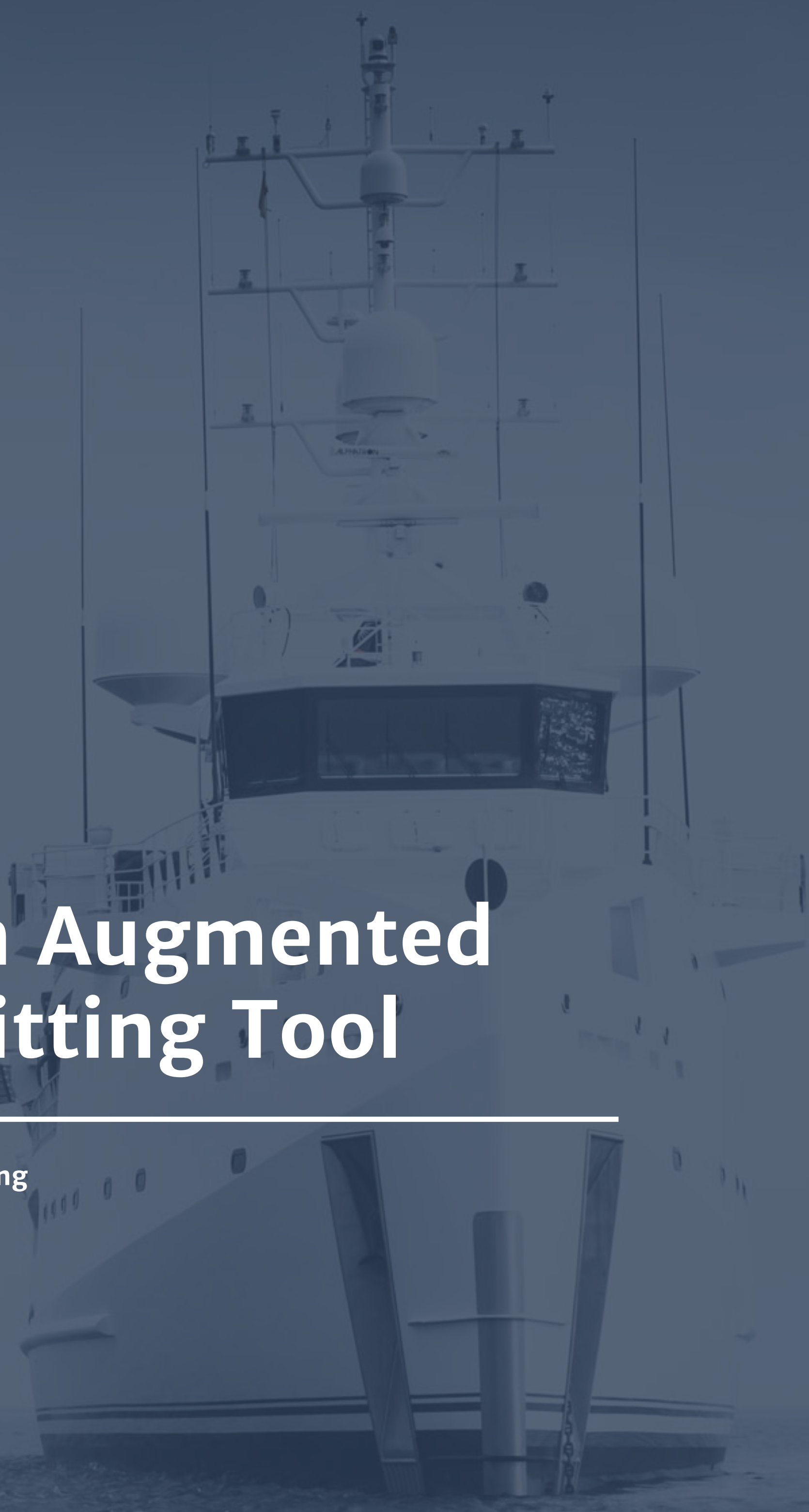
Developing an Augmented Reality Pipe Fitting Tool



Master Thesis Industrial Design Engineering
Sven Deinum - 09/2020

UNIVERSITY OF TWENTE.

Developing a Pipe fitting tool to make measuring and manufacturing of measured pipe spools more efficient

MSc Thesis
DPM 1739
Sven Deinum | S1585002

Education

Faculty:	Engineering Technology
Department:	Design, Production and Management
Programme:	Industrial Design Engineering
Master Track:	Human Technology Relations

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Examination date
18 September 2020

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Number of pages
75

Number of appendices
10

Abbreviations and terms

MVP	Minimal Viable Product
DSGo	Damen Shipyards Gorinchem
CNBD	Commercial New Build Division
O&T	Offshore and Transport
WB	Workboats
HSC	High Speed Crafts
DTC	Damen Technical Cooperation
CRO	Cruise, RoPax and Offshore
EB	Executive Board
CCO	Chief Commercial Officer
CEO	Chief Executive Officer
COO	Chief Operations Officer
CFO	Chief Financial Officer
D&P	Design and Proposal
R&D	Research and Development
Measure Pipe/Spool	Name of the custom made pipes fitted between flanges in the ships

TABLE OF CONTENTS

SUMMARY (ENG)

Due to ever growing competition in the shipbuilding industries and current day economic circumstances Damen Shipyards is in search of cost saving and innovative solutions that can strengthen them for the future. Allowing them to keep being able to deliver the quality vessels they are known for at competitive prices and with quick delivery times.

An initiative challenging employees of Damen to come up with innovative improvement ideas on any part of the business was launched. The goal was, and still is, to move the traditional world of shipbuilding into the 21st century. From this initiative project Paperless Yard was born. The intention of this project is to transition the yards into paperless environments using modern technologies. As form of trial it was decided to focus on a specific aspect of the shipbuilding process first. This part being the pipe workshop. Within the pipe workshop the process of measuring, manufacturing and fitting correctly dimensioned measure spools seemed to be one that often proves to be difficult process with possibilities for improvement. Measure spools are pipes that are customized to fit the real world situation. These pipes exist because it is impossible to install all the piping in a system as designed (Yokoyama, H., & Takeuchi, K., 2013). There needs to be a component in the system that will adapt to all the deviations.

The process of matching and adjusting these measure spools on site is a difficult and time consuming task. To make this task easier and aim for a 100% first time right percentage on the production of those pipes Damen started the Pipe Fitting in Augmented Reality (AR) project in which a pipe fitting tool was developed that could scan and measure between two flanges using a tablet and two AR markers.

This pipe fitting tool has been developed into a so called Minimum Viable Product (MVP). A prototype which achieves the minimum requirements for trial testing. The tool functions perfectly in optimal test setups but a user acceptance test at the shipyard proved the tool was not yet ready for extensive trial testing.

The aim of this project is to research how this pipe fitting tool has to be developed and what needs to be done to create a functional prototype ready for testing and implementation in the pipe workshops of the different Damen shipyards.

The first step in the process was to analyse the work and research conducted previously. Alongside the prototype was tested and evaluated in a test environment and on board of a real vessel. From this work the known shortcomings were confirmed. From the evaluation of previous work it was also found that the prototype did not conform to the original requirements. Also decisions made in the development were based on incomplete or unreliable documents and important stakeholders were not involved in the project.

The relevant stakeholders to the project were identified by researching the company structure of Damen as well as the shipbuilding processes within the company. Trough literature research important factors for failing implementation of new technologies in traditional businesses such as shipbuilding with regard to stakeholder management were found. It has been determined that the end users, being pipe fitters and foreman, have not yet been incorporated into the design and development processes of the project.

Furthermore extensive market research trough literature, experts and partner companies different possible technologies and approaches for digital metrology were identified. The future development possibilities for the current prototype and the chosen technology are also researched. This gives a complete overview of the technological possibilities both now and in the future.

Also process mapping was used to produce understandable and clear workflows of the current pipe fitting process while focussing on the measure spools within this process. This was needed to be able to find out how the information and communication flow are functioning within the production and engineering environment. Additionally this process mapping resulted in clear workflows in which the pipe fitting tool could be placed in different scenarios to figure out how it will impact the whole process and the stakeholders involved. In the end these workflow scenarios enabled the creation of rough business cases to elaborate on the cost saving potentials of the different scenarios.

Plans for business case and workflow validation sessions were planned at the yards and presentation and development meetings with stakeholder and end users were also planned. These planned activities could however not take place due to the Covid-19 pandemic prohibiting travelling. As a result the deliverables of this project have changed to delivering a roadmap for further development including advise on different implementation and development scenarios.

In the end it is important for Damen to define what their goals with both this and the Paperless project are before any different decisions can be made. Depending on this the roadmap and design brief delivered at the end of this assignment will help Damen guide the project and give them a solid basis to continue developing a successful pipe fitting tool.

SUMMARY (NL)

De constant groeiende concurrentie in de scheepsbouw industrie en de hedendaagse economische omstandigheden zorgen ervoor dat Damen Shipyards opzoek is naar kostenbesparende en innovatieve oplossingen die er voor zorgen dat ze klaar zijn voor de toekomst. Op die manier kunnen ze dezelfde betrouwbare schepen waar ze om bekend staan blijven leveren voor een concurrerende prijs en met een snelle levertijd.

Een initiatief is gestart waarin de werknemers van Damen zijn uitgedaagd om voorstellen te doen voor innovatieve verbeterprojecten voor elk onderdeel van het bedrijf. Het doel was, en is nog steeds, om de traditionele wereld van scheepsbouwen naar de 21e eeuw te brengen. Vanuit dit initiatief is project Paperless Yard ontstaan. Het doel van dit project was om de werven over te laten stappen op een werkomgeving zonder papier door gebruik te maken van moderne technologieën. Als test werd er gekozen om eerst te focussen op een specifiek aspect van het scheepsbouw proces, de pijp werkplaats. Binnen de pijp werkplaats blijkt het proces van het meten, produceren en monteren van paspijpen met de juiste dimensies een moeilijk proces met duidelijke mogelijkheden voor verbetering. Paspijpen zijn pijpen die aangepast kunnen worden aan de daadwerkelijke situatie. Dit soort pijpen bestaan omdat het praktisch onmogelijk is om pijp systemen te maken en installeren zoals ontworpen (Yokoyama, H., & Takeuchi, K., 2013). Er moet een onderdeel in het systeem zijn dat aangepast kan worden aan alle afwijkingen.
Het proces van het passend maken van deze paspijpen is moeilijke en tijdrovende taak. Om dit gemakkelijker te maken en een poging te doen tot een 100% first time right percentage voor de productie van paspijpen heeft Damen het project Pipe Fitting in Augmented Reality (AR) gestart. In dit project is een tool ontwikkeld die de afstand tussen twee flensen kan meten met behulp van een tablet en twee AR markers. Deze tool is ontwikkeld tot een werkend prototype dat aan de minimale eisen voldeed, een zogenaamd Minimum Viable Product (MVP). Het prototype werkte goed in een optimale test omgeving maar uit een gebruikstest op de werf bleek dat de tool nog niet geschikt was voor uitgebreide test sessies op de werf.
Het doel van dit project is onderzoeken hoe deze tool verder ontwikkeld kan en moet worden om een goed functionerend prototype te creëren geschikt voor uitgebreide tests en uiteindelijk implementatie in het werkproces van de pijp werkplaatsen op de verschillende Damen werven.

De eerste stap in het proces was het analyseren van het werk en onderzoek dat vooraf gedaan is. Tegelijkertijd werd het prototype getest en geëvalueerd in de test omgeving en aan boord van een schip. Dit bevestigde de al bekende tekortkomingen van de tool. Vanuit de evaluatie van voorgaand werk bleek ook dat de tool niet voldeed aan de requirements die ooit opgezet zijn voor de MVP. Ook bleek dat bepaalde keuzes die gemaakt zijn in het ontwikkelproces gebaseerd zijn op incomplete of onbetrouwbare documenten. Ook zijn belangrijke stakeholders niet betrokken geweest in het project.

De relevante stakeholders voor het project zijn geïdentificeerd door middel van het analyseren van de bedrijfsstructuur en het scheepsbouwproces van Damen. Door middel van literatuur onderzoek zijn belangrijke oorzaken voor het mislukken van het toepassen van moderne technieken in traditionele bedrijfstakken zoals scheepsbouw gevonden. Ook tactieken voor stakeholder management zijn gevonden. Gevonden is dat de eindgebruiker van de tool, de pijp monteurs en de voormannen, nog niet betrokken zijn geweest bij het ontwerp en de ontwikkeling van het project.

Daarnaast is uitgebreid marktonderzoek gedaan door middel van literatuur, experts en partner bedrijven te gebruiken. Verschillende technieken en toepassingen voor digitale meetkunde zijn gevonden. Potentiële toekomstige ontwikkelingen voor het huidige prototype en de gekozen techniek zijn ook onderzocht. Damen geeft dit een compleet beeld van de technische mogelijkheden voor zowel nu als in de toekomst.

Ook zijn processen in kaart gebracht om duidelijke workflow overzichten te kunnen maken van het huidige pijp productie proces. De focus ligt hierin op het proces van de paspijpen. Het doel hiervan was om te leren begrijpen hoe informatieoverdracht en communicatie functioneren binnen de productie en engineering afdelingen. Daarnaast konden deze workflows gebruikt worden om te bepalen hoe de tool binnen het proces past en hoeveel invloed het op het proces en de stakeholders heeft. Uiteindelijk hebben de workflows kunnen helpen bij het creëren van ruwe business cases om de potentiële kostenbesparingen te bepalen.

Er zijn plannen gemaakt om de business case en workflows te valideren op de werven. Hier zouden ook presentatie en ontwikkel sessies met de stakeholders en eindgebruikers gehouden worden. Deze plannen konden helaas niet uitgevoerd worden vanwege de Covid-19 pandemie. Hierdoor zijn de deliverables van het project veranderd naar het afleveren van een roadmap voor verdere ontwikkeling inclusief advies over de verschillende ontwikkelings- en implementatie scenario's.

Uiteindelijk is het voor Damen belangrijk om te definiëren wat hun doelen zijn met zowel dit project als project Paperless. Dit is essentieel om te weten voordat andere keuzes gemaakt kunnen worden in dit project. Door middel van de roadmap en de design brief die gemaakt is aan het eind van dit project heeft Damen een solide basis om verder te gaan met de ontwikkeling van de tool.

01

INTRODUCTION

In this first chapter the company, the project background, problem definition and research goals and objective will be presented to give an introduction to the project and the report which is written for this assingment.x

Chapter 1.1

ABOUT DAMEN SHIPYARDS

Damen Shipyards Group (DSG) is a leading worldwide shipbuilding company with Dutch roots. The headquarter is based in Gorinchem, the Netherlands. Annually approximately 160 ships are produced by the Damen Shipyards Group at their 36 shipyards located around the world. Additionally 1300 repair and maintenance jobs are done each year. Together a €2 billion turnover is generated. Damen is best known for modular construction known as the Damen Standard. By building a wide variety of standardized hulls delivery times can be reduced while still maintaining the important tailor made options and quality clients demand. Also a range of standard vessels are built on stock which allows for even quicker delivery times.

The family-owned company designs and builds, as their mission states, "*innovative ships of excellent quality, supported by a worldwide network of sales and services including maintenance and repair & conversion facilities*" (Damen, 2019). At the time of writing this mission is being realized by a worldwide workforce of 12.000 employees.

The vision of the Damen Shipyards Group is stated as: *"Our aim is to become a global market leader in the niche markets of shipbuilding, ship repair & conversion and related services, growing step by step developing quality vessels and services (Damen, 2019)."*

The wide variety of ships such as coasters, ferry's, tug boats, patrol ships and tenders for both the civil as well as the military market are a prove of how this vision is shaped by the company. An estimated 40% of all the tugboats in the world are built by Damen, reflecting the scale and size of the company on the global market. To maintain their leading position DSG is constantly involved in researching and utilizing innovative technologies in the ship building industry to further optimize and refine the design and production of vessels. An example of this is using Additive Manufacturing to tailor components, like ship propellers, for niche vessels.

Chapter 1.2

PROJECT BACKGROUND AND PROBLEM INTRODUCTION

One of the targets of the Damen Shipyards Group is to pursue the goal of realizing a Paperless Yard in the near future. In this development the idea is that processes and the information distribution of those processes within the shipyards will be done digitally.

In an ideal situation the whole shipyard and the engineering departments will become paperless. This is a big step for the company that will need a complete mindset change on both the engineering as well as on the production side of the company. To make sure the right choices will be made the first step of this project focused on a smaller and more specific part of the shipbuilding process. This will allow for smaller scale research and feasibility tests as well as lower risks for the company.

The piping department has been chosen by Damen as the focus for this project. During initial research and meetings done previously by Damen employees it became apparent that making the whole piping process paperless would also be a too large project with too many unknowns to implement in one go. From this previous internal research it also became apparent that within the piping processes the tasks of designing, manufacturing and fitting measure spools is a returning problem in terms of manufacturing efficiency and precision. As Damen does substantial amounts of work in fitting measure spools to both newbuild and refit vessels this is an area of the process where substantial amounts of time and money can be saved by improving the process. For these reasons the choice has been made to focus on the specific task of measure spool fitting for creating testing and implementing paperless solutions to improve the processes and make them more time- and resource efficient.

The main issue with the current pipe design and fitting process is that there are always deviations between the designed ship and the actual manufactured vessel. In production environments these deviations often are the result from measurement errors or undocumented changes (Lindskog et al., 2016). For the large vessels Damen manufactures environment variables such as temperature can also be an influence in measurement deviations as metal will expand at higher temperatures. This means that there is no possible way to make sure all the piping systems have the correct dimensions to create a perfect fit (Yokoyama, H., & Takeuchi, K., 2013). To make sure all the piping systems can be connected correctly without any stress on the material measure spools are used at strategic places in the system. These measure pipes are intentionally fabricated with oversized dimensions to allow for adjustments to create a perfect fit.

At the moment measure spool fitting and fabrication is a process of trial and error. The dimensions are measured by hand and the fabricated measure spools are adjusted based on these measurements. It is not uncommon that this process takes several times of measuring and adjusting to get the pipe fitting the right way. This means that a lot of trips for the personnel and their equipment between the ship and the pipe workshop. Often the pipe workshop is not located close to the production location of the vessels meaning there are specific transportation moments between the vessel and the workshop. In an ideal situation the workers are able to define the precise measurements of the to be produced measure spool with the use of a simple tool. Using these precise measurements, a correctly fitting measure spool can be manufactured without the need for further adjustments.

In cooperation with the company TWNKLS a so called Minimal Viable Product (MVP) solution for this problem has been created in the form of an Augmented Reality pipe measuring tool. This tool is capable of measuring a basic measure spool between two flanges and adjusting the pipe designs to fit accordingly using augmented reality markers and a tablet.

Within this graduation assignment the aim is to evaluate the current MVP solution and further develop the solution towards a useable tool for implementation in the production process of Damen. Implementing such a new technology and changes in the current engineering and manufacturing processes of a traditional type of business such as shipbuilding can be difficult. There will be many different dependencies between people, processes, facilities and so on that will require lots of research and communication to analyse the impact of certain changes in processes (Mahlamäki et al., 2009). Another challenge will be the almost inevitable resistance of the people directly affected by the possible changes. A common reaction to (major) change is to defend the current way of working, especially when people feel their security or status is personally threatened (Maurer, R., 1996). This potential resistance is often acknowledged as one of the more important influences in a successful change of the status quo (Waddell, D., & Sohal, A. S., 1998) as it has been recognized that in many failed efforts for change ignored resistance has shown to be a critical factor contributing to the failure (Maurer, R., 1996).

Researching the impact of implementing such a new technology in an existing production process and how it will affect those processes and the people involved will thus be a vital part of the development process. A detailed overview of the current piping processes and its stakeholders will need to be made together with an extensive and detailed list of requirements to create the needed input required to design and develop a successful and viable pipe fitting tool solution for all parties involved.

Evaluating the currently chosen technology with regard to its possibilities today and in the future will also be part of this assignment. It will be important to make sure there are plenty of possibilities for future improvement and implementation with other research projects within the Damen Shipyards Group. This will mean that an extensive overview of comparable solutions, competitive solutions, available technologies, upcoming technologies and current and planned developments of Damen will need to be put together.

Chapter 1.3

RESEARCH GOAL AND QUESTION (OBJECTIVES)

Based on initial orientation and meetings and conversations with Damen employees and previous project owners, the objective of this assignment is to develop the Pipe fitting tool further to when both the headquarters of Damen and the actual end users in the shipyards are satisfied with the solution. Both parties need to see an added value in the solution and need to be willing to incorporate it within the workflow of shipbuilding.
How does the pipe fitting tool need to be developed to make it an accepted tool within the shipyards as well as it being an added value to the process of shipbuilding.

Investigate
How does the current pipe fitting process look like?
What are the actors involved in the whole process of pipe system design and pipe fitting
What are the issues and errors that occur with the current pipe fitting process

Evaluate
What are the requirements for a pipe fitting tool of the actors involved with pipe fitting
What are the issues and points of improvement of the MVP pipe fitting tool

Design
How can the current AR marker be improved for ease of use
How can the pipe fitting tool be improved for ease of use and acceptance by the end users

Future
What resources, people and development are needed to implement the pipe fitting tool in a successful manner
What is a realistic timeline for implementation of the pipe fitting tool
How can the pipe fitting tool be expanded to fit and support other parts of shipbuilding

Research scope (relevance)

1.3.2 The research scope for this assignment is divided in two categories being 1. The scope from a company perspective and 2. The scope from an academic perspective.

1. From a company perspective, this assignment aims to research how the pipe fitting tool can be developed to make the pipe fitting process more efficient and eventually help reducing production costs.
2. From an academic perspective, this assignment will aim to add knowledge to the way digital technologies can support and evolve production processes and the people working on those production.

Approach
To achieve the set goals and answer the research questions structured research and design is required. The first steps in the process will consists of understanding the company structure and the processes behind ship engineering and production while focusing on the piping processes. Ultimately the goal of this is to figure out who the potential stakeholders of the project are. Parallel the current prototype and previous work and research conducted will be researched to figure out what has been done and who has been involved. The initial requirements will be evaluated and updated and based on this the next steps that are required will be defined. These will probably include improving already known shortcomings of the prototype or figuring out how to improve them. Ultimately the goal will be to conduct trial test at the production locations to figure out if and how the tool meets the requirements and if those requirements prove to be realistic and achievable.

02

ANALYSIS

In this second chapter the shipbuilding process will be explained and the current solution to the problem will be presented. The term Measure Spool will be explained and initial analysis such as a swot analysis and context analysis are written. This chapter is meant to give some context about the assignment.

