which steps/ requirements?

Which are the main similarities and differences regarding the AR project of HMC and TWNKLS (objectives, vision, mentality…)?

Is there something else that you would like to add?

Appendix K. Experts' Interviews Detailed Results

This Appendix includes the transcript of the experts' interviews with HMC and TWNKLS participants, three from each company.

HMC Interview Results

Participant 1

Personal data

"I have been pretty involved in the project of removing people from the jacket from the beginning. In 2008, we make an attempt with a camera system, however, it was a complete failure, technology was not ready. Nowadays it is possible, technology has improved, different technological possibilities: AR, drones..."

"The decision to remove people from the jacket its driven by clients' requirements on safety and HMC interests on avoiding transfer of people to the jacket. We do believe that it is a safe practice to stand on the jacket, but we want to fulfil clients' requirements and we want to eliminate the challenging and weather-sensitive people transfer process".

Positioning process

"The main part that needs to be improved in the current topside positioning process is to take out human element under the topside. In order to come up with a right solution, vessel crew was asked to give inputs on which kind of system could do it and which are the main requirements for the system based on their needs (simple, robust…). "

"In 2014, the innovation department initiates again (as in 2008), a project on removing people from the jacket. Many ideas came up: AR, drones, lasers… there was a selection, 6-4 options were further developed. Now we are investing on two: AR and laser positioning technologies."

"Comparing both innovations, AR has fewer interface requirements and preparation, its cost-effectiveness potential makes it our preferable technology. Laser positioning technologies is further ahead developed, however, it is more expensive, it requires more interfaces, it is more sensitive to errors, it needs many measurements processes. Laser positioning technologies and AR system are based on the same interface. Last year, the user interface was used on the positioning of 2-3 modules based through the laser methodology."

Usefulness

"I think the AR system is really useful. It should be carefully considered that the modules should be accurate enough to match with the software (good modelling and recognition) and it should be able to adapt its functionality to the weather conditions."

"The system allows more precise measurements on the relative position (from 5,5,3,1 to 10 meters instructions). It increases confident and it has the potential to speed up the operation. However, the system should be displaying real time information (little information delay tracking-2D display)."

Improvements

"Forecasts movement of the module in the future and adaptable user interface depending on user's preferences: 2D, 3D… "

People offshore

"High *acceptance to the system*, superintendents have been quite involved on the innovation process from the beginning (feedback, using it). It is more about the timing of acceptance and the prove they need. This system implementation is a great change and they have to accept it. How?"

1º) "Proving that the system works
2º) Using the system for OTIP while having the old way method as a back-up system. Get rid of it depends on how much confidence do we get from the system. We need to push a little bit. Expensive installations
3º) In the future (2-3 years from now), there will not be people standing on the jacket: either a very robust system or a secondary system"

"We have 4 vessels, 8 superintendents, it takes time to all of them get experience. The best strategy is to introduce the system to them at the same time. Since we gather them 4 times for year, we should include the system on these meetings to involved them on the project."

Implications

"Concerning the *training* required for the introduction of the system, the system should be included on the superintendent simulation training. In addition, vessel crew should be trained on maintenance, installation and operation of the system, since we are assuming that anybody from TWNKLS will be there and any IT worker will be specifically hired for this system implementation."

"We do around 15-20 topside installations per year. The fact of implementing this technology will not affect *the demand* of topside positioning processes, however, it will position HMC a small step ahead from competition (due to fulfilment of clients' safety requirements)."

2We expect no changes on the *organizational structure* of the vessel after the introduction of the system: not hired or fired people. However, someone in the vessel should be responsible of the system and trained on maintaining, installing and operating it. Extra training. Link with support at the office, IT department. Probably some changes on procedures will be needed."

Other applications

"This AR system could be implemented in other offshore processes:"

> "Pile positioning on the jackets. Because right know we do it through cameras under water and the visibility is quite bad. AR could improve this process by using its tracking system on the part of the pile that is above water. It would eliminate the need of underwater cameras (low visibility)."
>
> "Structures Measurements, for example decommissioned structures. In order to remove platforms, we cut it the structure and we need to measure how accurate is it cut, its shape, in order to be able to settle it down on the deck through distributed loads. Nowadays this measurement process is not precise, it takes place under water and lasts for a long time (first cut, second under water measurements, third structure lift, and finally settle down). An AR system could allow the measurement of the cut once the structure is out of the water (first cut, second structure lift, third measurements, and finally settle down). AR could make this process faster and more economic."

> “More relative positioning applications. This research considers topside positioning. AR could be useful for measuring relative positioning among vessels during operations that require two cranes in two vessels to positioning a load.”

HMC perspective

“Heerma offshore workers consider current topside positioning processes safe. The crew that go on the jacket consider it an exciting task and they feel safe. However, there is a golden rule that’s being broken: “never stand under a suspended load”. Moreover, even though there has not been any incident during topside positioning on jackets, once a module of 2,5 thousand tonnes dropped due to the brake of a crane boom wired. The module crashed on the edge and then came into the sea. There were no human damages, however all companies know that it happens and they want to avoid any possible danger.”

“Clients requirements is not the only reason for Heerema *investing* in this project. Getting the crew to the jacket is also a problematic and risky process: pick up of the crew on a small boat, sale to the jacket (weather sensitive), complex access to the jacket through ladder. The achievement of unmanned jacket topside installations will significantly reduce the operational risk of this process. “

“Heerema is willing to innovate as far as it brings *added value* to the company. Therefore, before every innovation investment there is an analysis on its added value. Concerning this system implementation, the added value is not related to sales increase or lower labour/equipment cost. It is about satisfying client’s requirements in a cost-effective way and reducing the complexity and risk of topside operation processes. An additional expected benefit of the system is the reduction of installations items (those that facilitate the transfer and access of people to the jacket). The process time is not expected to be reduced because the crew transfer to the jacket takes place while the topside is starting to be moved by the cranes.”

“It takes time before you can implement technology. Most of the time difficulties come up from the technology, when you want to implement it in a specific process it is needed to adapt the technology to the case. Most of the times technology is not directly applicable, it needs some changes, that’s where the successfulness of the system comes up. The system successful implementation depends on how much priority people give to it. “

“One of the advantages of the implementation of this system is that HMC has assigned *one specific team to develop and work ARPS,* and it is not an extra task within an existing team.”

Next steps

“To get together assistants-superintendent and superintendents in order to make them play with the system and to see what can we improve. Then to introduce their recommendations and take the system offshore. “

Additional comments

“I am really enthusiastic on this AR system development. I believe that once it works, superintendents will follow, even though they don’t think is needed because they not consider standing under an engineering suspended load a dangerous operation.”

Participant 2

Personal data

“I deal with the vessel operations, I am the link between the office and the vessels. We are in charge on signing all the drawings and the manuals. We support this project by giving advice on which system we think that it is feasible, on the equipment and interface that need to be prepared before they come offshore… We look which system works better and it is more cost effective.”

Current process

“The current process for topside positioning need to be improved in terms of *safety***.** We need this technology. It is a matter of continue improving it and testing, so everybody will start trusting it. However, I don’t think it is feasible for every module, every time it is required to look at the module, and analyse if it is feasible (maybe small modules, modules with difficult features are not compatible with the system). I think that the system should be able to be used almost for every module.”

Usefulness

“The system can benefit the topside installation process *by no sending people to the jacket* that need to climb and stand under the load. The trip and climbing on the jacket is more dangerous than standing under the engineering load.”

“A possible disadvantage is the chance of technical failure. We should be ready to send people to the jacket in case of failure and/or install a back-up system*. Redundancy* either sending people or with another system is needed.”

People offshore

“How to make offshore people to *accept* it? By using the system offshore. The system should be tested still having people on the jacket, and by trying not to use the people on the jacket, and just use the system. If the system proves that it is reliable, people will believe on it.”

“To be successful implemented, the systems needs to be: easy to install, 100% reliable and every time successful. If the system fulfils these requirements, then people will trust it and use it. Offshore people are already accepting the system, it needs to keep be trying. The next step is to use it in the simulator.”

Implications

“I think that the system will require a slightly different *training* procedure: it should include the user interface in the current training process. I think it will not be difficult to train people on the system. The system will not affect the *demand* of topside installation. Demands stays the same for topside installations, just the way of setting it down will change. I don’t think it would change *the organizational structure*. Well it depends if we buy the system ourselves or if we keep renting it. Probably we will buy it, then we need of maintenance and set up, maybe one of the current departments can work the system.”

HMC perspective

“I believe that the augmented reality system *will work* and it will be frequently used in the future, people on the jacket will not be needed anymore. Heerema enhances in-house innovation processes and it is willing to invest on innovative technology. The *added value* of implementing the AR system for HMC is to fulfil the requirements of the client and to avoid the people transfer risks. It improves safety."

"HMC is also investing on another technology system to eliminate the need of people on the jacket, laser positioning technologies. It is a system that it is much more expensive and complicated to install and maintain than the augmented reality system. Our preference is TWNKLS system, mainly for economic reasons."