Chapter 2.1

SHIPBUILDING PROCESS

In order to get a good understanding of how processes are followed within Damen it is important to get to know the global outline of how a ship is engineered and manufactured within the Damen Shipyards Group. The Damen group has three main activities being New-build, Services and Refit and repair. The New-build part of the company is the core activity of the company. This part consists of the design, engineering and manufacturing of new vessels. The Services department is responsible for after sale support such as warranty, maintenance and component replacement. The Refit and repair department is responsible for repairs of any ship and refitting of ships to update them with new technologies or make them suitable for a new owner or purpose. The vessels worked on by the refit and repair department do not have to be Damen built ships.
Below a global explanation of the shipbuilding processes of these three departments will be presented together with how they relate to piping and the pipe fitting tool.

2.1.1

Shipbuilding/pipe fitting process in new build ships

The shipbuilding process within Damen Shipyards can be roughly outlined within three phases. These phases are 1. Vessel Sales, 2. Vessel Design and Engineering and 3. Vessel build. In the first phase a customer either wants to order a custom built vessel or a stock vessel. Through the sales department the customers whishes are documented and the Design and Proposal department will create a proposal with specifications. When this proposal is accepted by the customer the ship design will be further developed in the vessel design and engineering phase.

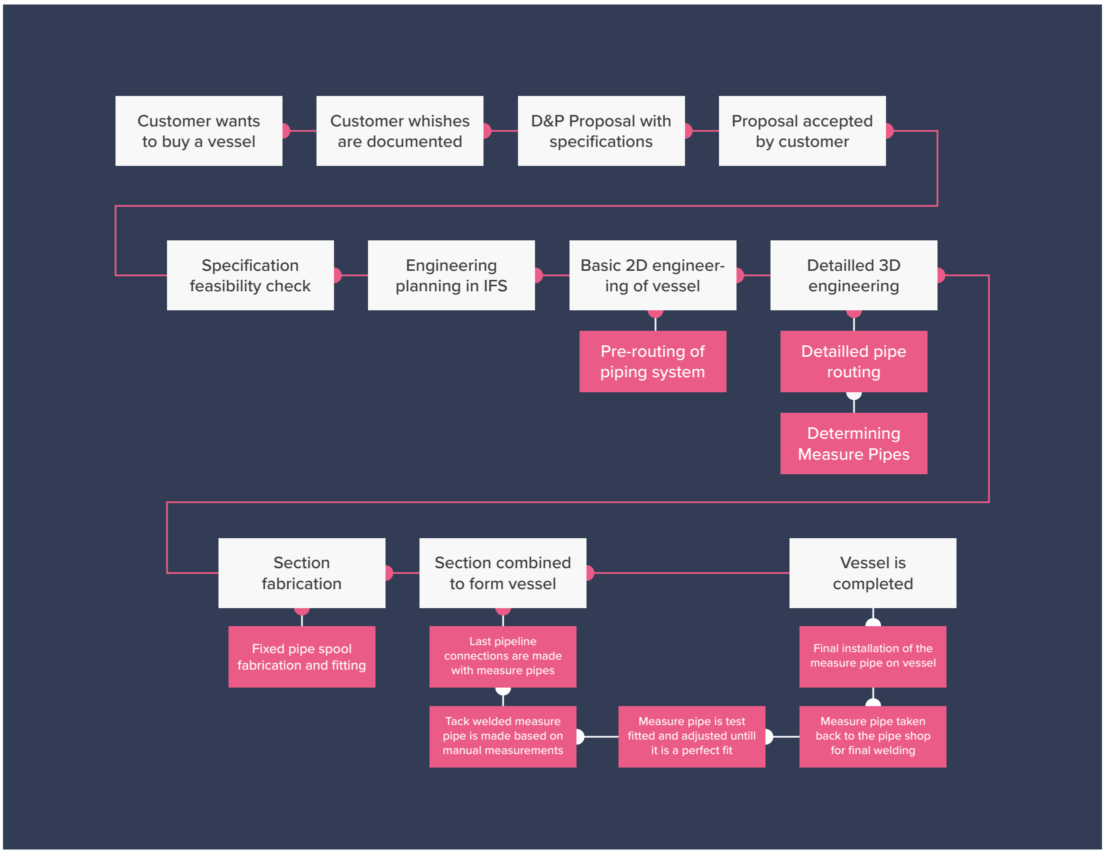

Figure 1, Ship Building Process

In this second phase the proposal is checked for feasibility of the specifications, rules and general arrangement plan. The engineering will be planned in the IFS system and engineers start on the basic engineering of the vessel in 2D designs. At this stage the pipeline engineers will start with the pre-routing of the piping systems. Once the basic engineering is finished and corrected where needed the detailed engineering in 3d starts. In this phase all the details are worked out per section of the ship. At this stage the pipeline engineers define the detailed pipe routings and determine the 'measure pipe' spools.
To be able to keep delivery times of the vessel as low as possible the third stage, the vessel build, is started while the engineering is not completely finished. The vessels are built in sections (for example; the engine room is usually one section), which means that construction of sections that have finished engineering can start while the other sections are still being engineered. At the construction of the sections the fixed pipe spools are fabricated in the pipe workshop and installed in the section. Large equipment like the engines are also installed inside the sections as these are too large to fit once the sections are combined
The finished sections are combined to form the vessel and all the remaining components are fitted. At this stage the final pipeline connections can be made and installed using measure pipes.

2.1.2

(After sale) Services

The part of the (after sale) services department of Damen that is relevant to this project is primarily the warranty and repair. This part of services provides assistance for Damen ship owners when parts of the ship break or when maintenance has to be done. When a ship with a warranty or maintenance job comes to the yard a services engineer is going to check in the vessel what components are in there and what parts need work done. Usually the parts list (Bill of materials) is available in the IFS system, but as in the construction of the vessel both the building and the detailed engineering are sometimes being done simultaneously there might be some differences between the designed ship and the real world situation. If piping systems are damaged and need replacement there could be a situation where there is no detailed information available about the dimensions of the pipe. This means a pipe engineer needs to measure the pipe and create a replacement measure pipe spool.
Another scenario can be that a pump or engine needs replacement and the replacement part is of a different specification. Again the piping system will need to be remeasured and new measure pipes have to be designed and fabricated.

2.1.3

Repair

The repair yards do repair jobs on both Damen vessels or vessels from any other shipbuilder. For Damen vessels the workflow is comparable with the one of the services department. For the vessels of other shipbuilders there is no detailed information available whatsoever. This means that for every part or component of the vessel that needs repair jobs done some detailed engineering or even reverse engineering has to be done. The engineers have to create an overview of the components installed on the ship and try to collect specifications of these components. Custom parts and components have to be reverse engineered, measured and constructed by hand if they need replacement.

2.1.4

Refit

Damen also provides refit services for all types of ships. In refit projects existing ships get overhauled to modernize equipment or interiors, or to change the specifications and gear of a ship to make it suitable for a different job or owner. Refits can mean a complete overhaul of the interior of a ship, changing or adding equipment on deck or on the bridge or it can be a change of engines, generators, pumps or other machinery. Changing these types of components will also affect the piping system of the ships resulting in needing to engineer new pipe spools to fit the new components.

Chapter 2.2

PAPER(LESS) IN PIPEFITTING

A significant amount of paperwork is created and printed for the piping workshops. The engineers prepare so called production albums containing pipe spools that can or have to be manufactured together. Depending on the system such an album can contain documentation for up to 25 spools. All of the details regarding the spools is explained in those albums resulting in a large amount of paperwork. As an example an album for a part of a firefighting system containing just three spools resulted in a document of 13 pages.

For the pipe fitting, measuring and installation process limited amounts of paper documents are used on site in the vessel. Most documentation on the piping to be manufactured is used in the piping workshop. In the vessel the pipe fitters do however use some paper documents. Especially when measuring dimensions for measure spools. This happens for both the measure spools pre dimensioned within the engineering CAD data and the smaller diameter spools that are crafted fully from scratch by the workers.

When measuring dimensions these measurements are written down and drawn on special ISO graph paper. This paper enables the pipe fitter to draw the pipe routing and corresponding dimensions in the same way a digitally generated technical drawing for production looks like.

This raises the question on how much the pipe fitting tool will relate or contribute to the paperless project. It seems like the project has lost sight on the paperless part of the project a little. By creating a pipe fitting tool the need for using paper on the vessel while measuring spools becomes obsolete. But mostly it will contribute to helping overcome potential human error and provide an option for adjustments and corrections when mistakes are identified. Another benefit could be that the paper does not have to be transported to the correct person as this process can also be digitalized. This can ultimately result in improving production speeds as information transfer via paper is a proven bottleneck for production efficiency (Djassemi, M., & Sena, J. A., 2006). Also not to forget is the actual target of saving time on the process of measuring itself.

Although the focus of this project is not on the paperless project it will be interesting to incorporate it in the decision making process and investigate how both projects could benefit from each other and how much they depend on each other.

Chapter 2.3

WHAT ARE MEASURE SPOOLS?

Each ship has an extensive piping system on board for a wide range of different applications. Examples of these applications are fuel lines, hydraulic piping and water pipes for firefighting systems. Piping systems usually connect different components like pumps, tanks and engines to each other. Sometimes piping systems also run through several different sections in the vessel. The pipe lines usually consist of several sections of pipes called spools. A pipe spool consists of three parts; the pipe, two flanges and the fittings.
Most of the piping systems and their routings are designed in detail in s 3D environment. The vessel that has been manufactured in real life however will never be exactly the same as the designed vessel. Manufacturing errors, material characteristics, welding and even the outside temperature will have an influence on the actual dimensions of a manufactured component or vessel. On a hot day a large vessel can be several millimetres or even centimetres larger than on a cold day. The welding of sections, structure elements and pipe spools also will create deviations in the materials. Engineers try to calculate these deviations and make sure the designs take into account these changes resulting from the manufacturing processes but it is impossible to account for all the deviations.
For piping systems it is important that all the sections are fitted without any strains or stresses as this can lead to damages and failures when the ship is in the water. As manufacturing deviations are imminent there needs to some flexibility in the piping design to account for these deviations. For this reason so called measure pipe spools are used. Measure spools are generally placed at the end of a pipe line just before the component it will need to connect to, or at a point where a piping system will cross over to another section of the vessel. The measure spool is designed to fit the designed system perfectly, however engineers at the yard will add some extra length to these pipe designs before fabrication. This overlength will allow for adjustments to be made to make for a perfect fit in the constructed vessel. Other than regular fixed pipe spools the measure spools will not be fully completed and treated at first. First they will be test fitted with loose flanges and adjusted accordingly before making the final weld and treatment. For test fitments the measure spool components are usually held together with a tack weld.

How many measure spools are fitted in each piping system differs based on the type of ship design and the chosen optional systems. For a basic harbour tug around 150 to 200 measure spools are used. In total the piping system in these tugs will consists of around 2000 pipe spools. In 2015 the DSGa shipyard manufactured and fitted approximately 12.000 measure spools. In total man hours this translates to around 50.000 hours spend on measure spool fabrication, fitting and adjusting in one year.

Figure 2, Measure Spool

Chapter 2.4

CURRENT SOLUTION

As mentioned before Damen has developed a so called Minimum Viable Product (MVP) for a pipe fitting and measuring tool. In this chapter the project history and current state of the Damen Pipe Fitting Tool will be presented. This will give some context on where the project originated from and on what requirements the current MVP is based on.

2.4.1

Project History and previous work

In the search for improvements within the Damen Shipyards group project Morpheus was launched. The project was a breeding ground for innovative ideas of anyone working within Damen. The project was set up as a Dragons Den style presentation session for the Executive Board. The best idea could be chosen to receive R&D funding from the board. Innovative research projects like artificial intelligent ship building and robotic welding arms for the yard in Romania were amongst the most promising ideas. The Paperless Yard idea was also one of the most promising ideas. As the name indicates the goal is to remove paper from the yards and replacing it with smart, digital, Augmented Reality (AR) or Virtual Reality (VR) solutions. Making a yard paperless could potentially be a huge time saver. Currently approximately 30% of the available time is spent on information gathering and processing.
After the first pitches a roadshow has been organized to present the idea to Damen employees in the engineering, management and manufacturing departments. This roadshow was also meant to create input and inspiration on how to create a paperless yard. One of these ideas was to make a pipe workshop completely paperless to start with. This would result in a more manageable project and would lower the risks attached to the development and implementation of such a change of process.
After evaluation and research the conclusion was that within the piping department the process of manufacturing, fitting and adjusting measure spools was a returning problem in terms of precision and efficiency. As such this specific part of the piping workshop had been chosen as the focus of the project. Implementing digital technologies, such as AR, for measurements in the pipe fitting process could provide highly accurate measurements and can be relayed to the people making pipes via apps on mobile devices. Making the process digital will also partially eliminate changes of human error. At the same time the communication will be faster and environmentally conscious (Damen Shipyards Group, 2018).
From here on the project has been managed by several people within DSGo and a prototype solution has been created. A team has been set up to manage this project and plans were made for the development of such a tool.

Together with TWNKLS, a full-service AR agency, Damen has developed a so called Minimal Viable Product (MVP) solution. This MVP works to meet the minimal requirements set by Damen for the solution. It consists of more than just a prove of concept and does allow for functional user testing. Damen needed a partner in this project as Damen does not have sufficient in house knowledge on creating augmented reality applications or 3D metrology technologies. TWNKLS had already developed an augmented reality measuring application for a stair lift company which showed some similarities in functionality with the wishes of Damen for their tool. Primarily based on this reason Damen chose TWNKLS as their partner in this project.

To tackle the problem presented by Damen TWNKLS has created an AR scanning application, based on their own technology. Using the software a measure spool design can be adjusted to fit the actual measurements. This adjusted measure spool design can be sent directly to the pipe manufacturers and in theory the correct fitting measure pipe can be manufactured first time right. This current solution can handle a small part (approximately 3%) of all the types of measure spool and pipe types used in the ships built by Damen. The application needs an XML file generated by the engineering department containing the initial measure spool design as input for the scanning.

Requirements
Together with different experts on piping engineering and production processes, namely being the head of engineering of the workboats division and a piping engineer, a set of requirements for the application and the measure spool designs have been put together. The current solution was developed with the following requirements:

Initial requirements for the MVP:

- Flange diameter range DN25-DN250
- Should work with steel or stainless steel
- Should work in panel- section- and hull building phase

- +-1mm and 1 degree accuracy
- Should work using predrilled flanges with baskets
- Function in anything between day light and no light (inside tanks)
- App needs to collect shape and dimensions of the pipe and the rotation of the flange and the bolt holes
- Output file should be PDF, xml or TeZet
- Maximum sparse processing time target is 5 minutes, as long as the next job can be started and processing will be done in the background. Otherwise this is too long

Initial requirements measure pipe XML blueprints

- Flange connected pipes only
- Pipe flange range DN50-DN125
- Supported pipe shapes
    - Straight
    - One 90-degree bend
    - Two 90-degree bends
    - S-shapes pipes, two bends with specific angle
- Situations where initial xml design needs to be changed to another design are out of scope (e.g. straight pipe to s-shaped pipe)
- Working volume of measure pipe is 1x1x1m cube with a maximum pipe length of 1,8 meter
- Each flange is assumed to be mounted on a 90 degree angle to the pipe, certain deviations are assumed to be absorbed by the gasket

User acceptance test

Back in December 2018 Damen and TWNKLS conducted a user acceptance test (UAT) at the Damen Galati shipyard in Romania. In this test the MVP would be conducted to a test in the real production environment together with some shipyard employees. The scope of the test was primarily focused on the technical requirements and functionality of the MVP. A complete summary of the test and the findings can be found in the document in appendix A.8. The test was conducted on a Damen Road Ferry 8117 that was under construction at the Galati yard at the time. This vessel is was an 81 meter long car ferry, a big vessel.

In summary the MVP was able to measure accurately when there was a situation with sufficient access and illumination. The pipe spool could be measured with sufficient precision and could be fitted with loose flanges. An actual definition of how accurate the measuring was is lacking. What did became apparent was that the ship building site presented challenging conditions at the pipe fitting locations. There often is limited space available around the pipe fitting locations to take sufficient pictures from different angles. Obstacles and other components of the ship were often obstructing the view to the markers.

Also there were limited measure spool cases available on the vessel that were suitable for testing. Primarily this was due to different technical specifications that were out of scope for the current MVP (such as shapes of the pipe spool). Also several pipes were larger than the 1x1x1 meter working volume that the application can handle at the moment.

The markers on their own were also not working as intended. They only fit a small selection of flanges and when the flanges were galvanized they did not fit at all. Also they were too big to fit in some tight spaces and some of the measure pipes were so short that there was no room for the start and end marker in between. Other than that the mounting of the markers to the flanges proved to be difficult, especially when working in tight spaces.

A useful feature that was lacking at the tests was that the tool does not scan and recognizes obstacles within the working volume. As there are often additional structures or objects in the vessel that differ (slightly) from the design it will be useful to correct the pipe routing based on scanned obstacles.

At the test the pipe workshop personnel were skeptical about the new tool. They say they can measure just as fast by hand and have a very low failure rate using their current way of working. As they have a full production schedule they prefer to be working with a stable application which does not involve experimentation. Again there are no reliable numbers available for the current failure rate or exact time spent on measure spool production.

Points of improvement and interest UAT

- Marker improvement
    - Research flange sizes and make marker fit these flanges
    - Define maximum marker size to make it fit in the vessels
    - Define minimum marker size to make sure the application still works
- Research measure pipe dimensions to define the minimal working volume the tool needs
- Research technical specification scope of the measure pipes
- Find information on failure rate of the current pipe fitting process
- Research how long it takes to produce a measure pipe with the current process.
- Research the skepticism of the workshop personnel and how they can be persuaded in accepting and adopting a new way of working

2.4.2

MVP Pipe Fitting tool

The current MVP pipe fitting tool is based on a Windows tablet with a camera with a 4K resolution and two physical augmented reality (AR) markers. These makers are supposed to be mounted to the flanges where the actual measure spool will need to be fitted. An application on the tablet is able to take pictures of the situation. Based on the AR markers in the picture a separate application on a more powerful computer can do 3 dimensional calculations to calculate the distance between the two makers. In the end the measure spool design can be adjusted to the correct measurements inside this application.

The current MVP pipe measuring process is as follows;

Step one
The first step is to install the start and end markers on the flanges which need to be connected to each other with a measure spool. As of now the markers are 3d printed parts that do not have a rugged design but they are sufficient for using in a test setup. They have to be secured tightly to the flange to assure the marker is centered to correctly. The marker itself needs to be placed perpendicular to the flange. The marker may be rotated on the flange to position as such that it is visible to the camera.

Step two
The next step is to take pictures with the tablet. A new project has to be created or opened on the tablet. When creating a new project the user will have to select or import the correct XML file containing the engineering and design data of the to be fitted measure spool. Once set up the application askes the user to take at least six images of the situation. For more complex situations more pictures may be required. The six images should be taken from different angles to provide the application with enough information for the processing. A few guidelines are set up to make sure the pictures are captured correctly:

- Both markers have to be visible in each image.
- Take photos from a distance 1-2m such that the visual black & white markers are not too big or too small in the images (see Figure 3 (bottom right)).
- The markers should not be very close to image borders. (Note that live camera view during capturing is bit cropped compared to the stored images used for further processing.)
- Avoid very slanted views of either marker (see Figure 3 (bottom left)).
- There should not be specular highlights on visual markers which make the pattern less recognizable.
- Keep your hands steady during capturing to avoid blurry images.

When sufficient images are captured and reviewed by the user the tablet will do a low quality, sparse point cloud processing. When the processing is finished the user can review the images again to check if the application recognized the markers correctly in each image. When everything looks right the project can be saved for the next step.

Step three
Now the data from the tablet application needs to be exported to a USB-stick so it can be imported on another computer for final processing. On the computer the files need to be put in the correct project folders so the software can find the project. Once the program is started the right project can be selected from the interface. The program will then start a high detail, dense point cloud processing cycle. When this process is finished it shows the images again for the user to make a visual check. When all is correct a 3d representation of the connecting flanges and the measure spool design based on the imported XML file. In this interface the user can make adjustments to the measure pipe. Red and green coloured flanges tell the user if the measure pipe dimensions are within the set error thresholds. If the flanges are coloured red the user needs to make additional adjustments to the settings.
Once the measure pipe is configured correctly the data can be exported to an XML file again which can be used by engineering departments of the yards to create technical drawings for the piping workshop. The workshop will use these drawings to manufacture or adjust the measure spool.

Initial shortcomings of the solution
As the application is in its MVP stage there obviously are many shortcomings and problems that need to be addressed before it becomes a solution that can be implemented as a large scale trial. In the process of this graduation assignment these specific shortcomings and improvement points will be analyzed in-depth. As for now the initial shortcomings which were found by using the application ourselves within the testing environment are listed below.

- Unwieldy marker installation process
- No “Go back” button or feature on the application
- Unclear what the types of project mean when you don’t know how the application is designed

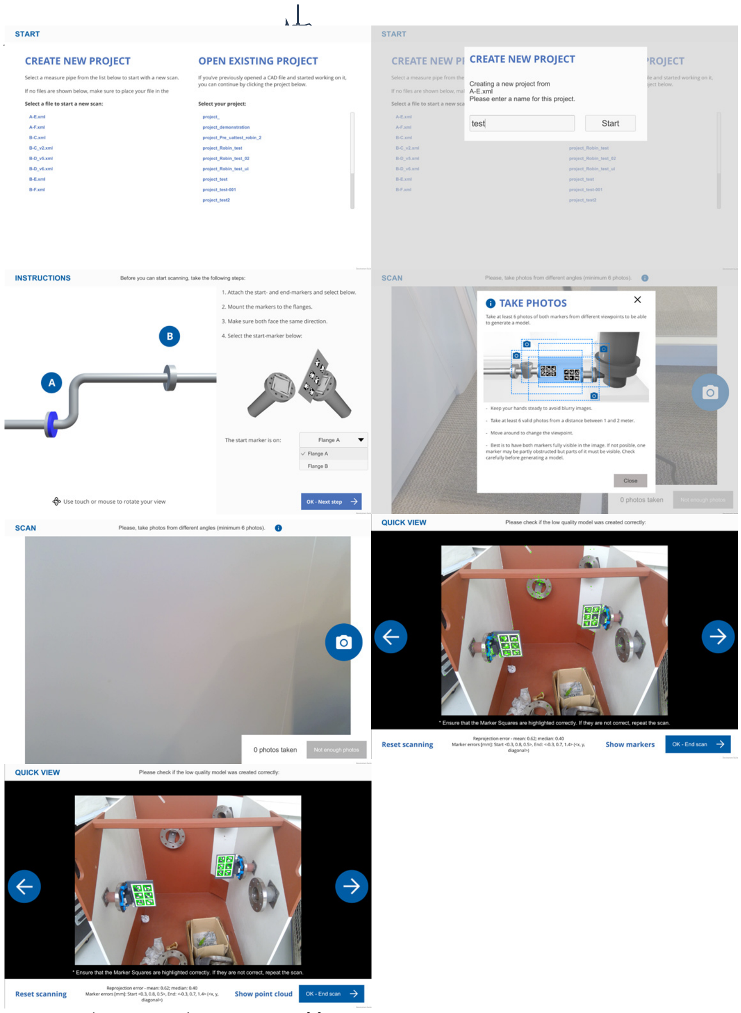

Figure 3, MVP pipe measuring process Tablet

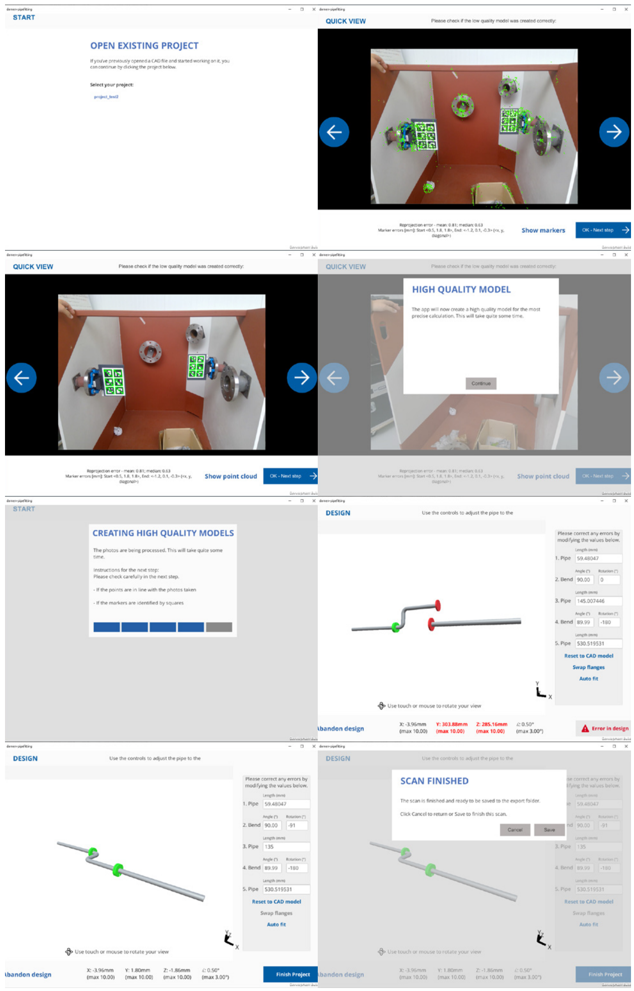

Figure 4, MVP processing on PC

- Low quality image processing on tablet is slow
- Solution works best in well-lit environment, in lower light situations the scans tend to fail more often
- High quality image processing also seems slow

2.4.3

Business case

At the initial start of the project a business case has been made to support this project. This business case presented two scenario's. The first scenario was based an improved first time right production percentage. The second one was based on faster production and fitting times using a measuring tool.

First Time right scenario
At the Damen Galati Shipyard (DSGa) in Romania 12.000 measure pipe spools have been fabricated in 2015. Approximately 70% of these were First time right, 30% is Second time right. Over a year this means that around 50.000 man hours are spent manufacturing, measuring, fitting and adjusting measure pipe spools at Galati. When 100 percent of the measure spools can be fabricated First time right approximately 8.000 man hours can be saved on the pipe fitting process. Calculated with the average payment of yard workers at the Galati yard this results in a saving of 130.000 euro over a period of one year for just the Galati yard. The detailed calculation can be found in appendix A.1.

Faster Production times scenario
This calculation is primarily based on a demo of the Metronor measuring system that has been done at the Damen Shiprepair Amsterdam yard. This demo will be evaluated in more detail later in this report.
The calculation that was done uses estimation of time savings based on the results of the demo. The tool would on average save 53 minutes of adjusting the pipes for each measure spool produced. This would result in a total savings of 266.000 euro per year for the Galati and Song Cam yards combined.

Reliability of the business case
The numbers in this business case do not provide enough substantiation to use as input to make decisions for this project. The main reason for this is that the numbers the business case is based on are not representative of the yards in Romania and Vietnam or they are not realistic. The first time right scenario is based on a change that will make everything manufactured first time right. This can be a good target to aim for but will in reality not be a realistic scenario. The faster production times scenario is

based on numbers from a demo on a Dutch repair yard. The numbers of this demo have been extrapolated to the piping production numbers of the Galati and Song Cam yards. These yards are both new built yards with completely different workflows than a Dutch repair yard. So extrapolating the numbers directly to the production numbers of those yards will not represent a realistic business case.
This business case could be a nice addition to a pitch or presentation in the beginning stages of the project but to make the right choices in the future a more extensive, realistic and reliable business case will have to be formed.

2.4.4 Lighthouse Festival user test

At Damen Shipyards headquarters in Gorinchem the Damen Maritime Festival is organized annually. This is an event for the (potential) clients, partners and suppliers of Damen consisting of exhibitions and demonstrations of Damen vessels and activities. A new addition to the Maritime Festival this year was the Lighthouse Festival. This was an exhibition of the current R&D developments at Damen. As the Pipe Fitting tool is also a R&D type of project to improve the efficiency of the shipyards this project also got a spot on this festival.
This gave an opportunity to conduct some quick user tests with people from different parts of the shipbuilding industry. There users who were willing to try the tool were asked to use the tool without any explanation of how the application worked. The users were only told what the tool does. During the test empirical data was collected and once finished a short discussion was held talking about how the users experienced the tool. In this test the focus was mainly on the image capturing process as the processing of the images would take too much time to test on the festival. Also the process of attaching the markers to the flanges had not been tested with participants but only explained.
The notes of the Lighthouse Festival can be found in appendix A.10.

General Findings
In general the idea of the tool is received positively. Many people recognize the difficulties of measuring and making good fitting measure pipes. So the need for such a tool is clearly existing.
One of the most common findings of the user test was that almost half of participants did not understand that both markers have to be in each image that is taken. If one of the markers is not in the image the image cannot be used for processing. Although this requirement is mentioned in the application people tend to not read or see this part of the explanation.
Also about one in four people would stand too close to the markers when taking pictures, and almost every participant would not move closer or further away from the setup when taking the different images. For the precision of the calculation a variety of angles and distances from the markers are required. This is a key part of information that is not yet clearly implemented in the application.
Also users stated that they were missing feedback on what was happening and what the application was doing. One user who had a more extensive walkthrough trough the while system also stated that he was missing a back button within the app.

Test setup
Several of the participants were people with either pipe fitting experience or ship engineering experience. These participants all stated that the flanges in the test setup were placed incorrectly. The way the bolt holes are positioned compared to the orientation of the flange were wrong. What the exact requirements are for the positioning of a flange will have to be researched by talking to people within Damen who have experience with this. This feedback also raised the question if the tool takes the orientation of the flange and the bolt holes in to account when scanning the markers. The tool should take this into account because this is important information for the piping workshop to create the correct pipe.

Questions and suggestions of participants
The most common question of the participants was if the tool has some sort of collision detection to make sure that other components or pipes on the ship are not in the way of the generated pipe. At the moment this is a feature that has not been developed or implemented in the tool. Participants suggested to create an connection with the Cadmatic (The CAD system Damen uses to design hulls and ships) system to use the available cad data in there to allow for collision detection.
One of the participants also asked if there was a possibility to take photos for different measure pipes and do a batch calculation instead of waiting for the process to finish before the next measure pipe location can be photographed.
An suggestion by two of the participants was to create a naming or numbering sequence based on the pipe naming used in the engineering and production departments. This would allow for more clarity on what pipes go where.
Despite not testing the marker placement process with the participants it was clear to them that it was

a time consuming and fiddly process. This resulted in several suggestions on how they would have designed the marker holder. The suggestions have been written down and will be used in the marker redesign process.

Errors and issues encountered
During the testing several issues were encountered with the tablet application. The first issue was several app crashes over the course of the day. This is an important issue that has to be figured out by the developer of the software but as the tool is a MVP solution at the moment it is not an important issue for the functionality and testing of the tool. A more important issue found was that the application recognized a poster in the background of the test setup as a marker instead of recognizing the actual marker. This also triggered questions about how well this solution will work in environments with difficultly lighted or dark locations.

Conclusion
In conclusion this small scale quick testing sessions gave some valuable insight in the shortcomings and points of improvement of the pipe fitting tool. It gave both new insights and also confirmed theories and the need for improvements that were already thought of by the Yard Support department.

Chapter 2.5

SWOT ANALYSIS

To help assess the potential for a pipe fitting tool for Damen Shipyards a SWOT analysis was performed. This analysis will help to visualize the important potential benefits but also the risks to take into account.

Strengths
When a pipe fitting tool is developed and implemented successfully this could provide significant time savings in the production process. Ultimately this will reduce cost per vessel for Damen and increase the capacity of the current pipe workshops.
A pipe fitting tool can also provide the pipe fitters with more accurate measurements and thus better fitting piping systems. This can improve the overall reliability of piping systems and prevent early repair jobs of components that do not fit perfectly.
A properly functioning tool can also provide the yards with more efficient options for production planning. In some cases the measure pipes can only be fitted and measured once the vessel is fitted with the propulsion system and when the vessel is launched. When the measuring can be done in an earlier stage of the build and the production of the pipes can be started the pipes only have to be fitted once the ship is launched allowing the vessel to continue to the next phase of building faster.
The tool can also potentially improve the ergonomics of the job the pipe fitters have to do by not having to measure by hand in difficult positions.

Weaknesses
Technological limitations are possibly the biggest weakness of the tool. Fast and precise measurement of piping systems is almost completely depending on using the correct technologies and the availability of those technologies.
The possibilities for integration with systems such as CAD software used by the Damen engineers will also be a potential pitfall for the successful implementation of such a tool.
A weakness somewhat related to the technological limitations is that the tool will have to function within the working environment of a shipyard and the insides of a vessel under construction or a fully outfitted ship that needs a repair. This means that a technology has to be found or developed that works well in areas with limited illumination and limited space.

Opportunities
An opportunity for Damen next to cost and time savings can be that they can provide the tool as a service to other companies or shipyards when they have a unique and well-functioning solution. This can provide a whole new source of revenue for the company.
The development and implementation of such an application can also provide Damen with valuable experience on how to incorporate new and relatively novel technologies in a traditional production process such as shipbuilding.
When a successful solution is developed the same platform could potentially be used and developed further to suit other improvement and digitalization projects within Damen.

Threats
Potentially the biggest threat to the project is failing

to get user acceptance for the proposed solution meaning that costly investments are going to waste.
Another threat is that the tool will not work in all cases of pipe fitting. This will result in the pipe fitters needing to resort to the old way of working. The problem with this is that the knowledge of the old methods will slowly get lost especially with newly trained employees, and these employees not being able to solve the problem without the proper knowledge.
Another result of a tool that is not functioning in all cases will be that the tool can become disused because workers are not motivated to use a tool that is not always working properly.
Competing companies or shipyards can also pose a threat when they have been able to develop a more effective solution.

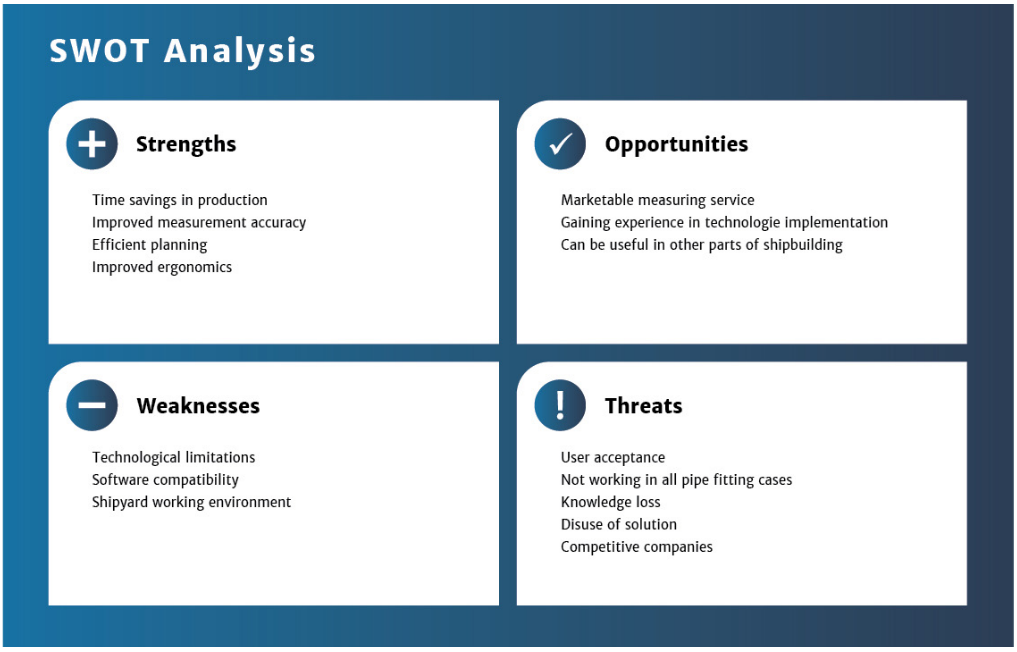

Figure 5, SWOT analysis

Chapter 2.6

CONTEXT ANALYSIS

A very important aspect of the successful implementation of a pipe fitting tool will be that the solution will function correctly in a shipyard environment.
A shipyard can be a loud, messy and dangerous environment to work in. There are strict safety guidelines to ensure a safe workspace. Safety shoes and helmets are mandatory and depending on the type of work being done on a ship safety goggles can also be mandatory.
The insides of the ships are, depending on the type of ship, usually very tight spaces. When walking through the ship you often need to stoop to avoid hitting your head and the stairs are very steep. Especially in the machine rooms all the space is used as efficiently as possible. This means that there will be pipes, engines, pumps etcetera everywhere. The images in figure 7 show a machine room in a Multi Cat 2613. Even without the engines in place it looks crowded. There are low ceilings and there are piping systems on the floor which you need to walk over or around. As shown in figure 6, when everything is installed, metal gratings are placed on top of the piping systems on the floor to allow easier access to the engines, control panels and valves in the machine rooms.
The examples in both these figures show one of the more ‘spacious’ machine rooms. When looking at

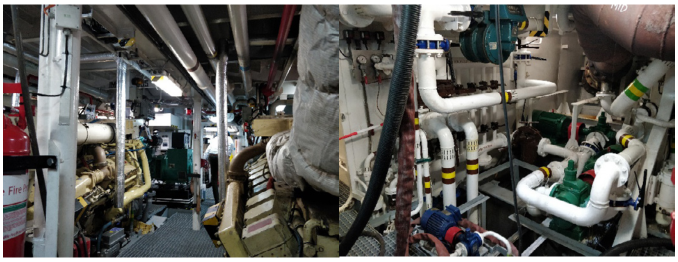

Figure 6, Machine room of a ship in operation

Figure 7, Machine room of vessel in production

a ship like the Damen Stan Patrol vessels of 22 or 16 meters in length there often is no space at all to walk around when the engines are installed.
Apart from the limited space the insides of a ship are often dim spaces with limited illumination.
For the pipe fitting tool this means a measuring system should be really portable, work in tight spaces with limited range of mobility and be effective in dimly lit environments.

2.6.2
Paper in the environment

The process of measuring and fitting measure spools does not involve a lot of paperwork as mentioned before in this report. The actual manufacturing information on paper is used by the piping workshop and not relevant while installing the spool on the vessel. The only paper used on the vessel is documents with installation information such as the system and the location. And the other form of paper that is used is the so called ISO paper. In figure 8 an ISO paper is shown. Pipe fitters use this paper to draw and dimension the actual measured, correct dimensions of the measure spool. This drawing is then used to either manufacture a completely custom spool or, in most cases, to make adjustments to the measure spool.

2.6.3
Limitations

A technical limitation that will be present in some of the vessels is interference with digital signals. Within the working environment of a vessel being built any digital signals such as WiFi, mobile data and Bluetooth can be disturbed or blocked. This is due to the fact that most vessels are built from steel. Steels is an electronic conductor which means any electrical signals can be absorbed by this material blocking it from reaching the desired device. This limitation will have to be taking into account when looking into digitalizing information distribution via digital devices.

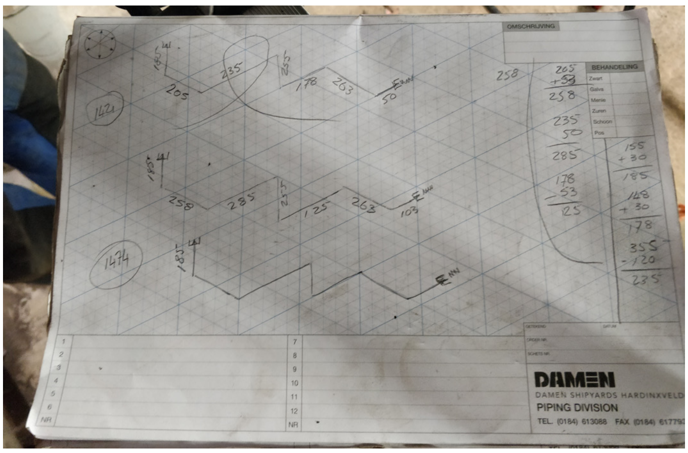

Figure 8, Iso drawing of pipe spool measurements

03

RESEARCH

In this third chapter different subjects will be researched starting with a literature research on change management and digital metrology. After this a market analysis will be presented and the current prototype is tested and evaluated. The stakeholders of the project are identified in this chapter and the current process of pipe fitting is researched and visualised. The aim of this chapter is to familiarize with the technological possibilities of the tool and the workflow of Damen. In the end the requirements for the pipe fitting tool are presented.

Chapter 3.1

LITERATURE

From the documentation and initial research conducted it became apparent that the result of the initial development phase was not completely as desired. On one hand there was is a prototype that has been tested and presented to some of the end users and stakeholder. The initial reactions of the end users were sceptical and they did not understand the need for this development. On the other hand there seemed to not have been a lot of research into the different possibilities for digital metrology technologies before choosing the current technology.

This makes it interesting to do some research into both these subjects. Change management can be helpful in gaining trust and support of the important stakeholders. In this subject we can also learn from previous experiences on implementation of new technologies to traditional industries. The reasons for failed implementations can help understand which are the right choices to make and what things to avoid in a development process.

For digital metrology it is interesting to see, apart from a market analysis, which technologies are being developed at the moment and what the outlook for these technologies are. Also how technologies such as AR and 3d metrology are being used and implemented in existing workflows and what the results of these developments are can be helpful in the decision making process later on. This can be especially relevant for choices made for the long term as they can help with defining which requirements there are for these new technologies to function properly in the existing workflows.

3.1.1 Change management

A concern about the implementation and development that rose straight at the beginning of the project was skepticism by the workshop personnel about the adoption of a new way of working. In the documentation of the field testing conducted back in 2018 (see appendix A.8) this was also mentioned briefly. The workshop personnel were skeptical about the proposed solution. They said they would be able to manufacture measure pipes at the same speed using the conventional way compared to the new concept. In literature the issue of implementing innovations on the factory floor is also mentioned. Klein and Sorra (1996) even state that the implementation of innovations usually do not fail due to the innovation being ineffective, but rather the implementation itself that is unsuccessful. The decision for implementing innovation is usually made by senior management. The failure of this implementation occurs when employees do not use the solution frequently or consistently. The result is that, despite the decision for implementation, the benefits of implementation are not realized (Klein & Sorra, 1996).

Middle managers can be used as the facilitator or communicator of knowledge between the employees on the factory floor and the senior management (Riege & Zulpo, 2007). This can be a vital tool for senior management in making correct innovation decisions that can be implemented in a correct manner. Riege and Zulpo (2007) also explain that the knowledge that factory worker is inherently different from the knowledge other employees such as management, engineers or technicians have. The factory workers are no ‘knowledge workers’ but they have knowledge in physical processes as their work is often physical and based on following processes to complete a stage in production. Often their knowledge is discovered by trial and error, process familiarity and experience in industry (Riege & Zulpo, 2007). How these workers gather their knowledge explains how it is almost impossible for management to understand what is going on at the factory floor exactly. The knowledge is experience based and not learned by theory and it can also be very company specific knowledge. The knowledge is often difficult to be rationalized (Yokoyama, H., & Takeuchi, K., 2013). The transfer of this knowledge can be difficult due to language differences, social differences, practical experience and network position that differs between the different communities of people (Bechky, 2003).

The previous work done on this project shows some relation to the statement made by Klein and Sorra (1996) that the decision for change has been made by senior management. For successful implementation and development it will be vital do identify and incorporate the people wo will directly or indirectly involved in the change of implementing a pipe fitting tool. The people who ultimately will have to use the tool to complete their jobs might be the most important as they could choose to either use it or not. They can also be a great source of input and feedback in this project.

To successfully incorporate those people and make them accept and be part of the change a proven change methodology can be used. Within Damen many projects have been done by following the ADKAR model of change. The ADKAR model presents five building blocks to follow to successfully make change.

These five steps are "Awareness of the need for change, Desire to participate and support the change, Knowledge of how to change, Ability to implement required skills and behaviour and Reinforcement to support the change" (Hiatt, 2006). Mainly the first two building blocks will be important to complete as previous tests of the pipe fitting tool proved that many manufacturing personnel at the yards did not see the need or benefits of implementing new technologies in their workplace.

3.1.2 Digital Metrology

The shipbuilding market, and the manufacturing industry in general, is a highly competitive market. The low volume, highly customized market that Damen is operating in make the production process complex. Even more the globalized production of Damen requires real time information about everything involving design, planning assembly and so on. To remain on top of the business al these factors need to be closely monitored and it is vital to manufacture at low cost and with reduced time-to-market (Nee et al., 2012).

From this need to produce at low cost and low time-to-market time Damen's project Morpheus was created. As stated before the Paperless yard project and the pipe fitting tool were projects started from the Morpheus project.

AR technology has initially been chosen for the solution for the pipe fitting tool. In fields such as gaming, learning, entertainment, sports and even military and medical AR technologies have been widely implemented (Ong & Nee, 2013). Within design and manufacturing AR has found a good number of applications, but it has a lesser presence due to the tough requirements with regard to high accuracy, fast response and the need to align with industry standard (Ong & Nee, 2013). Hung, Alem and Livingstone (2012) and Nee et al. (2012) explain that the lack of research into human factors of AR applications are another reason for the slow implementation and development of these applications in manufacturing. A difficulty for users can be the lack of transparency of the underlying systems of new technologies. Also different systems in the same production environments can cause misunderstandings and difficulties (Schwenke et al., 2002).