Participant 3

Personal data

"I am involved in the practical side of the system implementation: how are we going to use it? is it usable? how the workers will relate to it? The innovation team keep is updated on the project and system progress."

Current topside positioning process and AR system usefulness

"The current should be implemented by *eliminating people from the jacket*. We established this goal 10 years ago, however by that time the technology was not ready. Two years and a half ago we decided to try it again, since technology was already available."

"Augmented Reality looks like a suitable and simple technology that can achieve our goal. I have to say that I was impress by the AR system. It comes from a theoretical environment and TWNKLS is really different from HMC, understanding among parties took a bit longer that with people that work on our industry. "

"I think that if you want a great innovation in technology, you cannot take it from the traditional industry, you need to take people from another industry involved. Before we were investing on improving process (such as better lifting capacity), but not on completely new technology. I am impress with the AR system. Sure, there are some difficulties, but it is *completely new technology in a very traditional environment* (offshore)."

"The advantages of implementing the system are *safety*, elimination of some equipment (such as ladders to access the jacket). Any more benefit is more a bonus. Maybe the system can allow the topside positioning process on a bit worst weather conditions since there is no need to transfer people to the jacket (high weather sensitive process). The *disadvantages* are mainly related to *reliability issues*. Our industry is really traditional, we do have many risks already, we don't want to introduce new risks. We do not know what is the risks of this system stopping working. In contrast, we do know that the people in the jacket will work (radio spare battery, previous experience). To rely a 100% in a system is difficult, to move away from your trusting method of working to having something new. "

People offshore, system introduction requirements

"The system is a completely new technology. Introducing something completely new requires the slowly introduction of the system and early involvement of the users on the process. We try to make small steps/improvements, we take suggestions from offshore workers, we want to make people use it and trust it. We already run the system in parallel with the current positioning process methods, therefore, the crew are familiar with the system. We think that the right system should be *gradually implemented* to get users reliability, the system needs to prove to be accurate and stable all the time."

"The *process of introduction* should be gradual. Initially we keep still people on the jacket, so everybody is comfortable on using the system. After it, we should use the system without people on the jacket but we the possibility of sending people there in case of need. Finally, the system will be used with no people on the jacket, no access ladder."

"A *robust* system is essential. Every system offshore has several computers running simultaneously, then there is an extra computer somewhere, power comes from three separate engine rooms; a whole back up system behind to make it extremely reliable. This system should follow this. You need a backup, redundancy on the system or another method to reach the same goal."

"The system needs to be *simple to set up,* since crew should be able to do it. Here is the challenge between TWNKLS and HMC: a technical very complicated system should be operated by not technical people. We have few IT, software people on the vessel and we don't want to include more. It the systems needs to be modified and adjust it every time before we use it (difficult set up), then it would not be user friendly, we don't want it."

"Acceptance of the crew depends on the system proving itself: will the system give me the same accurate information as the assistants-superintendent that are experience? System has to replace people and be reliable. Then people will trust it, then they will accept it."

Other applications

"Translate reality to computer information can have quite a few applications, it can replace traditional methods of measuring measure things or tracking motions."

Implications

"Concerning the topside installation *demand,* I think it will not change. Projects drive the demand, not the way to do it. There will not be so much changes on *procedures or* protocols. We just should make sure the system works and people understand it. Concerning the *training* it is important to define who will operate it and which training it will need. The answer to this question heavily depends on the user interface. We have a software engineer on board, he will probably have to be trained on the system (not to deep, he does not need to be able to change the software). How much training people need depends on how user-friendly end up making the system HMC and TWNKLS."

HMC perspective

"The *added value* of the AR system for HMC is safety improvement. It will not reduce the process time (the lift of heavy modules requires slow movements) and it will not reduce the cost of the process. HMC invested in AR because we wanted unhuman positioning, and AR could do it. We had already a solution, laser positioning systems, but it is very expensive. This AR system could maybe be operated by our own crew, this is a big step we were looking for."

"In the past 4-5 years, HMC do experiments on more technologies. Usually we have been working on the evolution of existing technologies (same technology in a newer version). TWNKLS is very different technology to our industry. The only risk is to build the trust on this technology, get to people to accept it and use it."

"I like the system, I am more and more surprise about what you can do with AR. It is interesting how AR is so different for traditional offshore methods. People involves with the system are positively impressed. They see the benefits but they wonder if it will work 100% of the times. It is something that we have to demonstrate!"

TWNKLS Interview Results

TWNKLS's participants were people involved in the ARPS project, they are AR experts. They have been involved in the project for a long period (1-2 years) and are already familiar with offshore processes and topside installation operations. The interview follows the scheme present on Appendix H. The answers are collected following the same structure: ARPS, system usefulness, system introduction, system implications for the marine and AR industry, and TWNKLS perspective.