AR technology can improve efficiency as it can control required data and make it visible when needed. This can prevent communication errors due to inefficient information management (Moon et al., 2015). When 2d drawings need to be translated to 3d production of pipes these miscommunications can happen easily. So for AR to function correctly and efficiently it requires 3D data as input. And for novel innovations and technologies to function effectively within manufacturing environments precise measurement systems will have to be integrated within the production process. This will in turn help with more efficient use of resources such as time and materials (Durakbasa et al., 2016). Metrology within a production environment also has to be quick, accurate, robust and as automated as possible. It should be integrated seamlessly within the production line (Schwenke et al., 2002). 3D measuring and especially 3D scanning is proving to be a promising technology in supporting redesign processes and production systems (Lindskog et al., 2016). Also for reverse engineering purposes 3D measurement data using 3D scanners proves to be a powerful tool. This is mainly due to it being more accurate and less time consuming compared to manual measuring (Kuş, 2009).

For 3D measuring and metrology there are mainly two different methods for acquiring coordinates of the shape of an object. These two methods are 1. mechanical using an arm with some sort of probe fixed to a table or 2. optical using technology such as laser scanners using light (Kuş, 2009). The point clouds that these technologies produce can, once processed, help verify measurement and make sure that designed components will fit (Lindskog et al., 2016). Overall optical methods seem to be the preferred technology as this provides more flexibility and a higher resolution compared to mechanical methods. This will proved a higher measurement accuracy (Kus, 2009). The trend is also that optical components are constantly being miniaturized in their development. This is beneficial to the applicability of the components in production and it will limit the cost of the components (Schwenke et al., 2002).

Application of these kinds of components in existing production lines does however often prove to be a difficult process. This can be caused by the fact that companies often work with different systems in parallel when implementing new technologies (Lindskog et al., 2016) but it can also fail due to component failure. Technical metrology components can be sensitive to contamination, temperature and vibrations (Schwenke et al., 2002).

So for successful implementation and efficient use of these new technologies it is vital for companies to create a structured way of working with these technologies. It will also be important to choose the right technology and make sure it will be able to cope with the environmental conditions of an active shipyard. To gain an overview of possible technologies and proven examples of successful implementations an extensive market analysis will be needed.

Chapter 3.2

MARKET ANALYSIS

This market analysis is conducted to get an overview of applications of digital (3d) measuring techniques, augmented or virtual reality applications and point cloud technologies in industry. Also (3d) scanning and measuring technologies will be explored. The aim of this analysis is to get insight in what technologies are available for implementing 3d measuring and AR technologies. For the project it will be important to compare the technologies based on accuracy versus speed or efficiency. Transportability and size of the technology will also play an important role as it will be vital for Damen to have a tool that can be moved around easily in tight and crowded spaces on a vessel in production. Also the analysis will be used to trigger creativity and inspiration for solutions.

Figure 9, Faro Laser Scanner (Faro, n.d.)


Figure 10, Leica Laser Scanner (Leica Geosystems, n.d.)

Figure 11, Creaform Handiscan (Creaform 3D, 2019)

3.2.1

Scanners

A wide array of different (3D) scanners are available on the market. A lot of different methods, technologies and techniques are available in wide price and accuracy ranges for both the consumer- and professional market.

Laser Scanning

The basic principle of (3d) laser scanners is that they utilize laser beams to measure distance. A laser emitter shoots out a laser beam which will reflect back when it hits a surface. This reflected beam will be received by a sensor on the laser scanner and based on the travel time of the beam a distance can be determined (Wehr & Lohr, 1999).

Maybe the best known brand of 3D scanners is Faro (see figure 9). This company produces high quality laser scanners primarily for the professional market. These devices can have an accuracy of 1mm over a range of 0,6 to 350 meters. Within Damen a small team is already utilising a Faro scanner for various projects like quality controls or reverse engineering. The biggest downside of this device and technology is that it requires expert knowledge to create a high quality scan and the scanning process is relatively time consuming. Also a lot of time is needed for post processing raw data before it is usable. The device is also not handheld. This technology does however not need illumination to function. Companies like Leica manufacture a more consumer aimed version of scanner using the same laser scanning technology. This Leica scanner (see figure 10) has a more limited high accuracy scanning range of 1,5 to 3 meters but does complete a scan in three minutes.

Handheld Laserscanning solutions are also available in the form of the Creaform Handyscan (see figure 11). This is again a professional grade scanner. This scanner is able to do direct scanning to mesh visualization giving the user feedback on what has been scanned and what not. Also more and more affordable handheld consumer 3d scanners are hitting the market which could provide a cheap alternative if the specifications are withing the desired requirements.

Structured Light Scanning

Structured light scanning is another technology capable of making accurate 3d scans of objects. This technology is based on projecting specific patterns on objects. Based on the deformation of these patterns on the surface of the object being scanned a translation to a 3d representation can be made (Pavlidis et al., 2007). An example of a product utilizing this technology is the Artex Eva (see figure 13). This handheld scanner weighs only 0,9kg and can scan objects as small as 10 cm with an accuracy of 0,1mm. It can function using a battery pack and a laptop making it a very mobile solution. Prices range from €6.700 for the basic version to €13.700 for the scanner with the best specifications.

Figure 13, Artec Eva Structured Light Scanner (Artec 3D, 2020)

Coordinate measuring machines (CMMs)
Another technology is a Coordinate Measuring Machine (CMM). A CMM is a fixed robot-like arm with a probe at the end. The user touches the to be measured part with the probe and based on the position of the arm a point cloud is created.
Metronor produces portable CMM systems for several different industries. One of their core industries is piping systems. They offer the Metronor SOLO system which is a completely portable CMM system using a camera and a hand held probe. The system can measure distance between flanges and it can measure the flange size. For shipyard industries they have the Metronor SOLO Twin available. This system uses two cameras instead of one which effectively doubles the field of view making it suitable for confined spaces. The system works seamlessly with TeZetCAD software

Figure 12, Metronor Solo Twin (Metronor, n.d.)

to create pipe designs in an instant based on the measurements made with the Metronor system.
There has been a demo of this system at Damen Ship repair in Amsterdam.

Optical Coordinate Measuring System
Another CMM variant exists is the Optical Coordinate Measuring System. This This technology exists in both fixed and handheld mobile variants. The technology uses light to measure the part. An optical sensor measures reflected light and coverts it to a intensity value. In a fixed machine a direct backlight may be used to define the silhouette of the scanned part. An example of a handheld version is the Maxshot 3D scanner. This tool is again primarily used for production measurement controlling and not for reverse engineering. This tool does have a very high accuracy of up to 0,015mm. It is made for lager components of 2 to 10 meters in length.

Industrial CT scanning
CT scanning, Computed Tomography, is a scanning method based on radiographic technology. The technology is ideal for locating and measuring volumetric detail in 3D. It can scan internal structures and features of any part of component that fits inside the scanner (Jesse Garant Metrology Center, n.d). The size and the fact that this technology is not mobile is one of the biggest downsides of the technology. As the technology is relevant and interesting for industry research into mobile CT scanning is being conducted (Sauerwein, C., & Simon, M., 2003). The technology is however not meant for reverse engineering but rather for evaluation and inspection of components and structures.

Time Of Flight Camera
A very novel technology being developed by Lucid Vision Labs is a depth of field cameras using time of flight sensors. The technology combines a camera with a time of flight sensor to create a tool that can photograph and film and define the depth of field of the imagery at the same time. A time of flight sensor uses infrared light pulses. The return time of the reflected infrared pulses used to define the depth and distances in the imagery.
This technology has not yet been implemented but a somewhat similar system as the time of flight camera currently is available as an accessories for tablets. This accessory adds depth perception to the camera systems. These additions are still in a rapid

development phase and new improved versions are developed continuously. For the Pipe Fitting Tool these depth cameras could be an interesting possibility as they can be incorporated with the current tablet scanning solution.

The best options currently are, according to TWNKLS, are the Intel Realsense or the Structure Sensor mkII depth cameras. The cameras are relatively similar other than that the Intel camera has a field of view of 85 degrees with a range of 0.11 to 10 meters, the Structure Sensor has a larger field of view of 160 degrees but a lower range of 0.3 to 5 meters. These depth cameras can add precise 3d measurement data to the existing tablet application and eventually they might even make the use of AR markers obsolete. An example of the functionality of the Intel Realsense sensor can be found in the Panasonic Toughbook. This tablet uses the camera to do accurate 3D measurements. The solution has been developed for warehouse optimization, facility maintenance, wound monitoring in healthcare and taking photos at police crime scenes. It could also be used for documentation of insurance claims such as car crashes. It has a stated range of 16cm to 10 meters (Panasonic, n.d.). The exact accuracy of the measurements is not stated.

Figure 14, Lucid TOF (Top left), Panasonic Toughbook (Top right), Intel Realsense (Bottom left) and Structure Sensor (Bottom right)

3.2.2

3D scanning and AR Applications in industry

Thyssenkrupp

Thyssenkrupp is one of the largest technology companies in the world. Their Elevator Technology company produces elevators and escalators as well as stair lifts. These stair lifts are built completely custom to the specifications of the customers stair at home. In the past these stairs were measured using difficult capturing techniques with several camera's and markers. Using the Microsoft HoloLens this process has been optimized. Using an augmented reality interface on the HoloLens the user can measure the stair using a handheld marker devices which is connected to the HoloLens. This marker creates a point cloud of every step of the stair and enables Thyssenkrupp to visualize the stairs and the custom lift system directly at the house of the customer, both on the HoloLens using augmented reality or on a tablet.

Figure 15, Thyssenkrup Hololens Solution (Windows Blogs, 2017)

Reflect one

At Land Rover there was a need for a training application for car repairs. Hands on training by taking cars apart is way more effective than learning from wiring diagrams and drawings, but this is not a cost effective way of teaching. Using the Bosch Cap AR platform a tablet application was created. This application represents an x-ray like interface showing the user what components and wiring is behind each panel of the vehicle. Apart from showing the exact location of the components the application can also individually select components to show them from different angles. The original connections, drawings and wiring diagrams are also visible in the application.

Figure 16, Reflect One Land Rover Tool (Re-flect, 2019)

Caterpillar AR Maintenance

At Caterpillar service engineers are working on a wide range of machines and engines. Usually the engineer will get to the site, take a look at the machine and then get on a computer to figure out how to repair the machine before returning to do the fix. By using AR Caterpillar created a tablet application that gives a virtual step by step tutorial on how to fix the issue on site. The application can also be used on phones and even digital glasses enabling a hands free use of the application. The application also seconds as an extra quality check by scanning pictures of each step in the repair to check if everything is correct.

3.2.3

Piping measuring technologies in industry

Nikon/Hitachi Engineering and Services (Laser Pipe Spool Control)

Nikon Metrology and Hitachi Engineering and services have developed a system to accurately measure industrial piping systems. This system is mainly created to evaluate the dimensional correctness of pipes produced. Using Nikon laser scanning technologies significant time savings are achieved by digitally measuring the produced pipes instead of measuring them by hand. This is a fixed system meant for design checking applications.

Naval DME

Naval DME provides different 3d scanning services primarily for the maritime sector. The most interesting service with regards to the Damen pipe fitting tool is the pipe spool replacement service. Using Leica laser scanners Naval DME scans existing piping systems in ships to create accurate point clouds and 3d data. Using 3d software the pipes in need of replacement are modelled and produced with the correct dimensions ensuring a perfect fit.

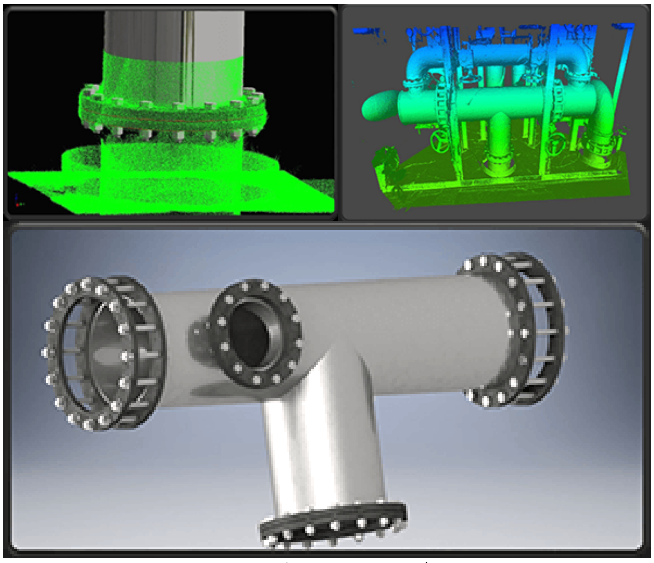

Figure 17, Naval DME Scan results (Naval DME, n.d.)

3.2.4

Conclusion

Summarizing a large amount of different technologies and approaches are available in the world of 3d measuring, scanning and AR solutions. Although many of those technologies sound very promising and interface with the goals of the pipe fitting tool none of them really stands out as the correct technology to choose. Many existing tools are based on reverse engineering and quality controls where for the pipe fitting tool there is a need for a system that gives almost instant measurements between two flanges. Some tools and applications already are made for piping systems such as the Metronor solution. This solution has already been tested by Damen and has proven to be unsuitable for working in confined spaces.

Before a good choice of technology and application can be made it has to become clear for Damen what their own future vision is regarding digitalisation of the engineering process. A lot of technologies, and especially AR applications, rely on accurate 3d data to function and visualise in real time. So if that is something that Damen as a company wants to implement and develop some changes will have to be made to the way ships are engineered and developed in 3d. There will be a need for digital twins of the vessels which will need to incorporate a lot of small details.

Overall this market analysis presents the many possibilities available and some inspiration for how to incorporate such technologies in existing industries.

Chapter 3.3

MVP TESTING AND EVALUATION

This testing session was conducted on board of a Damen Multi Cat 2613 being worked on at the DSGo yard. The tests were conducted inside the engine room. All three engines were removed at the time of testing as well as some piping. This meant that there were some flanges available to mount the markers to. The Damen Multi Cat is a large workboat with a large machine room with relatively much space compared to other ships built by Damen.

Figure 18, Testing Location

The objective of this test was to better understand the technology and in what environment it is supposed to be used. By testing in a real environment issues with for example illumination can be discovered.

In total nine test scans have been done at with seven different setups. Where possible both markers were placed on a flange, but in some of the tests only one marker was attached to a flange and the other marker was placed on the ground to represent a flange location.
While setting up the markers it became apparent that the marker design is far from optimal at the moment. For the smaller flanges the connection system is too large, it does not fit galvanized or painted flanges and the marker sometimes is too large does not fit on the flange due to other components around the flange.

Of the nine scans made two failed at low quality processing on the tablet with the error ‘insufficient image quality’. The two failed scans occurred at the same test setup so possible causes for this error can be too much distance between the flanges, or insufficient illumination. However a later scan using a similar setup did process correctly so why the first two failed is difficult to pinpoint.
The other six scans also did process correctly on the tablet. The expectation was that more would fail due to poor illumination. It must be said that the lighting on this vessel was relatively good as the engines were taken out of the machine room and there were holes in the roof where the engines were lifted through allowing some more light in the machine room.
One thing that was difficult during the scans was taking pictures from at least six different angles with the tablet. Even in the empty and large engine room in the vessel there are obstructions like other components, pipes and walls that make it difficult for the user to take enough different photos. Also there is quite some distance needed between the markers and the tablet to make both markers fit in the field of view of the camera. This distance needs to be around two to three times the distance between the both markers.
A simple but potentially problematic issue that arose during testing was that the tablet went from a full battery to completely empty in seven scans.

Figure 19, Marker size compared to normal flange

All of the successful scans except for one processed correctly on the pc application to generate a high quality point cloud. One of the scans failed due to insufficient image quality although the tablet processing found the quality to be sufficient. Also one of the scans failed initially on the pc but after copying the files again and redoing

the scan it did succeed. The processing of the scans did take, on average, 20 to 30 minutes per scan with exceptions of up to 50 minutes.
For now the pipe design the scan generates is limited to the preset chosen at the beginning of the scan. It would be useful to have the option to change this afterwards to suit the flanges better.

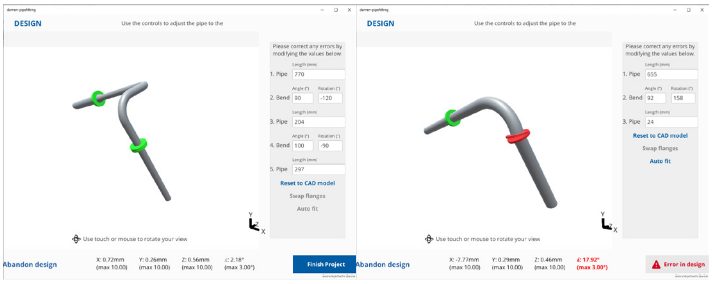

Figure 20, Correct (L) and incorrect (R) pipe design

The full notes and result of the test can be found in appendix A.4.

Summary of findings

- Battery of fully charged tablet is completely empty after just seven scans
- Yard workers doubt the solution due to the time and effort needed to position and photograph the markers
- The yard workers do see the potential of the tool
- The yard workers think the process should be fully automated before it will be effective and efficient
- Marker mounting is difficult and time consuming
- The app worked surprisingly well in the dimly lit engine room used in this test
- It is doubtful if the tool will work in a completely filled engine room due to the limited space available
- 20 to 30 minutes to process projects on a computer, some extremes of up to 50 minutes
- You are limited to the pipe design chosen before the scanning process which means that it is not possible to change the design afterwards to better fit the flanges
- Scanning does not take into account any obstructions or obstacles in the path of the pipe design as of now
- The software does not take into account the position and orientation of the bolt holes on the flange

3.3.2
Points of improvement and conclusions so far

Based on the existing documentation, previous work and the testing and using of the MVP a list of improvements and conclusions so far can be created. This list summarizes the things that need improvement and the things that need further research and testing to define the proper requirements for a successful and functional tool.

Conclusions so far

- The pipe fitting tool is not ready for testing and implementation in production
- The currently delivered solution is not an MVP and does not meet the initial requirements
- Pipe fabricators, pipe fitters and job preparation have not been included enough in the design process so far
- The current piping workflow for Damen Galatia and Damen Song Cam is unclear
- It is not clear how the current solution would fit in with the current pipe fabrication workflow
- The used technology for the tool seems to be outdated and has its limitations concerning accuracy
- There is no conclusion or documentation available on how well an assisting tool will help productivity in the pipe fitting and fabrication process
- The current tool functions well within the optimal test setup, accuracy is sufficient
- When developed a little further the current MVP could act as an “in between” solution to use for testing.
    - This test can determine if it will be worth it to continue develop such kind of technologies
- The business cases give a rough indication of the possible achievable savings but are both not complete or sufficient enough to base decisions on
- A less ‘high tech’ solution might work just as well as the current tool or even more high tech 3d scanning solutions
- The acceptable precision of normal measure spools has to be determined
- Maximum marker dimensions have to be determined
- Minimum marker size needed to achieve required accuracy has to be determined

- Average and maximum length of measure spools will have to be determined
- Chosen flange range will have to be validated
- The smallest pipe diameter used for measure spools has to be determined
- A future vision for the project has never been determined
    - The link to the 'paperless yard' project has been lost
    - Potential tool extensions to other activities in shipbuilding have not been considered up front
- Differences in piping processes in the worldwide Damen yards have to be determined to define if and how the solution can be implemented worldwide
- Current "failure" rate of the piping process has to be determined
- Current time spent on production, fitting and adjusting of measure spools has to be determined

Conclusion

The conclusions so far represent the result of the initial analysis. Quickly after starting the project it seemed that the MVP was not as good as it was presented. Although some point of improvement were mentioned the analysis showed that the MVP does not meet the original requirements set up for this project previously. The research and development process of the previous project owners proved to be not as well organised as thought and some miscommunications between different stakeholders in the project resulted in a tool that was thought to be good but actually needed a lot more improvement to get it up to standard with the term minimum viable product.

The goal of this analysis stage was to get an understanding of the project, the tool and the previous work done. By achieving this a starting point to continue can be made. The important steps to take next are to find out who exactly are all the stakeholders of this project and how they relate to the project. Also getting a better understanding of the piping process and exact workflows are necessary to find out how the implementation of this tool will impact the processes of the production.

Chapter 3.4

STAKEHOLDER ANALYSIS

While working on projects like creating a Pipe fitting tool stakeholder issues are an important factor.
R&D projects have an effect on the interests of different stakeholders in different ways. In order to manage these R&D projects better it is important to understand in what ways these interests are affected by the project (Elias et al., 2002). Within R&D conflicts can arise due to technical and social factors. So understanding the relation between the design process and design conflicts is important in getting consensus on the design (Lu et al., 2000).
Understanding how the pipe fitting process works and how it can be improved involves getting to grips with the human activity involved in the system (Lelea, 2014). At this stage it is important to distinguish the difference between an actor and a stakeholder.
An actor is commonly defined as a "person who performs a certain function within a system or process" (Lelea, 2014). Identifying the actor in a process is linked to the human activity in a system or process.
A stakeholder is commonly defined as "actors who have a stake or an interest in an issue" (Lelea, 2014). Identifying the stakeholder is linked to the problem or issue addressed within the project.

To find out what the influence, interests and relationships between all the actors and the pipe fitting tool is each actor needs to be analysed by addressing a set of questions that will give an insight in how they are related to the project and to each other. This will also give an insight into interests that may be clashing with each other. In the answers to the questions below should be clear.

- Are the stakeholders going to help or hinder the introduction of the pipefitting tool?
- Who are the partners and opponents in the project, and who don't even know the project exist?
- If people don't know about the project, should they?
- How are the stakeholders involved in the project currently? How much should they be involved?
- What is the interest, power and influence of the stakeholder on the project?
- When do the specific stakeholders get involved in the project?
- Who needs to be kept in the loop on changes of the project?

To help identify and analyse the stakeholders and actors it is useful to define an issue. The stakeholders and actors can be mapped and related to the specific issue to define their stake in the project. As the scope of this project is to develop a pipe fitting tool to improve the efficiency of the pipe fitting process the issue can be defined as: increasing efficiency in the pipe fitting and measure spool production process.

3.4.2

Pipe Fitting Tool Stakeholders/actors

Based on the company structure and the ship building process at Damen a lot of the potential stakeholders and actors can be identified. At this point in the project which of those people are or actively involved in the project is not known or clearly documented.
All the potential stakeholders have been identified by looking at the company structure of the Damen Shipyards Group. This structure and the stakeholders are shown in figure 21.
By going through the shipbuilding process and the company structure the groups of people who will be involved in either developing, implementing or using a pipe fitting tool could be identified. This process has been done several times over together with three different people to get the most complete overview possible. The stakeholders involved in the development of the pipe fitting tool are also marked in figure 21. The people not involved in the project are greyed out.

To explain what the function of each stakeholder or actor involves short descriptions of what they do have been created and listed below.

Operation Support Manager (stakeholder):
The manager of the Yard Support department is responsible for managing the people and projects of the Yard Support department.

Operation Support Project Manager (actor):
A project manager at the Yard Support Department is responsible managing and running improvement projects for the CNBD yards.

R&D Engineer (actor):
The Research and Development Engineer is responsible for developing and researching new technologies that can be of added value to either the

ship building process or the design and technologies of the ships being designed and built.

Yard Management/director (stakeholder):
Director of one of the Damen Shipyards. Responsible for running and managing the yard.

Manufacturing Engineer (stakeholder):
The Manufacturing Engineer is an engineer working at one of the Damen the shipyards. The Manufacturing Engineer is responsible for finalizing the ship design as created by the engineer at DSGo. The last details of the design are also figured out by this person.

Job Planner (stakeholder):
The Job Planner is responsible for planning the activities involved in building the ship at the yard and making sure enough people and the correct materials are available at the right time.

Production Manager (stakeholder):
The production manager is working on behalf of DSGo at the yards to oversee and manage the production of the ships of the specific business unit the manager is working in. The production manager can also work closely with the Yard support department to give feedback on improvement projects and overall performance.

Foreman
The foreman is responsible for a few different teams of yard workers. These workers can include pipe fitters, welders, steel worker and so on. The foreman is responsible for the work that is being done at the yard. The teams answer to the foreman and the foreman distributes tasks and decides who and what is needed when and where based on the production planning.

Pipe Fitter (actor):
The Pipe Fitter is responsible for fitting the piping system of the ships. This person is also responsible for measuring and defining the dimensions of the measure pipes to produce them at the pipe workshop.

Pipe Workshop (actor):
Responsible for making the correct pipes and measure pipes based on technical drawings and dimensions from engineering and pipe fitters.

Repair, maintenance and Refit yards (actor/ stakeholder):
These yards work quite similar to Newbuild yards except that at these yards only maintenance and repair jobs are done. These jobs also require engineering and job planning.

Software Developer (actor):
The software developer is responsible for creating a functioning application or tool based on the input and requirements set by a designer and the yard support division.

Hardware Supplier (actor):
The hardware supplier can be any external supplier that produces or sells products needed for the project. This can be tablets, 3d scanners and so on.

3.4.3

Power/Interest of stakeholders

Now that the stakeholders and actors have been identified their power and interest on the project can be assessed. Also social differences, relationships and recourses can be identified. Lelea (2014) provides a template with questions to be addressed to find out what each stakeholders power and interest in regard to the issue is. This table can be found in appendix A.2. Also there are questions to answer on how the underlying relations between the different stakeholders are and what their social differences are.

Different methods can be used to get the information required to define the power and interest of a stakeholder. Reed et al. (2009) presents different methods to do this. Snow-ball sampling and semi-structured interviews are useful tools for the first stage of identifying and mapping stakeholders. Snow-ball sampling uses the interviewing of initial stakeholder categories to help identify new stakeholders and contacts. A form of snow-ball sampling has previously been done to create the list of stakeholders presented before. A potential weakness of the snow-ball methods is that the results collected can be biased by the social networks of the first person interviewed. This is why the list of stakeholders has been created with more than one person.
Semi-structured interviews are useful for collecting in-depth insights into the stakeholders and their relations. Using the results of the structured interviews maps and matrices of stakeholder influence and power relations can be created. Based on that focus groups can be identified which can potentially be used for the design and evaluation process of the pipe fitting tool in the future.

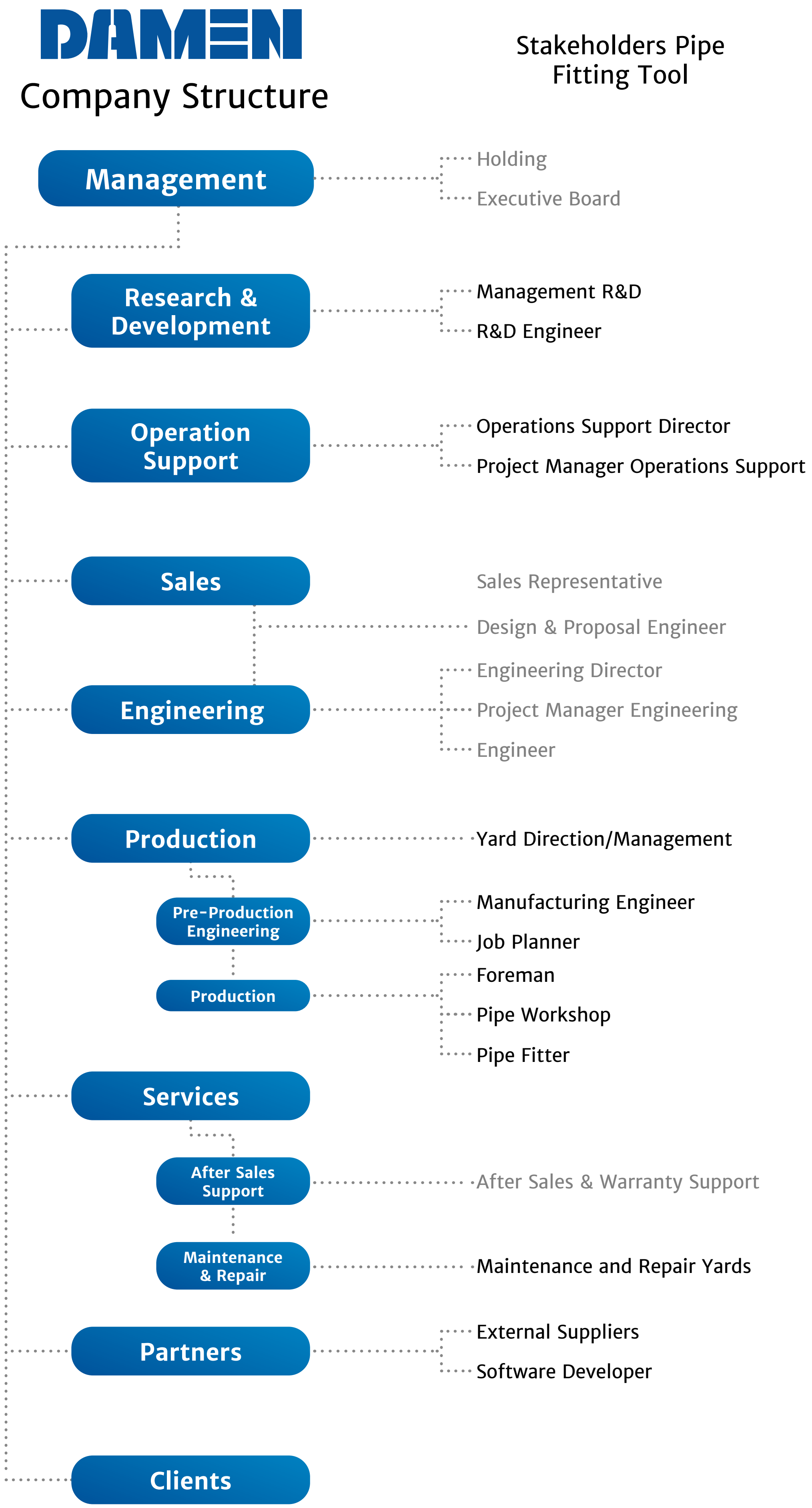

Figure 21, Damen company structure and Stakeholders

3.4.4

Relations between stakeholders

As an important part of project management is to be aware of the types of power people can wield to influence actions and opinions of other people (Bourne & Walker, 2005). To make the relations between those people and their power more clear graphical imaging has been made. In this image the stakeholders are mapped and their relations are shown. Using this kind of imagery could potentially show that some people have little influence on the project, but do have a lot of influence on other people that are more close to the project. Other potential results can be that the image shows individual people with limited influence that, once grouped, can be of major power and influence on the project due to their combined knowledge and skill (Bourne & Walker, 2005).

3.4.5

Influence vs. Importance diagram

To define which of the stakeholders need to be actively engaged in the design process, which ones need to be actively consulted and which ones just need to be kept informed an Influence versus Importance grid has been made. In this grid the importance of the stakeholder with regard to being impacted by the change of the pipe fitting tool or importance on the successful development of the tool has been mapped against the overall influence on decisions and the project in general. The four sections created in the graph provide a good guideline on which stakeholders to involve actively in the project and which not.

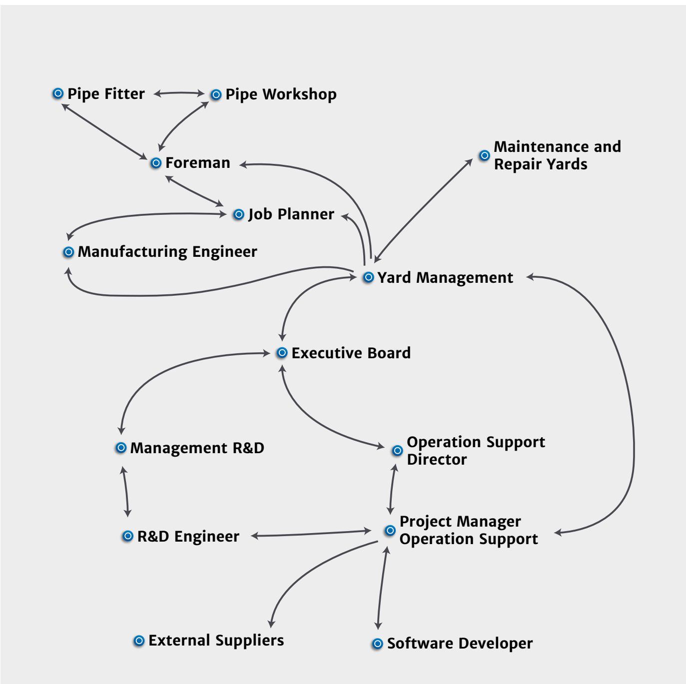

Figure 22, Relations between stakeholders

3.4.6

Conclusion

A conclusion that can be drawn from the relations in figure 22 is that there are a lot of different people and stakeholders between the project manager operations support running this project and the actual end users of the tool. These people are the pipe fitters and the pipe workshop. Up until now most of the communication about the tool to the yards has been between the operations support project manager and the production manager of the yards. By working from a distance in the office in the Netherlands this is completely logical because the pipe fitters are not working from a desk and available to answer emails or phone calls. But it is important to incorporate these people in the project. Realistically this will mean that there have to be some on location testing, designing and evaluation sessions at the yards.
From the diagram in figure 23 it can also be seen that the pipe fitters and the pipe workshop are stakeholders with limited influence on the project although they are impacted by the project. This means they are important to the project and should be incorporated in the project. Other than that the yard management, foreman and the operations support department are the most important to involve in the project. The other stakeholders have to be updated on the progress and occasionally included in the decision making.

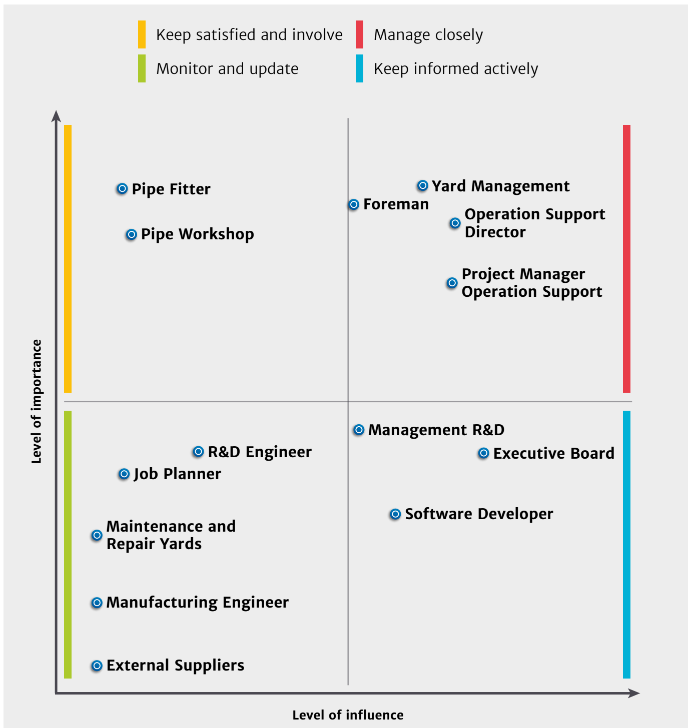

Figure 23, Importance vs. Influene diagram

Chapter 3.5

PROCESS MAPPING PIPING WORKFLOW

Within the Damen group there are many differences between the way of working within the different shipyards. These differences can be due to a difference in the type of yard, but they can also be results of differences in culture. The fact that Damen as a company often buys existing yards instead of creating new yards of their own will also create certain differences in the way the yards are organised. Ultimately it will be important to get to grips with what those differences are and how they will affect the effectiveness of a pipe fitting tool.
As the focus for this project lies on the Damen Galati yard in Romania and the Song Cam yard in Vietnam these two yards will be used to define a process map of the current piping workflow of Damen new built yards.

At the headquarters of Damen in the Netherlands only global information on the production processes on the yards are available. Overall this information is sufficient enough to use for decision making combined with knowledge of experienced people who have had functions as project managers on the yards.
Detailed information on specific processes and workflows such as the manufacturing process of a measure spool is not easily available and often not well documented. For this project it will be a valuable asset to research and document this.
Process Mapping can is a tool that can help create a detailed understanding of the current way an operation is working but also an understanding of how it should be in the future. Process mapping will provide insight in people and processes but also it can help with knowledge acquisition (White & Cicmil, 2016). And for knowledge to be useful it is important to know where this knowledge exists and how it can be transferred.
As the Damen Galati yard in Romania is a more easy destination to travel to for potential testing the priority was given to research the workflow at this yard first. Together with an operations support project manager with experience at Galati a preliminary measure spool workflow has been set up using documentation of an earlier improvement project for the piping department. Using this preliminary workflow a plan of approach document has been set up. This document contains a short introduction to the project, a small summary of work that has been done and the findings of this work, the goals of research and the questions there are regarding the piping workflow. This document has been set up in close cooperation with people with experience and knowledge of the Galati yard. The full document can be found in appendix A.6.
A part of this document containing questions about the piping workflow and a presentation containing a summary of the project and the work done so far has been sent to the head of production in Galati. Based on this email conversation a measure piping workflow of the current situation could be created. This workflow is shown in figure 24. The full email conversation with all the details can be found in appendix A.5.

Based on the email conversations, the available information on regular piping and production workflows and conversations with experts it seems like this is the correct workflow containing at least all the important steps and most of the details in the process. To completely confirm this is however only possible to also speak with the workers of the different departments at the yard. They can confirm or give additional feedback on their expertise within the process. This is best done on location. For now the workflow in figure 24 will be used as a reference point for the project.

Initial conclusions that can be drawn from the workflow is that there are, as already know, different transportation steps between the pipe workshop and the fitting location on the vessel. This transport step is taking around 20 minutes each time and is not planned. The transport is arranged by the foreman when needed. The goal is to have one general transport per day from and to the workshop but when needed multiple transports are arranged. A downside of this is that a lot of component fitting and work will have to wait for the piping to have been transported back to the workshop, adjusted, finished and transported back to the vessel to be fitted. Apart from this on average about 10 percent of the measure spools are "problematic" meaning these require more than one test fitting and adjusting cycle before they fit correctly. These spools will require additional transportation steps.

Figure 24, Current measure piping workflow at Galati

3.5.2

Workflow at Song Cam

Now the workflow for the Galati yard is clear it will be interesting to create the same overview for the yard in Vietnam. Again the summary presentation and questions have been sent to the head of production together with the pipe workflow document created for Galati. The questions and answers again can be found in appendix A.5.2.

This yard has a completely different business model. Damen Galati manufactures complete new built vessels including hull fabrication. At the Song Cam yard the hulls are built at partner yards and delivered as so called hull ++. Only outfitting, painting, commissioning, trials and delivery are done by the Song Cam yard. Consequently about 90 percent of the piping done at Song Cam consists of measure spools, making a potential time and cost saving on this process an interesting opportunity for the yard.

The production processes are however quite similar to the Galati one. The only difference being a lot more custom piping work and adjustments to predesigned piping spools. For this custom piping the workflow is different depending on the scenario. The pipe spool can be straightforward and easily manufactured to fit but it can also be a situation that proves to be difficult to get right. In figure 25 a scenario from a vessel being manufactured in Song Cam is shown. The pipe spool they are trying to create is to connect the pump of the firefighting system to the water inlet already present in the casco hull. The flanges do not line up and have angle differences in multiple directions. Multiple pipe spools manufactured have cracked or did not fit at all due to difficulty in measuring. The main difference between Song Cam and Galati will be that there will be many more cases like this at the Song Cam yard compared to the Galati yard as they have to work with hulls manufactured elsewhere. So a pipe fitting tool solution will have a lot of comparable aspects but will most likely have to be tailored to the specific workflow scenarios of the different types of yards.

Figure 25, Fifi measure spool "problem child"

Chapter 3.6

REQUIREMENTS

Based on the evaluation of previous work, testing and using the tool in the test setup and in a real vessel and evaluating the piping workflows the initial requirements of the project can be evaluated, adjusted and expanded.
The initial requirements were set up as the minimal requirements needed for a functional MVP solution. However not all of the set requirements have been met as shown in table 1. The project was however signed off by Damen as acceptable. A contradiction in the requirements is that two different ranges of flange diameter have defined of which one of them has been met and the other one not.

The initial requirements have been updated with the current knowledge of the project and the list has been expanded. The current set of requirements is listed below.

Initial requirements	**Requirement met?**
1. Flange diameter range DN25-DN250	No
2. Should work with steel or stainless steel pipes	Yes
3. Should work in panel- section- and hull building phase	Not sure yet
4. +-1mm and 1 degree accuracy	No/Unknown
5. Should work using predrilled flanges with baskets	Yes
6. Function in anything between day light and no light (inside tanks)	No
7. App needs to collect shape and dimensions of the pipe and the rotation of the flange and the bolt holes	No
8. Output file should be PDF, xml or TeZet	Yes
9. Maximum sparse processing time target is 5 minutes, as long as the next job can be started and processing will be done in the background. Otherwise this is too long	No
Initial requirements measure pipe XML blueprints	
10. Flange connected pipes only	Yes
11. Pipe flange range DN50-DN125	Yes
12. Supported pipe shapes a. Straight b. One 90-degree bend c. Two 90-degree bends d. S-shapes pipes, two bends with specific angle	Yes
13. Situations where initial xml design needs to be changed to another design are out of scope (e.g. straight pipe to s-shaped pipe)	Yes
14. Working volume of measure pipe is 1x1x1m cube with a maximum pipe length of 1,8 meter	Yes
15. Each flange is assumed to be mounted on a 90 degree angle to the pipe, certain deviations are assumed to be absorbed by the gasket	Yes

Table 1, Initial Requirements

Technical Requirements

1. The tool has to be able to scan a measure pipe within a working area of **1,5x1,5x1,5** meter
2. The tool has to have an accuracy of +/-1mm and 1 degree
3. The tool has to work with pipe flanges of size DN25 to DN250
4. The tool has to work with flanges of max 40 mm thick
5. The tool should function in anything between day light and no light (inside tanks)
6. The tool needs to collect shape and dimensions of the pipe and the **rotation of the flange and bolt holes**
7. Any needed marker needs to be max 100x100x100 mm in size
8. Output file should be PDF, xml or TeZet
9. Changes to initial xml file should be possible on the tablet or pc
10. Should work in panel- section- and hull building phase
11. Adjustments to mounting angle of flange to pipe should be possible in the application

Pipe Design Requirements

1. Steel or stainless steel pipes
2. Predrilled flanges with gaskets
3. Flange connected pipes only
4. Flange is assumed to be mounted on a 90 degree angle to the pipe, deviations are assumed to be absorbed by the gasket
5. Supported pipe designs; Straight, one 90 degree bend, two 90 degree bends, S-shaped pipe with two bends

Workflow requirements

1. The tool and the scanning process has to self-explanatory and can be learned without prior knowledge of 3D scanning with a manual
2. Maximum space processing time is 5 minutes, as long as the next job can be started and processing will be done in the background
3. The tool has to be able to create correct pipe design by itself
4. *The process has to be XXX% faster compared to the existing process**
5. The application has to name the files in sequence with the naming used in engineering and production departments

General Requirements

1. The scanning tool needs to be moveable by one person
2. The tool has to be understandable for all the pipe fitters working at any of the global shipyards of Damen

Whishes

1. The tool is incorporated with the 3D environment used by Damen Shipyards Group
2. Object/surface recognition for collision detection
3. Automatic pipe routing without engineering xml

**As the current process time is not known this will have to be determined in a later stage*

04

DESIGN

In this chapter a revised research goal will be presented. After this the different possibilities regarding technical development and the implementation of the tool in the piping workflow are being discussed. Using these implementation scenarios a rough business case is created and a potentially more simple solution for the pipe fitting tool is presented alongside concepts for attaching markers to the flanges. The goal of this chapter is to present the possibilities for further development of the tool.

Chapter 4.1

REVISED RESEARCH GOAL AND OBJECTIVE

From the previous analysis and work it has been discovered that the current project has not been developed and researched enough to make the correct choices and design decisions. This means that the research goals and objectives for this project have been revised to better reflect what this project needs and what is realistic to be achieved within the set timeframe for this assignment.
The main research question is still relevant and is defined as follows:

How does the pipe fitting tool need to be developed to make it an accepted tool within the shipyards as well as it being an added value to the process of shipbuilding.

The existing sub-questions have been expanded to fit the new targets of the assignment. These are shown in bold. The main difference in the project is that the end result is no longer a working prototype but rather an advice on how to continue the project, a toolkit to help development and scenarios containing possible solutions and their impact on the existing workflow.

Investigate
How does the current pipe fitting process look like?
What are the exact measure spool production workflows?
What are the information flows between stakeholders and processes?
What is the impact of a pipe fitting tool on existing workflows and processes?
What are the actors involved in the whole process of pipe system design and pipe fitting?
What are the issues and errors that occur with the current pipe fitting process ?
What are the bottlenecks in existing workflows?
How does the business case for the tool look?
How can the end-users and important stakeholders be included in the development process?

Evaluate
What are the requirements for a pipe fitting tool of the actors involved with pipe fitting?
What are the issues and points of improvement of the MVP pipe fitting tool?

Design
Can the current AR marker be improved for ease of use, and if so how?
How can the pipe fitting tool be improved for ease of use and acceptance by the end users?
What is the correct technology and direction to choose for further development of the tool?
What different scenarios for functionality of the tool are available?

Future
What resources, people and development are needed to implement the pipe fitting tool in a successful manner?
What is a realistic timeline for implementation of the pipe fitting tool?
How can the pipe fitting tool be expanded to fit and support other parts of shipbuilding?
How does the roadmap for potential development and implementation for the pipe fitting tool look?