Participant 1

ARPS

"The *idea* behind this project started at the beginning of 2015, and I joined the project at the end of 2015, when I started working at TWNKLS. The client saw our technology, AR, in other applications (such as tracking of inside room structures), and they thought about the possibility of using AR for offshore tracking. This technology is an example of technological push and pull. From the beginning, the idea is to use AR as a simple and economic tool for unmanned topside positioning."

Usefulness

"The main advantage of the AR system is that people do not need to stand on the jacket. It fulfils HMC's clients' requirements, because they consider this practice as unsafe."

"In addition, this system *can make the process faster; not for topside installations* because it takes long times due to the heaviness of the structures, but windmills structures installations, that require thousands of installations processes, could be done in less time. So right now, the main advantage of using the system is safety, maybe in the future it saves time, that translates into monetary savings."

"Compared to laser system, ARPS allows Heerema to *run the system by them shelves* instead of renting laser technological services for every offshore operation The main disadvantage is that it is a vision system, so it highly depends on the weather conditions. Therefore, the ARPS has the benefit to allow unmanned topside positioning in a cost-effective wat, but the system should be tested to be robust under offshore weather conditions. IT will be tested in a few weeks. We will include an error range system indicator."

System introduction

"Nowadays, the system has a difficult set up process that involves *technical knowledge.* The use of the system right now, required the education of high technical people. We are working on making a simpler set up process. The goal is that in the near future, TWNKLS will not be offshore anymore and it will become a second line support (if something is really wrong TWNKLS can go offshore): remote assistant by TWNKLS, and web base user interface through Wi-Fi. "

"The introduction of the system requires the *system to work and to build trust from people offshore*. Trust come from testing the system, but it is difficult because you can just test it a couple of times per year per vessel. Other way to get trust is to have people abroad convince about the validity of the system, that it will be effective."

System implications

"Offshore people should be *trained* on the system. Standard checks procedures on both, the user and system level (cameras, algorithms…) should be stablished. User level requires training by simulating the system and possible scenarios in the simulation center.

The superintendent should be trained on best and worst-case scenarios such as system fail, limited visibility, inaccurate measurements…in the simulation center. The management interface and hardware set up needs specialized training, a real engineer. In this case, new people or training of one IT engineer from the vessel. The people or person running the system should be trained on different circumstances, so they are able to set the system up for different projects."

"Concerning *future applications,* there are many possibilities: movement of structures from one vessel to another, jacket placements (level it and hammer piles installation). All this AR applications possibilities can be considered in advance in order to set up the cameras and tracking system in a way that the equipment can be reused (like strategically position the cameras for the different applications). Once the hardware is there, some modifications will be needed, but it would make things easier. The successful implementation of the system really useful for the offshore industry, since other applications can follow. In addition, other industries can benefit by implementing outdoor tracking such as on *the construction or steel industry*."

TWNKLS perspective

"This is a new system; therefore, it is uncertain whether it will work or not on real offshore conditions, however, I think it will success. We are going to try it in a couple of weeks. We are prepared with different algorithms, different tracking methods a complete equipment and software backup system."

"HMC is investing on this AR application for topside positioning processes, however, at R&D level, *AR can have many other applications.* The question is if HMC wants to just focus on this application and/or to further invest on other possibilities. There are some offshore applications easier to do than topside installations, they could be further research. I am aware that we are a small company, and that HMC should invest wisely since they do not have money for every investment on AR."

"There can be some differences HMC's and TWNKLS's visions. Heerema aims to use the system by themselves, maybe they have a different perspective on what are good enough weather conditions to use the camera system, they aim to get different configurations of user interface (it can be achievable through web based UI interface connection)."

Participant 2

ARPS

"The idea generation of the project is the result of *a Heerema request* given the AR capability on tracking indoor environments. The initial expectations on the project were to achieve precise edge base video tracking and real-time feedback."

Usefulness

"The system allows *unmanned topside positioning, it fulfills clients' requirements* and it provides more precise results than current methods. Compared to laser systems, this system is more robust, lasers can be interrupted by any drop of rain, they have higher visibility constrains, and equipment requirements. The only limitation of the AR system is to assure a correct *match of the 3D model* and the real image. The structures are continuously swinging, a good tracking speed is required and to don't loss track. Weather is not a limitation for using the system, if the weather allows the process, the system will also do it."