4.1.2

Research scope (relevance)

The research scope for this assignment is divided in two categories being 1. The scope from a company perspective and 2. The scope from an academic perspective.

1. From a company perspective, this assignment aims to research how the pipe fitting tool can be developed to make the pipe fitting process more efficient and eventually help reducing production costs.
2. From an academic perspective, this assignment will aim to add knowledge to the way digital technologies can support and evolve production processes and the people working on those production.

4.1.3

Project Deliverables

Due to unforeseen circumstances such as the Covid-19 pandemic and correlating financial setbacks the project deliverables of the project also are subjected to change. Due to the circumstances travelling to shipyard locations in foreign countries was not possible. At this moment there are still restrictions on travelling which state that purely business essential travelling can be conducted. Unfortunately this project does not qualify as business essential so any planned testing, presentation and research sessions

planned at the Galati yard in Romania for this project got cancelled.
Initially the deliverable of this project would include a revised prototype ready for trial testing. This did however prove to be a more difficult target than anticipated due to improper previous development. So the new deliverable would be an extensive project development roadmap including advise on which direction to choose for and why. For supporting this advise testing and researching on location at the yard was essential. This means that the deliverable for this project will change to creating a development roadmap including different possibilities and development scenarios. These scenarios will include the now known pros and cons as well as a business case that has been created as true to the real situation as possible with the limited information available. Also the consequences of embedding the tool into the existing workflows and how much change they will require will be presented. When possible the possibilities and consequences on both short and long term are explained. Additionally a design brief will be created containing a summary of conclusions and an overview of which steps to take next. Presentation material and testing ideas and setups created previously will be added as a toolkit for further development.

Chapter 4.2

POSSIBILITIES WITH CURRENT TOOL

In this chapter the possibilities for the further development of the MVP pipe fitting tool will be discussed. The requirements and wishes for the tool have been presented to the partnering software developer in different meetings to discuss feasibility of those requirements. Also the future possibilities and potential of the tool was discussed.

4.2.1 TWNKLS

To explore the future possibilities and the best ways to continue several meetings with TWNKLS, the software partner of this project, have been conducted. In this meetings the findings of the evaluations and research conducted has been presented.

First Meeting
In the first meeting the MVP and how it incorporates the initial requirements have been discussed. In this meeting some miscommunications between Damen and TWNKLS have been uncovered. The initial requirements and how they would be validated have not been communicated to TWNKLS in the correct way. As far as TWNKLS knew the project had been delivered to satisfaction of Damen as the project manager of Damen signed off on the project and its requirements and deliverables. The requirements of Damen however described a MVP solution which could be used for trial runs in production. The delivered solution however was more a proof of concept that worked in the test environment but was not really fit for production testing as was shown in the user acceptance test conducted in Romania.

Second Meeting
The second meeting was meant to define the technical possibilities of the current solution and how this solution could be expanded in the future. The main focus for this meeting was to see if and how the markers for the tool could be made smaller and what that would do with the accuracy of the tool. Also the technological possibilities with regard to the processing times was an important point of conversation.
TWNKLS presented that they doubt if the current technology is the correct way to go. Apparently the current MVP had not been tested for accuracy enough to conclude if the required accuracy of +/- 1mm and +/- 1 degree would be achievable. TWNKLS would choose for a different technology if they would start this project again today and they proposed to do the same for the continuation of this project. For Damen however this would mean to restart the whole project, and invest a significant amount of money, while the current project did not deliver the desired results or conclusions needed to make the decision to continue developing a pipe fitting tool. Therefore the decision was made to look for relatively minor improvements to the current MVP to make it function enough to be used for more comprehensive testing.
Possible improvements are:

- Implementation of smaller markers
- Code optimization for improved processing times
- Skip dense point cloud processing and only use sparse processing for pipe adjustments
- Pipe design without XML from engineering
- Addition of bolt/flange rotation

Possible future improvements

- Addition of tablet accessories for 3d scanning
- Switching to Ios/Android devices
    - Both Google and Apple are developing AR solutions with measuring capabilities
- Switching to a new technology or approach completely

For the continuation of the project it was decided to create different development scenarios which could be presented to TWNKLS.

4.2.2 Developments scenarios

For the further development of the current tool three scenarios have been identified. These scenarios are 1. Minimal adjustments, 2. Optimal adjustments and 3. Future vision.

Minimal adjustments
This scenario consists of the minimal adjustments needed to make testing and evaluation in a production environment possible. In theory this will make the current concept into an actual MVP that is useable. Trials and testing will still have to be done under supervision of the operations support department.
These adjustments are:

1. Adjust tool to function using smaller markers
2. Enable bolt hole and flange rotation registration

in the measurements
3. Complete accuracy tests to validate they are within requirements
4. Do a user acceptance test

The primary goal of such a minimal development is that the general use of such a tool can be validated in the real production environment with the end users in a relatively short amount of time and with limited resources. This scenario can help define if the current solution is the correct one or if it has too many disadvantages and there is a need to find another solution.

Optimal adjustments

In the optimal scenario the MVP will be developed more into a proper functioning prototype. These developments will allow for a more complete testing and evaluation process including the option to test out different workflows. Potentially this scenario could also be used as a proper longer trial without supervision of the operations support department.
The developments in this scenario are:

1. Adjust tool to function using smaller markers
2. Sparse processing will be replaced by live marker recognition
    a. This enables live feedback on picture quality
    b. No processing times on tablet so no work interruptions
    c. Saves a lot of battery on the tablet
3. Shorten dense processing times
4. Enable (wireless) batch exporting and processing
5. Enable ability to change XML pipe design after scanning
    a. Enables more freedom for adjustments
    b. Could be useful for reverse engineering
    c. Useful for unexpected changes to components or obstacles in the pipe path

This would be a next step scenario when it is certain that this technology and solution will meet the requirements and will create the efficiency and cost savings Damen is looking for.

Future vision

This future vision is meant to present how the technology of the current solution might be used when fully developed and implemented.
In this scenario the following thing will be implemented:

1. Automated processes where possible
    a. Automated processing and pipe design adjustments
2. Live 3d scanning
    a. With 3d scanning accessory or separate 3d scanner
3. Flange recognition in 3d scan mesh/data
    a. Might need small active markers on the flanges
4. No CAD modelling or drawing adjustments after scanning, engineering data should be adjusted automatically
5. Minimal to no processing times, everything live
6. Options for live visualizing of components or piping that still has to be fitted.

This scenario is for now primarily meant to trigger the inspiration of the software developer and in the end to present to Damen what other possibilities there are apart from only being a measuring tool.

4.2.3

Scenario choice

Up until now there are still many unknowns for the project. Some end users and stakeholders are still not involved enough in the project and their requirements and feedback are not mapped yet. For this reason the choice is made that the priority for now will be on testing and evaluating the current solution together with the end users and stakeholders. As mentioned in the results of the user acceptance test done in Romania by Damen the pipe fitters and workshop personnel did not react positively to the current MVP. This was mainly because it just did not function properly and did not represent the potential of such a solution well. For this reason the choice has been made to continue with development scenario “Minimal adjustments”. Although there are doubts that the current technology is the right one to develop it would be too costly and time consuming to develop a completely new tool before being able to test and evaluate the actual added value of implementing this solution to the production workflow. By developing the solution to match the minimal requirements to be able to function a testable MVP can be created with limited investment in a short timeframe.

TWNKLS Meeting

The choice for this development scenario was discussed with TWNKLS and at this point it became clear that some of the previous promises for possibilities were not realistic. The most important thing was that only using sparse processing to calculate the dimensions was not possible after all. This means that getting the processing times down to acceptable limits would become more difficult. But as the dense processing would happen on more powerful computers instead of on the tablet this would not mean that it would be a big problem. A simple solution would be to, for a final solution, create an automated batch processing system with powerful computers. This means that regular work could go on as normal and the scans are processed in the background. The fact that dense processing can't be skipped also means that sparse processing, apart from validating image quality, is somewhat unnecessary. Other solutions can be thought of for making sure image quality is correct. Gamification with interactive elements and feedback on the interface can provide the needed input for a user to know when a picture is correct. A requirement for this is that the software is able to recognise the markers live, which is possible. Another positive for skipping sparse processing is a significant battery life improvement for the tablet as it does not have to do heavy calculations and the user can continue with the next scan straight away and does not have to wait for processing to finish.

A request for a quote for the following work has been sent:

- The implementation of smaller markers
- Marker accuracy testing (in cooperation with Damen)
- Add/adjust the detection of bolt hole and flange rotation
- Removing sparse processing when possible
    - Replacing with live marker recognition
- Enabling batch dense processing
- Improving processing times where possible
    - Trade-off between time and accuracy, shorter processing times at the cost of slight accuracy loss could be acceptable
    - Defining the requirements for computer processing power/which processor is needed to significantly lower processing times

The following requirements are part of this quote:

- Accuracy of +/- 1mm and 1 degree
- Working area needs to be increased to 1,5x1,5x1,5 meters
- Supported flange range should be DN25-DN250
- Detectable surface of the markers should be made as small as technically possible
- Definitive measurements have to be defined by testing
- Will be based on trade-off between size and accuracy
- Original requirements regarding pipe designs and such are still the same as defined before

TWNKLS Proposal

The proposal of TWNKLS was to tackle the improvement points in steps. The size of the markers is the main problem for not being able to test in a realistic environment thus this issue will have priority. Apart from this the whole application will have to be update to 2020 software build standards and bug fixes will have to be made to make sure the whole application will be functional again.
In table 2 a summary of the work, an estimation of time needed and the corresponding costs are shown.

[redacted]

For the proposed work several risks have been identified. TWNKLS can not guarantee that the app with smaller markers is able to support the accuracy required by Damen. The following risks are identified:

1. Less accurate 3D reconstruction because of reduced image resolution on markers in photos taken
2. More photos needed in app photo taking to solve 3D reconstruction in engine
3. More photos needed taken close by to enhance detection and identification of markers
4. Reduction of possible work area of 3D reconstruction and subsequent pipe fitting because of risk 3
5. Upgrade of build environment can reveal app rework in order to get app working again

What level of accuracy can be achieved will need to be determined by operational testing performed by Damen. This operational testing is out of scope for TWNKLS and will need to be done by Damen. Additional adjustments and bug fixes as a result of the outcome of testing will also be out of scope for this quote.

Timeline

The indicated lead time for the work defined in this quote has been estimated on 3 to 4 calendar weeks. To staff the project an additional four weeks are needed after receiving a valid purchase order from Damen.

Chapter 4.3

DEVELOPMENT SCENARIOS

For the further development of the pipe fitting tool three different scenarios based on the measure spool workflow of Damen Galati have been identified. These three scenarios are 1. The current workflow and the current (MVP) tool design, 2. The current workflow adjusted for the current (MVP) pipe fitting tool and 3. Optimized pipe fitting tool in current workflow.
A more long term scenario could be to create a complete adjusted workflow and integrated optimized pipe fitting tool. This could also include the different options and scenarios for the development of the MVP pipe fitting tool as discussed in chapter 4.2. This would however not be a realistic approach to develop and implement without proper testing and trials. The three defined scenarios are all a more realistic scenario that could be implemented without major changes in the workflows.
In these scenarios the technical possibilities of the pipe fitting tool have been kept in mind. The requirements of the pipe workshop, pipe fitters and foreman have been tried to be taken into account by consulting with a project manager of Damen Gorinchem with expertise and knowledge of the piping workflow of the yards in Romania. Ultimately these scenarios will have to be discusses, validated and adjusted to the requirements of all stakeholders.

4.3.1

Scenario 1: Pipe fitting tool in current workflow

In this scenario almost no changes will be made to the current workflow and the changes to the pipe fitting tool as developed until now will also be limited. The changes to the tool will primarily be to make the markers smaller to make it more useable and the processing times will have to be limited where possible. For the workflow the main change will be that the measure spools will not be transported to the vessel for test fitting. They will be manufactured as normal, including overlength and loose flanges. The measuring however will be done using the pipe fitting tool. The XML file with adjusted measurements will be sent back to the engineering department and converted into a production drawing . This drawing is sent to the pipe workshop where the measure spools will be adjusted and finished before they are sent to the vessel for final fitment.
The savings and efficiency step in this scenario will primarily be loosing a transportation moment and having a higher first time right percentage. The full workflow is shown in figure 26.

4.3.2

Scenario 2: Pipe fitting tool in adjusted workflow

This scenario is in the basics the same as scenario 1. The main change here is in the piping workflow. Instead of manufacturing the measure spools before measuring as part as the regular piping production packages only the fixed spools are manufactured. These will be fitted and measurements for the measure spools are made using the pipe fitting tool. These measurements are sent back to engineering in an XML file and converted to a production drawing. With this drawing the correct fitting measure spools is manufactured by the piping workshop and can be transported to the vessel for final fitting.
The main savings in this scenario will be that the measure spools do not have to be adjusted after production. They can be manufactured and finished in one go resulting in time and material savings. Additionally the same savings as in scenario 1 still apply to this scenario. The full workflow for this scenario is shown in figure 27.

4.3.3

Scenario 3: Optimized pipe fitting tool in current workflow

In this scenario the main developments will be in the pipe fitting tool. The changes to the workflow will be the same as in scenario 1 where the produced measure spools with overlength and loose flanges will not be transported for test fitting. The change to the tool will be that instead of generating a XML file to be processed by the engineering department the tool will generate adjustments values based on the dimensions of the manufactured measure spool with overlength and the correct measurements. Using these adjustment values the pipe workshop can adjust the manufactured measure spools and finish them for final production.
The main savings in this scenario will be less transportation movements, less communication and data transfer moments and no extra work for the engineering departments. The full workflow for this scenario is shown in figure 28.

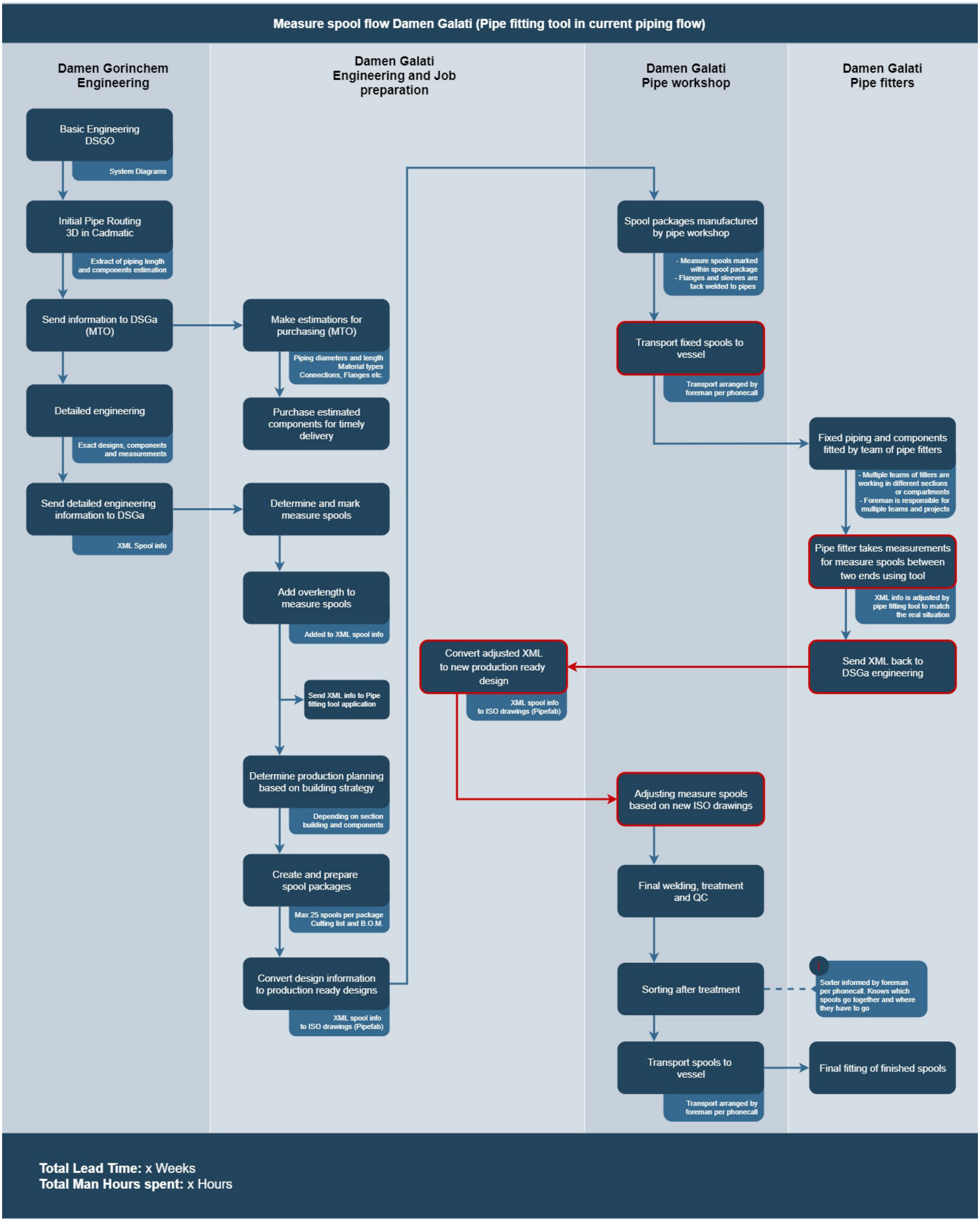

Figure 26, Workflow scenario 1

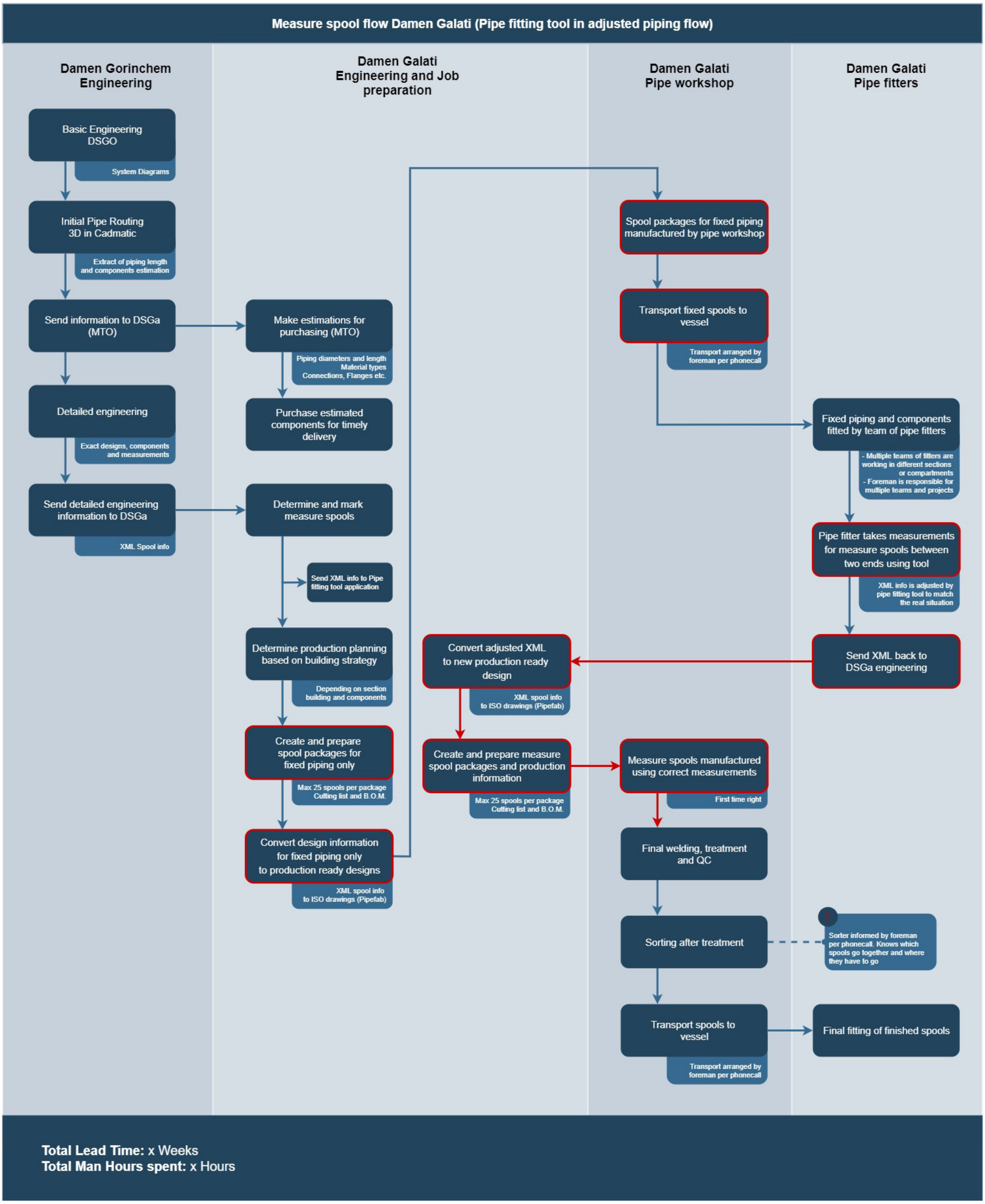

Figure 27, Workflow scenario 2

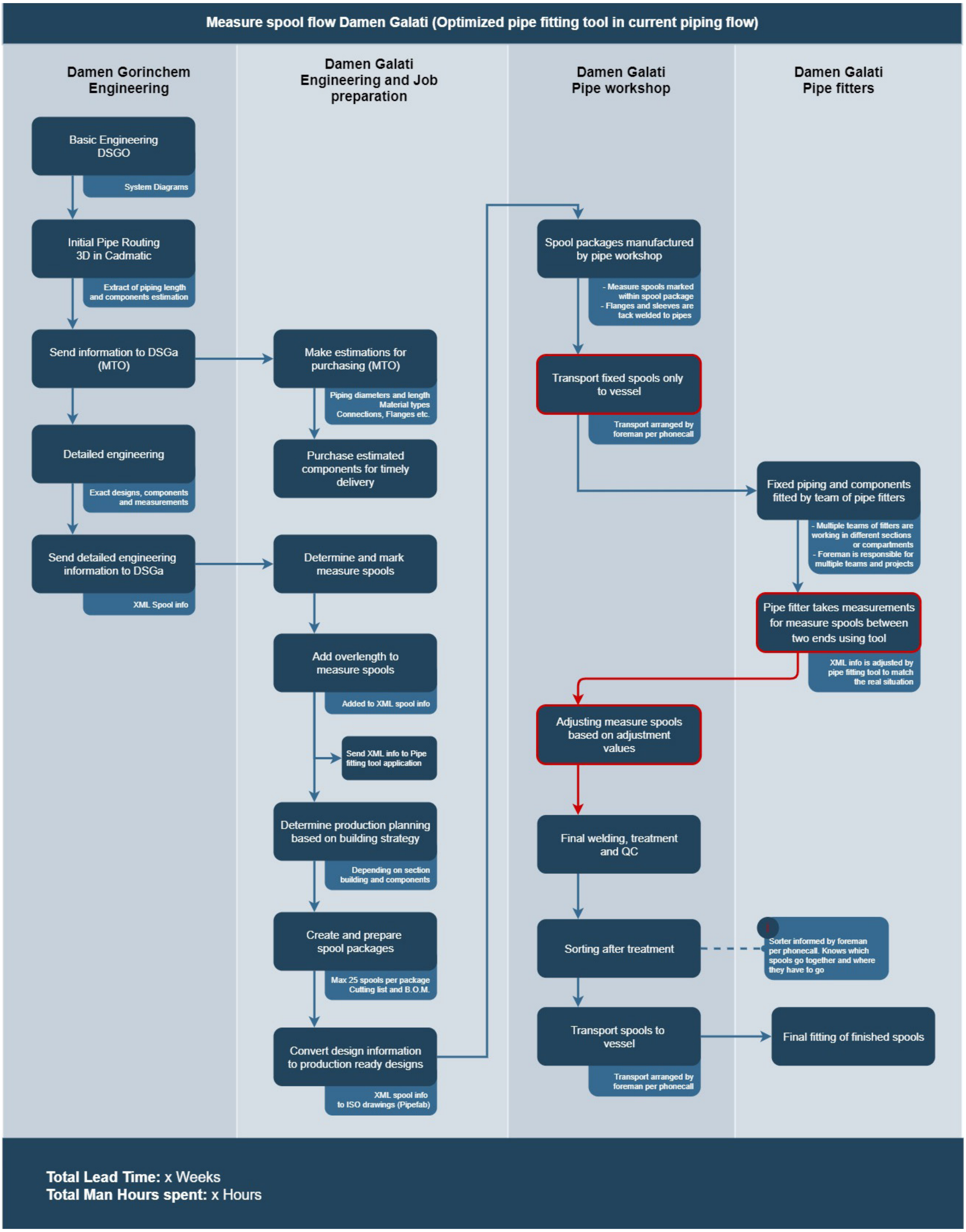

Figure 28, Workflow scenario 3

Chapter 4.4

BUSINESS CASE

As mentioned in chapter 2.4.3 the original business case for this project was not reliable enough to use as a basis for decision making. The numbers gave an insight in the possible savings and the potential there is for such a project. Due to the use of non-representative numbers for the production numbers of the Galati yard the business case lacks a realistic image of the situation.
Within this project one of the targets was to create a more realistic and reliable business case. This business case would mainly be used to calculate the realistic potential cost savings, the investment return rate and the differences between the different workflow scenarios. Another interesting aspect would be to see what the investment return rate is based on different investments. With quicker potential return rates some risk on investments could be justified.
Also no real data on how much time savings the current MVP would provide is non-existent. This has not yet been tested or timed.
Preliminary research showed that getting accurate numbers such as time spent on different aspects of pipe fitting, measuring and production would be difficult, especially when trying to collect them from the office in the Netherlands.
Plans to collect such data on location in Romania were made. Based on interviews with different stakeholders such as production planners, pipe fitters, pipe manufacturers and foreman the hope was to collect some insight and expert estimation on time spent in production and manufacturing. Also empirical research while doing timekeeping on different steps in the production processes were planned. Combining the expert estimations, the timing data and the numbers of the original business case would hopefully provide a more clear image on the reliability of the numbers based on how much they differ from each other.
However, as mentioned before, due to the Covid-19 pandemic travel restrictions prohibited travelling to the yard in Romania to do the planned research. At the time of writing, nearing the end of the project, the travel ban is still in place. This means that any data that needs to be collection has to be collected via digital communication from a distance. As found earlier this proved to be difficult.
The first hurdle was to communicate clearly what numbers were required and to figure out which contacts and people were needed to get those numbers. Once in contact with the correct people very specific questions were asked regarding how much time each step in the workflow would take on average. The standard answer to these questions would be: "It depends" or we don't know specifically. They could only give answers for specific situations and pipes they have built. They could not, or did not want to, give any educated guesses. This can also be due to not really understanding what we wanted due to language barriers for example. Speaking to these people on location with a translator would be much more efficient.

So creating a reliable business case within this project proved to be difficult and somewhat impossible. For this reason it has been decided to use the numbers of the original business case and use them to calculate the differences between the different implementation scenarios and workflows created in chapter 4.3.

In table 3 the original numbers used for as the baseline for the current situation is presented. This represents the current workflow without any implementation of a pipe fitting tool. This situation also takes into account a second time right percentage of 30%. The second time right spools are the ones that have to be readjusted a second time because they did not fit after initial adjustments. The table lists the different steps in the workflow and the corresponding time spent per step for one spool and next to that the total hours spend each year. The yearly numbers are based on an average of 12.000 measure spools that are produced in Galati on a yearly basis.

In the tables 4, 5 and 6 the business cases for the three different implementation scenarios for the Galati yard are presented. The time and costs savings are calculated towards the numbers of the current situation. In this calculation it is assumed that the pipe fitting tool will result in a 100% first time right production. Realistically this will not be possible but for now it is assumed that the amount of second time right spools is negligible. In table 7 the same workflows have been calculated for the Song Cam yard.
The potential cost savings are based on an hourly wage of [redacted] Galati employees and [redacted] for Song Cam Employees.

[redacted]

Investment

The exact investments for the three implementation scenarios are still unknown. The reason for this is that at the moment it is not completely clear how accurate the current technology is and how easy it will be to further develop it. Also the costs and impact on potentially changing or adjusting the piping workflows on different levels in the workflow can't be calculated at the moment as critical information and knowledge is still lacking at the moment.
Only for the scenario of implementing the current tool in the current workflow a rough indication can be given. For a successful trial phase an investment of at least €25.000 will be needed for improving the MVP will be needed. Other than that probably the same amount will be needed for project management from Damen, travel and research costs on site and different trial test. This will come on top of the money already invested up until now. On estimation this sum is around €100.000.
The potential cost savings will however make the return on investment time for this investment around a year for this scenario once implemented.

The other implementation scenarios potentially provide more cost saving opportunities, but they will both require a lot more investment. These investments will be both on the tool development side but also on the workflow adaptation side of the project.
Further research will be required to create reliable and valuable business cases including the exact costs of developing different tools and adjusting workflows. For now this business case gives an indication on how the different implementation scenarios translate to potential cost savings.

Chapter 4.5

LOW-TECH SOLUTION

During the researching and developing of the project there were several moments where it was thought that there could be a more simple and cheap alternative for the problem of measuring pipe spools. In theory the only parameters required to make a measure spool fit correctly is the distance between the heart of the two flanges in the X, Y and Z direction and the angle between the faces of the flanges. The rotation of the bolt holes could be a useful addition but generally the orientation of the flanges and the bolt holes are standardized.

The reason this idea was not really used up until now has to do with the fact that the initial assignment consisted of the further development of the choses AR solution. Until late stages of the project it was believed that this technology could provide for the set requirements. This was until the software developer started expressing concerns and doubts about the achievability of the requirements. In short it is unknown if it is possible because it has never been done really. The only way of knowing is by developing the solution using smaller and better markers and do accuracy tests afterwards while accepting the risk of the project failing. This in turn made the question of can't it be more simple more relevant again, triggering meetings with R&D to come up with more basic potential solutions to the problem. Initially the purpose of this idea is to trigger Damen into exploring out of the box solutions and showing that, depending on the long term goals, simple, less high tech solutions, could provide the desired result.

The idea

Together with the Research and Development department of Damen a brainstorm was done to create idea's for a "low-tech" solution for measuring pipe spools. Several ideas were proposed but the one that stood out was a solution using digital angle measuring devices connected to each other using tubes or an extruded profile. Using three angle measuring devices the distances between the hearts of two flanges can be calculated using some simple math using the values of the devices and the known lengths of the tubes or profiles between them. When using an additional two angle measurers the angle difference between the faces of the flanges can also be calculated.

In figure 29 the idea is roughly shown in 3d. This 3d model was also used to test the theory that this tool could work.

By using math the angle values and the known lengths of the components the required dimensions can be calculated. To make this easy for a prototype an Excel sheet has been created in which the angle values have to be inserted and the result will be automatically calculated. In figure 30 the sheet is presented. In appendix A.9 the formula for the calculation is shown in detail.

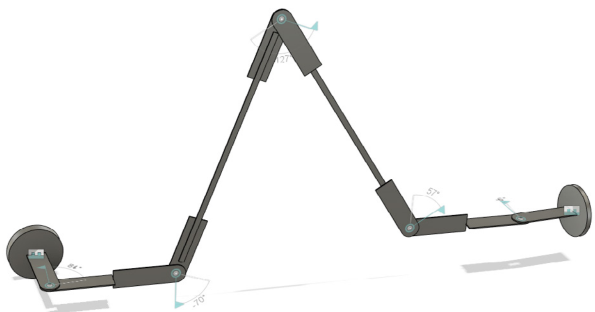

Figure 29, 3d Model low-tech solution

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U	V	W	X
1																								
2																								
3		**Angle 01**	122,9				Tool Length	500			**Angle 08**	174,4			Angle 12	0			Angle 14	4,973371			Angle 21	84,5
4		**Angle 02**	52,8				Angle Ruler Length	112,5			**Angle 09**	95,5			Angle 13	90			Angle 15	0,626629			Angle 22	5,5
5		**Angle 03**	109,9								**Angle 10**	84,4							Angle 16	94,87337			Angle 23	90
6		Angle 04	63,6								**Angle 11**	5,6							Angle 17	78,81447			Angle 24	0
7		Angle 05	63,6																Angle 18	6,312155				
8		Angle 06	6,5																Angle 19	11,28553				
9		Angle 07	83,5																Angle 20	78,71447				
10		**Flange Angle Differen**	**0**																					
11																								
12																								
13		Side A	444,6352								HH	1000,021			H1	225			H2	1003,8			V3	111,9821
14		H	891,777								VH	87,02219			V1	0			H3	1019,538			V4	0
15		V	50,33413																					
16																								
17																								
18																								
19																								
20																								
21																								
22																								
23																								
24		**Dx**	**999,8246**																					
25		**Dy**	**199,522**																					
26		**Dz**	**50,33413**																					
27																								

Figure 30, Excel Sheet

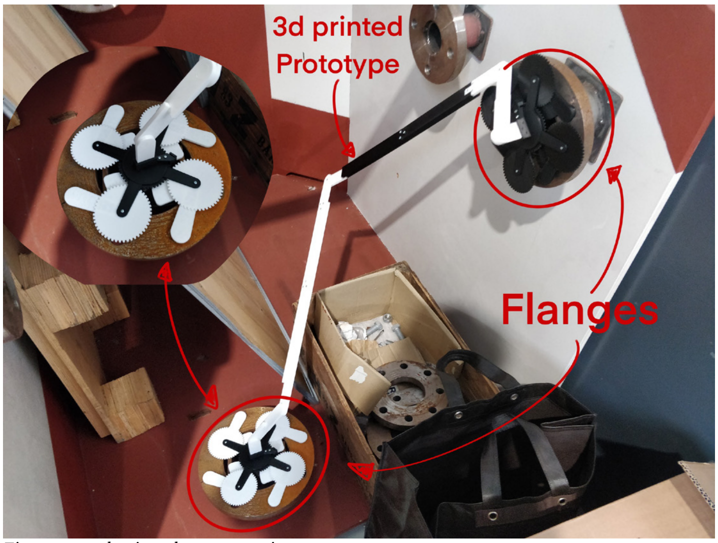

Figure 31, 3d printed prototype in test setup

Potential
If a prototype of such an solution would prove to be accurate and useful it could be transformed in a much more refined tool fairly quickly. A first step could be to change the angle measuring devices with wireless versions. These wireless devices could communicate with a smartphone, tablet or any other wireless device running an custom application containing the formula to calculate the parameters.
To boost accuracy the angles can also be measured with digital encoders. Encoders are devices capable of measuring rotation angles with extremely high accuracy. Encoders with Wi-Fi capability also exist which means that the tool can utilise a small rechargeable battery to function and the values are automatically transmitted to again a smartphone or tablet.

The application can ultimately be integrated with the engineering system and data of Damen. The existing measure spool data can be loaded into the application and be automatically adjusted to fit the actual measurements. This system would function in a similar way as the current MVP application does.

Prototype
The 3d model and the Excel sheet proved that the solution would theoretically work so as a next step a 3d printed version with normal hinges has been created to evaluate usability on the existing test setup. In figure 31 the 3d printed prototype is shown in the test setup.

The printed prototype is roughly based on using hinge points with similar lengths as the angle measuring devices would have. This results in a relatively large tool. In the current test setup the size is not an issue as there is enough space around the flanges. But in a realistic working environment in a ship the tool might be too big, especially when working on smaller measure spools. Realistically this kind of tool will require either a set of different lengths or sizes of tool, or a telescopic variant to be able to work with different spool lengths and tight spaces. The hinge points containing the angle measurers will also have to be as small as possible to be able to create a small enough tool.

For prototyping purposes normal angle measuring rulers will be fine at first. This will also result in a very low cost prototype to build. For less than 200 euros the rulers can be bought and using the in house facilities of the Damen workshop and some leftover tubing a working prototype can be fabricated.
This prototype can be utilized to present as another option to the users and stakeholders. In the case that this solution proves to be the preferred one with promising results Damen could choose to further develop this prototype with wireless encoders. At this point they can also create a set of different sizes to test if they will fit in different scenarios.

As the investment of developing and testing a working prototype for this solution is relatively limited the advice would be to have it developed alongside the AR solution. This will allow Damen to present the two different solutions to the stakeholders and collect responses and feedback on either ideas. Potentially the stakeholders will have radically different responses to both concepts which could help in making the right decision on how to continue with the project.

Chapter 4.6

FLANGE CONNECTOR

One of the first points of critique heard when testing the MVP is how unwieldy the process of attaching the markers to the flanges is. As the MVP is a prototype this is not directly an important aspect for the overall functionality of the tool. On the other hand it does not help the project as it does not represent the efficiency and time saving goals of the tool. In the previous chapters the possibility for 3d vision systems capable of recognising the flanges without markers was discussed. Although this is a technology that is possible there are, at the moment, no systems available that can provide this technology without requiring manual post processing of the scan data. This post processing will take time and resulting in no net time savings. Any digital metrology technology will require some form of makers in the short term. Regardless of the actual final tool, being it the AR scanner solution, the low-tech solution or another technology an easy and quick solution has to be found for attaching something to flanges. Unless there is a scanning technology which can automatically recognise flanges some form of marker or physical measuring device has to be attached to the flanges of the to be measured spool.
This flange connector has to be adjustable to fit the many different flanges used in ships. At the same time it has to be sturdy enough to attach to the flange completely flat and fixed. Other than that it has to be a form of a quick release system to make it easy to attach and detach. Preferably the connector also has a way to make sure the orientation of the connector to the bolt holes of the flanges is fixed and always the same.

Requirements
Damen mostly uses flanges created following the DIN guidelines. These guidelines present a range of standardized flange sizes and corresponding bolt hole sizes and orientations. For the requirements and concept development in this project the DIN guidelines as presented by for example Filter Technics (n.d) have been used as a baseline for defining dimensions.

- Has to fit DN25-DN250 flanges
- Has to fit on flanges with 20-30mm thickness
- Has to fit galvanized or painted flanges
- Has to have a fixed orientation on the flange
- Needs to be attached and detached by one person
- Should have a quick release system
- Has to mount flush to the flange surface

To make the connector fit galvanized or painted flanges the most important aspect to take into account is that the bolt holes of the flange are usually 18mm in diameter minus the thickness of the paint. Usually 17,5mm diameter will fit snugly in the hole.

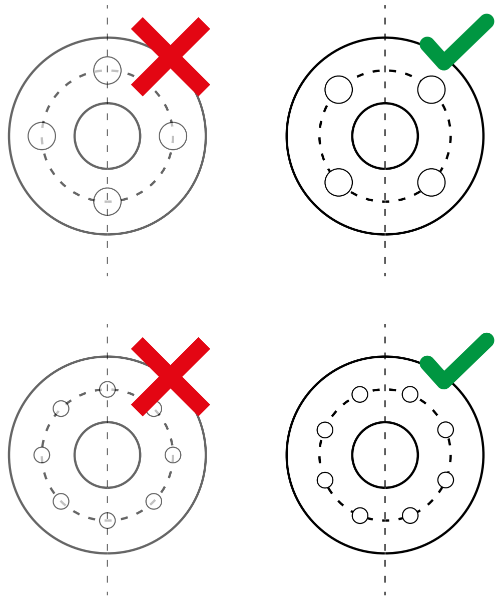

Figure 32, Incorrect (L) and Correct (R) flange mounting

Proper flange orientation
Dames uses guidelines to installing flanges the correct way. In general the flange should be fitted perpendicular to the tube or pipe it is attached to. Other than that the bolt holes have to be aligned or orientated in a specific manner. In figure 32 the correct way is shown. Most important is that there have to be two bolt holes at the top of the flange, both at the same distance (or angle) from the vertical centreline from the heart of the flange or pipe. This centreline is vertical and perpendicular to the flat and level surface of the vessel.

Off the shelf solutions
Off the shelf flange connectors or adapters to attach tools to a flange do not exist really. It seems like a fully customised tool will be required to fulfil the requirements for the flange connecter suited for a pipe spool measuring device.

4.6.2
Concepts

Concept 1
The first concept is based on the existing 3d printed marker holder. The main issue with this holder was that the arms of the connector has to be put in the flange holes and then mounted with loose bolts and nuts. This is a tough job when done by one person and is even more difficult when working in tight spaces. Also the connect had a limited range on which it would fit. The smaller flanges in the range would not fit.
To make it fit to the smaller flanges slots were made in the base of the connector to allow the arms to move further inwards. Also the four arms have been connected to each other using a gear system. This gear system makes all the arms move at the same time and making sure they automatically line up to each bolt hole when moved into position.
To clamp the connector to the flange a ratchet mechanism is added. The idea is that when the arms are in the holes on the flange they are clamped inwards. The ratchet will make sure the arms don't move outwards again and the pressure will keep the connector in place on the flange.
A 3d printed prototype showed that this system was a little to flimsy and the ratchet mechanism was not able to provide enough force to keep the connector properly attached to the flange.

Concept 2
The second concept is a much more compact system using only two arms instead of four. The arms are again connected using a gear system making sure they move at the same time. The main advantage of this system with two arms is that the orientation of the connector and the marker on there is always the same when the flanges have been fitted correctly. The way the system connects to the flange is an expandable part on the arm. This part fits in the bolt holes. When inserted a bolt is screwed in which makes the part expand and clamp in the bolt hole. In figure 34 this system is shown.
A 3d printed version of this concept has been tested and the clamping did provide some strength. This strength is however not sufficient for a lot of weight. For small marker it would be sufficient.

Concept 3
The third concept consists of a block with two rods that slide in a rail which will fit into the flange bolt holes. A second block with two fixed rods sits on top of the first block and can be screwed up and down with a knob. The fixed rods will clamp the connector to the flange edge when the knob is tightened. The rods in the slider will align themselves to the middle when the two blocks are screwed together. Two alignment pins

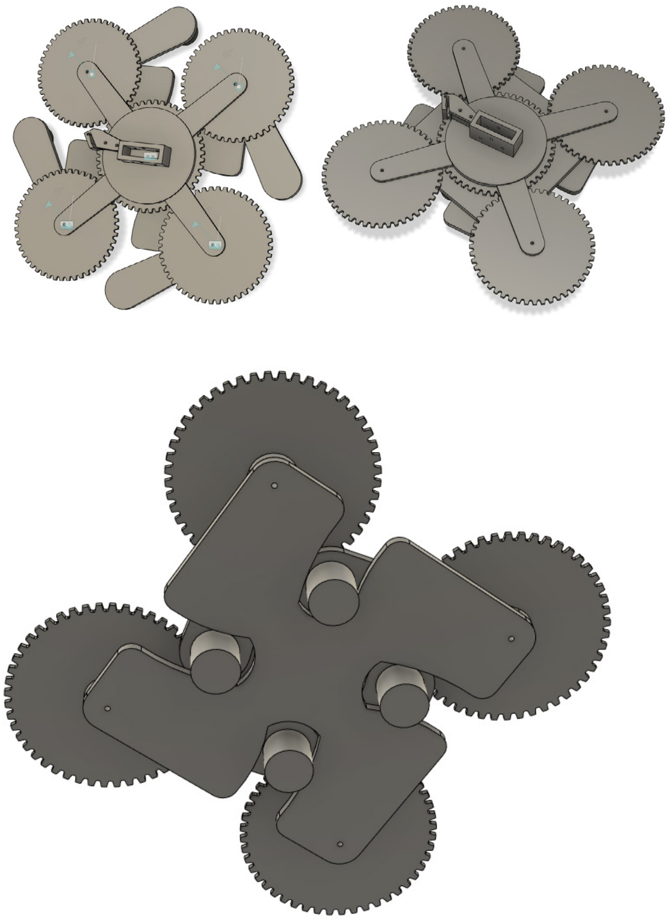

Figure 33, Flange connector concept 1

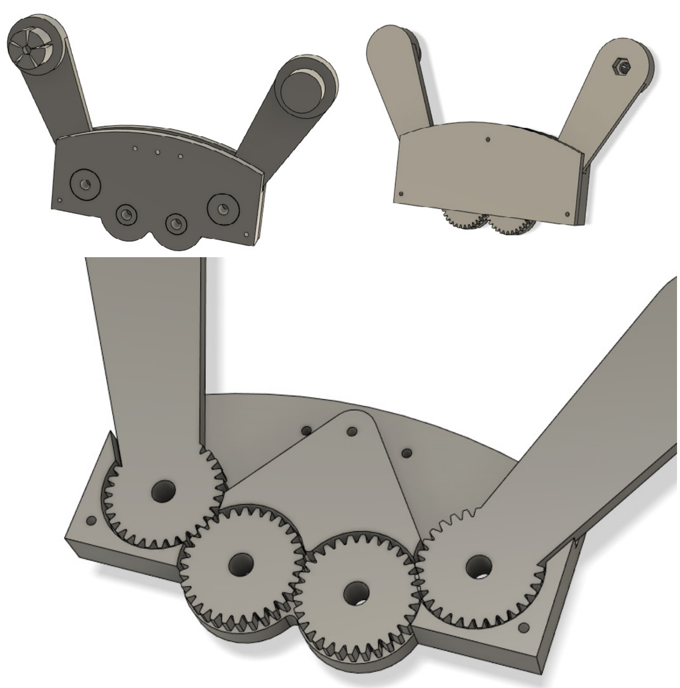

Figure 34, Flange connector concept 2

make sure the two blocks stay aligned and straight. This concept can be machined from a solid block of metal to create a strong connector. Rubber can be added to the rods for extra grip. In figure 35 and 36 the concept is shown connecting to a flange.