“Concerning future developments of the system, first the system will *automatically track* the markers, then the system will be able to track the structures without markers, just using the 3D model. This process could take a few months. In the future, more hardware could be implemented to improve this system and its applications.”

System introduction

“The technological introduction of the system requires *the right technology* (pc, cameras, back up equipment, tablet, wifi network), a full operating system, and the right training.”

System implications

“At least, two people should get special *training* on the system: the superintendent and the system administrator, who set up, maintain, and control the software. The superintendent needs training on the UI and the other user needs training on how to operate the system (turn on, set up, restart, monitor…). Heerema should include the system in the *simulation centre* and train the crew on worst case *scenarios*.”

“Concerning the *organizational structure*, the introduction of the system implies the creation of one extra position, the one who operated the computer system. This extra position can be overtaken by one guy from the vessel. His job is to configure the system, set up the cameras, check the match of the 3D model and the real structure view. There are several things that can go wrong: tracking system, software program, power supply.... There should be a solution for each problem (complete backup system, universal power supply). There is a need of establishing *protocols* for each possible scenario.”

“The system works or not, *operate it does not require high skill worker*. TWNKLS is not needed during day to day operations. Just in case of problems, new processes… It should be taken into account that the introduction of the system implies the *creation of a communication* process between the system administrator and superintendent concerning the quality of the tracking, when to start…”

“There are many future applications of this system, it just requires a 3D model and it can provide information on relative positioning of objects. This is the *first time that AR is used with such a big and complex 3D models*. Topsides and jackets are structures with a lot of features that needs to be tracked. It can be considered as a big step forward for the AR industry, that is usually involved on the tracking of simple and small objects. “

TWNKLS perspective

“I am expecting a *successful ARPS implementation*. I think the tracking and speed of response (6 times per second) is good enough to track these offshore structures. In the future, markers will be tracked automatically. However, getting rid of the markers is not an easy task, but I don’t think it is an important requirement. “

“Investing on ARPS is a right decision because it is an accurate system that provides more information on the process that can be shared among the crew. It eliminates the need of sending people to the jacket, what can lead in a shorter operation time and less restrictive weather limitations.”

“In collaboration with us, we should come up with suitable cameras positioning locations taking into account the process and positioning conditions. HMC wants to operate the system by themselves, but for the first operations, TWNKLS needs to be offshore. After several times, HMC can operate the system by themselves.”

Participant 3

“I am the founder of TWNKLS and account manager of the Project. This project started two years ago, in 2015. Heerema saw our technology and they ask us if it would be possible to apply it on OTIP. We said it could be possible, they relied on us and the project started.”

Usefulness

“The *benefits* of the system are linked to safety for HMC’s clients; and cost reduction, this system requires low preparation and can make the process faster, saving a bit of time saves a lot of money.”

System introduction

“A *successful system introduction* requires system robustness and user friendliness. This system entails a new metaphor, software, graphical user interface…, we do not know if it works, we assume it will since we have worked closely to HMC to understand the process and create the right system. The main *limitation* is the unknown behavior of the system on different weather conditions, it is related with the robustness of the system. “

System implications

“The *training* on the system should ideally take place in the VR training center of HMC. As a second option, it could take place through scale models tests. The training is essential because the system cannot fail offshore.”

“The ideal situation is that TWNKLS will not be offshore during OTIP, we will send a box with the equipment and they will use it. The next two times we will go offshore to test the system and show how it works, then the idea is to HMC to do it by themselves. Remote assistance from TWNKLS is the goal. “

“I think that this system can have *many other applications,* such as windmill installation, bridges placements, more generally any structure placement. It could deal with heavy and complex objects. *Is the first time that the AR industry deals which such as a big dimension project*. The combination of the measurements and AR technology makes this project really powerful. There is a high interest of this technology in the marine industry market because they want to achieve unmanned OTIP.”

TWNKLS perspective

“This is a project that has a huge R&D part, we create algorithms, we cannot test the system in house, as usual. I think that with good 3D models of the structure we will reach our ideal situation.”

“HMC was really open minded with this project, they trusted on our skills from the beginning. We collaborate close and fast through an iterative process. I think this project is a new experience for them since they usually buy software and do not develop it. The process is being successful, they explain us really well what they need and we build it.”

“The main difference with HMC is that they have really long cycles before placing jackets and topsides (6-12 months to get information and place the structures), however in software development we need faster iterations to test and develop the software. Base on Cad models we build 3D models that need testing and high accuracy ranges.”

“There are few OTIP per year, how would you proof its robustness? *We have video footage of previous installations, we can test the system with different algorithm over and over*. In addition, we can tested also offshore a few times, like we are currently doing.”