Quick adjustment for current prototype

The current 3d printed marker holder can also be adjusted using an off the shelf component to make the installation more easy. Snap tight expandable rubber plugs as shown in figure 37 can be used instead of the current nut and bolt construction. The rubber part of the plugs expand outwards when the small lever is pressed down. If the plug is inserted in a bolt hole it will expand and fix itself in the hole. This cheap component can be incorporated in new 3d printed legs for the current marker holders making installation and removal much easier and it will remove any loose components which can become displaced or can fall when installing the marker on the flange.
This component can also be incorporated within any of the three concepts presented. Especially in the first and second concept.

Conclusion

This chapter functions as inspiration for further development. Concept 1 and 2 have been 3d printed and tested, the thirds one has not yet been tested. Depending on the chosen further steps in this project a choice can be made. Concept 2 is useful for a lighter and smaller marker. Concept 3 is probably suited for when more strength is required. For initial testing the advice would be to update the current maker holder with the presented snap tight rubber plugs for initial testing. This will provide the quickest method of creating a quick and sturdy maker holder and flange connector.

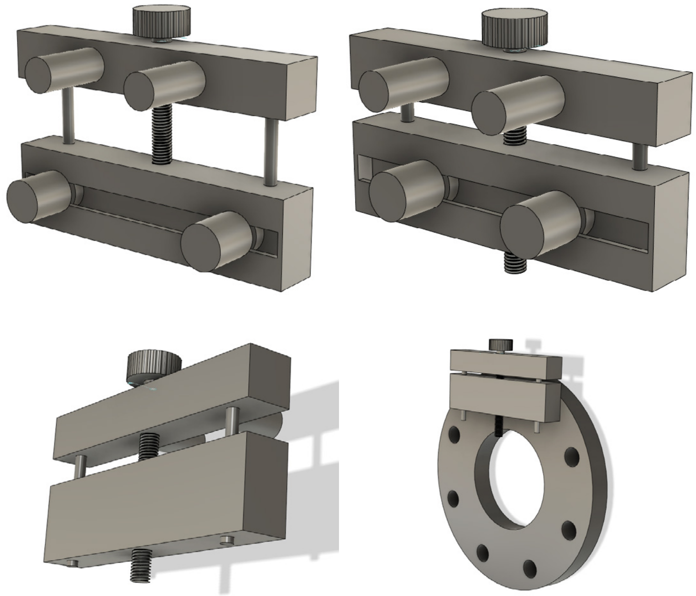

Figure 35, Flange connector concept 3

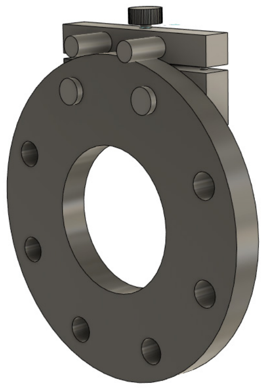

Figure 36, Flange connector concept 3 to flange

Figure 37, Snap tight rubber plug (United States Plastic Corp, 2020)

05

RESULT

In this chapter the end result of the project is presented in the form of a development roadmap in which the steps to take in further development are presented. An effort is done to put this roadmap in perspective to the roadmap of project paperless yard. Ultimately an advise is written on the different scenarios that can be chosen and a design brief is created to aid a potential project handover. After this the project will be finalized in the conclusion.

INTRODUCTION

In this chapter the potential next steps to take to further develop the tool will be presented. First a roadmap for development will be presented to create an overview and guide for development. Next a design brief for the first steps in the roadmap will be presented. This design brief will be supported with a toolkit containing presentation materials and summaries of research and findings to help the next project owner continue the project with all the information needed.

Chapter 5.1

DEVELOPMENT ROADMAP

For the further development of the project a roadmap has been set up. This roadmap purely is based on the steps needed to complete the project and does not take into account a precise timeline. The timeline will be strongly depending on the developments of Damen as a company but also external factors.
Below the roadmap and the steps to be taken will be explained. In figure 38 the complete roadmap is displayed visually and summarised.

Step 1: Validation and Collection
Step one in the roadmap will be to validate the work conducted up until this point. This is also the step to collect the missing information needed to be used as input for decision making. At the same time this is the moment to activate and inspire the end users and important stakeholders to support the project and actively participate in the development of it.
A good starting point will be to organise focus group presentation sessions with the different stakeholders. Mainly the foreman, pipe fitters, pipe manufacturers/ welders, engineers and possibly yard management are important for these sessions. In the sessions the current prototypes and ideas can be presented. The sessions can also be used as initial feedback sessions. Ideally some demonstrations in the real work environment can be conducted together with the end user. The ultimate goal is to collect user requirements that have not been taking into account yet.
Also observations on the current workflow can be conducted to validate if the workflows created in chapter 3.5 and 4.3 are correct. Time measurements can be used to create input for the business case.

Step 2: Evaluation and Decision
At this step the results, feedback and input of the testing and validation stage has to be evaluated and summarized. The list of requirements will have to expanded with the results from the previous step and it has to be determined which requirements have been met and which ones have not.
Also the business cases for the different development scenario's and workflows can be completed using accurate and realistic values.
At the end of this stage a decision about which direction to choose for the further development of the tool will have to be made. In short the initial options will be;

1. Continue with the current MVP pipe fitting tool solution
2. Change the direction and start researching and developing other tools or techniques
3. Terminate the pipe fitting tool project and focus on new or other “Paperless Yard” projects

A possible fourth option can be that the results for the MVP prototype are promising but the support of stakeholders is missing due to a poorly functioning prototype that is not yet suitable for usage in a realistic environment. If this is the case the choice can be made to accept the quote from TWNKLS as presented in chapter 4.2 for reworking the tool and application to support smaller and improved markers. Using this improved tool prototype the presenting, testing and validation steps from step one will have to be redone again together with the stakeholders.

To be able to make this decision most important will be to research if the chosen technology for the MVP is capable of achieving the desired accuracy as stated in the requirements while still being suitable for usage in a shipbuilding environment. The decision to terminate the project at this point or not depends on the results of the previous step. There has to be sufficient support

and trust of the different stakeholders to continue with the project. The end users and the pipe workshop will have to be motivated to help with the development and be receptive to the implementation of it. It will also be important to align the requirements and wishes of the different stakeholders. Mainly the differences between the yard workers and the higher management in the Netherlands will need to be aligned.
The decision to terminate the project, maybe temporarily, can also be to be able to define the short and long term vision and goals of the paperless project. Once these objectives are more clearly defined the pipe fitting tool project can be adjusted to help meet and realise these objectives.

Step 3: Developing
When chosen to continue developing the MVP pipe fitting tool this is the stage where the tool will have to be developed into a complete working prototype. The tool will have to meet all the requirements set in the previous steps and development. It will be useful to focus on one specific yard for the development of this prototype as there are significant differences in both the workflows as well as social aspects. As the focus up until now has been on Galati and Song Cam it will be smart to continue with Galati first as this yard is easier to travel to. Most of the information collected for now has also been collected for the Galati pipe workshop.
The development of the prototype will require regular testing and evaluation using realistic test setups. Also constant updates for the stakeholders and feedback and evaluation meetings are important to both aid the successful development of the tool but also keep the stakeholders interested and inspired for creating a feasible tool.
At this stage it is also important to make a decision on which workflow scenario will be used. The different workflows presented in chapter 4.3 can have a significant differences on production times, production planning and cost savings. Using the business case and the feedback from stakeholders a decision can be made.
Once there is a functional prototype that meets all the important requirements work can continue to the next step.

Step 4: Trial
At this stage the production trials can start. Ideally a part of the pipe workshop and on site engineering at the yard will completely switch to using the tool for pipe measuring and fabrication while the other part continues working as usual. This way accurate comparisons in efficiency but also time, material and cost savings can be made. This will require accurate planning and possibly training of employees beforehand. The trial will probably need to run for several weeks to make sure employees get used to the new workflow but also to allow for data and feedback collection on a large range of different scenarios.
Continues data and feedback collection will be key as well as adequate support on site for any issues and questions on the tool. A project manager will most likely have to be on site to supervise the trial and if any external partners are involved in the development these will have to be at least available for support via digital communications.

Step 5: Reflection and Decision
At this stage the results from the trial stage will have to be evaluated. Based on these results and the feedback of the users the decision to start implementing the tool in the workflow or if it needs more development and testing first. If the decision is made to implement it the final feedback of the users will have to be implemented in the tool to create a final version.
If more work is needed the tool will need more research and development as well as additional trial sessions.
Once feedback have been implemented into the tool the project can continue to the final stage.

Step 6: Implementation
The final step will be (worldwide) implementation. At first the tool can be implemented at the Galati yard. This will mean that personnel of the pipe workshop and the engineering department will require proper introduction and training on the new workflow and tool. Next the tool can be implemented together with the new workflow.
For worldwide implementation it will be key to define the current piping workflows for the specific yards and try to place the tool within these workflows. Again involving the end users and stakeholders of these yards will be important to generate interest and understanding for the workflow change. Realistically the tool will require tweaking and fine tuning to make it custom fit to the workflow of the different worldwide yards. It will be best to develop and implement the tool in stages.

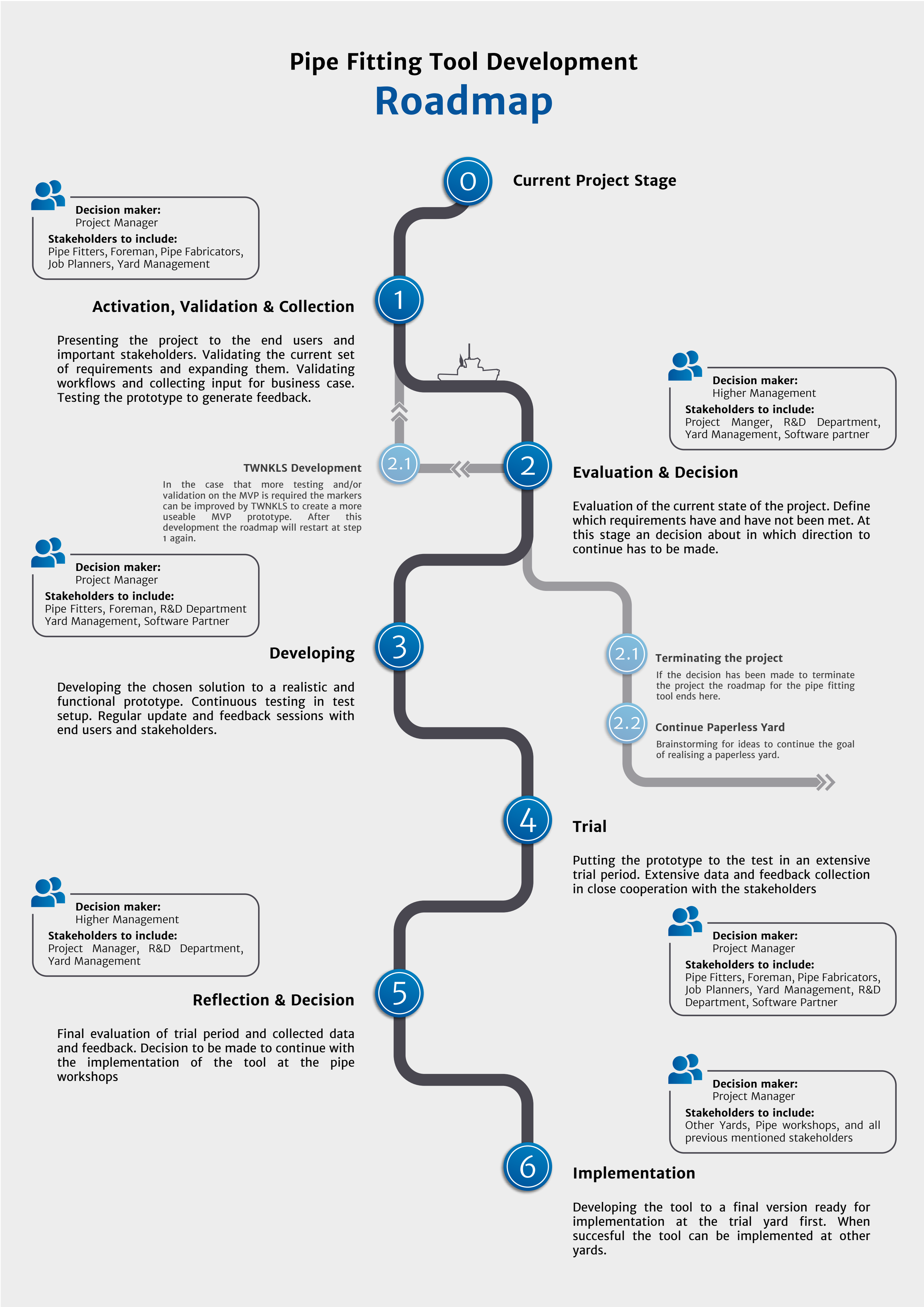

Figure 38, Roadmap Pipe fitting tool development

Chapter 5.2

RELATION TO PAPERLESS YARD

This assignment and project has been, as mentioned before, the result of the paperless yard project created by Damen. It was meant to be a the first step in the project and serve as an example and a low risk trial for potential (larger) future Paperless projects. The main target of project Paperless would be to find out if and how tasks within the shipbuilding processes could be digitalised using modern technologies. Often the main issue with using paper is that it takes up too much space, the costs of processing the paper is too much and it can be a bottleneck for productivity (Djassemi, M., & Sena, J. A., 2006). At the pipe workshop large bundles of paperwork is printed and used for the production of each set of pipe spools so this seemed to be the perfect starting point for the project paperless. However in the search to find solutions and ways of improving the pipe workshop one of the bottlenecks identified by Damen was the manufacturing and measuring of measured pipe spools specifically. And although this is indeed an opportunity to use to figure out how to improve this task using modern technologies, the result of that would not completely benefit the paperless project. Implementing such a tool would make the use of notepads and iso drawing paper on the worksite obsolete when measuring measure spools, it will however not make the pipe workshop paperless. The bundles of paper for pipe spool production will still exist and the now handmade Iso drawings as a result of hand measuring will be replaced by printed iso drawings created by the computer.
Purely the handling of measuring will be digitalised while the complete piping workshop will continue to operate the same as before.

This does not mean that this project can not be relevant to the Paperless project. This project can help by showing how modern technologies can support people in doing their jobs quicker, more efficiently and maybe most important, with less human error. Aldred (1998) proved that with transitioning to a paperless manufacturing system the cycle times are on average 25% lower. This project can also show how to approach any future project in which paper will be replaced with modern technologies as these changes often have an impact on the tasks and work of employees and other stakeholders.

For future development of this project for Damen it could be interesting to research how the technology of the pipe fitting tool could benefit the whole piping workshop. For instance the same technology could be used to function as a quality control tool to evaluate if the manufactured components are within the engineering margins.

Using technologies such as tablets could also provide possibilities for creating a centralized system which includes all the engineering and measuring documentation for every different vessel in production. By selecting the correct project/vessel on a tablet all the required documentation can be presented on a display to the pipe workshop. This documentation can also be linked to the measuring data of the pipe fitting tool and be automatically updated making sure everyone always has the most up to date information. This way the printed document bundles are not necessary anymore and no paper is wasted on printed documents in the bundle that would potentially not even be used. Additionally not using paper documents creates a system in which one central source of information exists, a so called Singe Source of Truth (Liebrecht, C., et al., 2018).
In an even bigger development step these systems could eventually be combined with modern manufacturing machines using computer guidance and control supporting the employees in setting up machines and manufacturing components with the best precision available. At some yards or production locations of Damen these kinds of machines are already in use.

For Damen it would be an interesting question to ask if and how they want to continue with the Paperless project. Is going paperless throughout the yards still a target and if so how quick do they want to achieve this goal? Are they trying to achieve an industry 4.0 production environment, of which paperless is a method of (Liebrecht, C., et al., 2018)? If they want to continue with the project it would be smart to try to combine creating a paperless pipe workshop with the pipe fitting tool to create a well implemented system that functions in harmony with the whole pipe workshop, the workers and all the other stakeholders involved.

5.2.2

Roadmap

In figure 39 a very basic roadmap shows the relations between project paperless and the project pipe fitting tool. In this roadmap the pipe fitting tool stays a component of project paperless. The decision for choosing to continue with paperless yard will however mean extra research steps on how to tackle the project. For the pipe fitting tool the paperless project will have consequences in the form of it needing to be able to implement with the bigger developments. The technology of the pipe fitting tool will have to be able to communicate with other systems. The decision for technology to choose for the tool will also have to incorporate the possibility of using the same technology for different jobs in the shipbuilding process.

Ultimately the pipe fitting tool will be a small part in the bigger paperless project. And neither of the projects are really depending on each other to be successful.

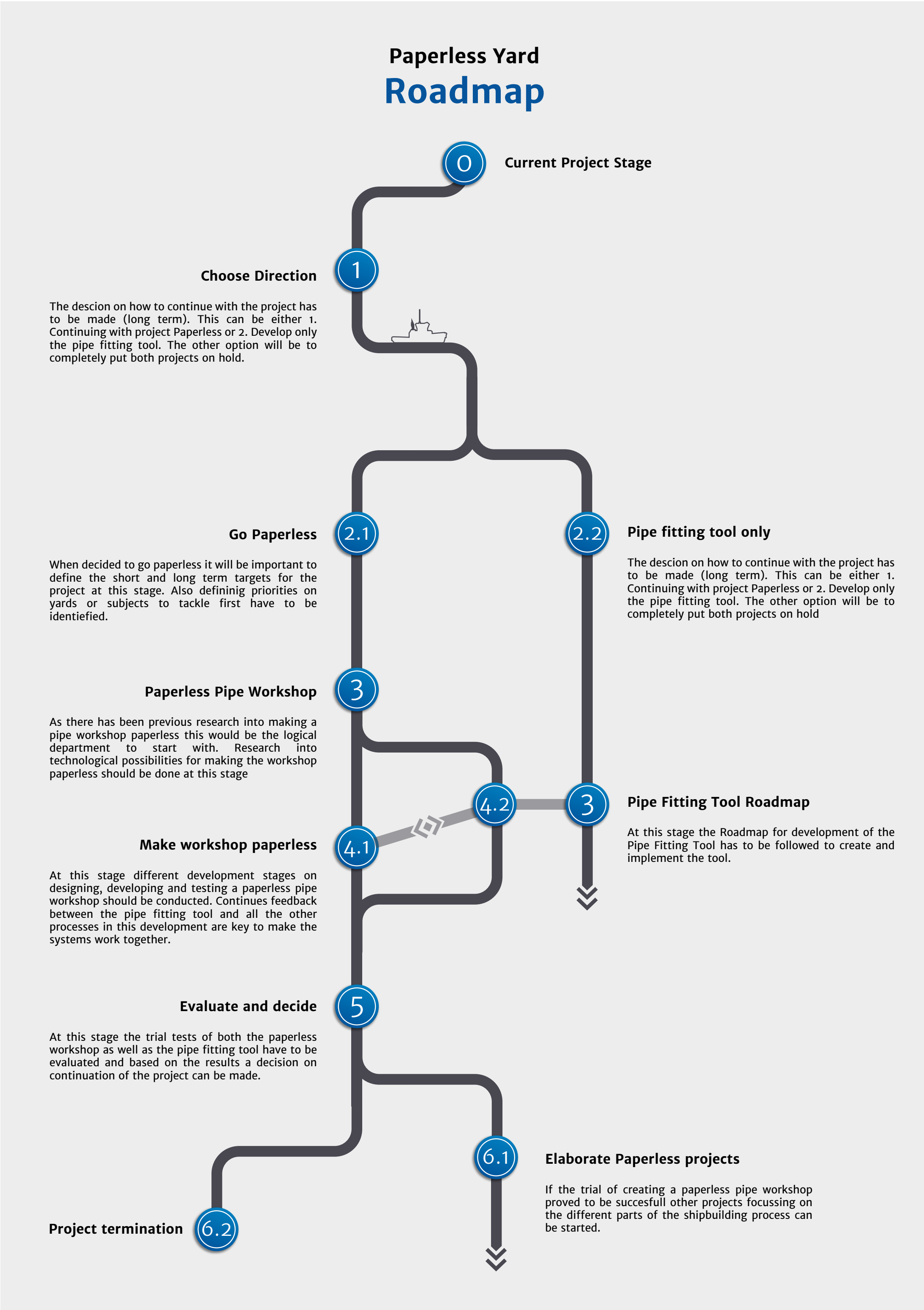

Figure 39, Development Roadmap Paperless

Chapter 5.4

ADVICE AND RECOMMENDATIONS

By combining the knowledge acquired during this project a final decision on how to exactly continue with the project cannot be made. There is some critical information missing to make these decisions. What can be done is writing an advice on the different development scenarios and how to continue with the project.

5.4.1

What do you want?

First and foremost the question “what do you want with the project” has to be answered. This question relates to both this projects focus, the pipe fitting tool, but the bigger Paperless yard project as well. The first one to answer will be what does Damen want with the Paperless project. This reason for this is that moving to a paperless yard will almost certainly involve using advanced digital systems and data, information and communication devices. If Damen still has the target to switch to a paperless yard it would be important to adapt the pipe fitting tool to this target by enabling and designing a possibility to link it to future systems. Second the question do we want to continue with developing a pipe fitting tool has to be answered. For this question to be answered Damen has to first figure out in which business unit or at which department this project belongs. Due to changes in the company structure due to reorganisations there is no obvious project owner for this project anymore. Ideally the project will be placed with people who have knowledge of improvement projects at the yards but also in close cooperation with a R&D department. The same will have to be decided for the Paperless project. After this it has to be decided if there are enough incentives to continue with the pipe fitting project. Are the potential cost savings enough to allow this project to continue and to invest recourses into it. This question is especially relevant at the moment as the spending and allocation of recourses is strictly monitored due to the current financial situation.

5.4.2

The development scenarios

With regard to the different development and implementation scenarios as presented in chapter 4.2 and 4.3 the advice would be to choose for the second scenario being implementing a pipe fitting tool and adjusting the workflow to it. Only by doing this the tool can be utilized with maximum effectiveness. By not adjusting the workflow to the implementation of such a tool it will be difficult to streamline the process. In this case the tool and workflow will be a compromise of the two entities. The biggest time saving that can be achieved in the production of measure spools is manufacturing them to the correct dimensions the first time. When the workflow is not adjusted to the use of a pipe fitting tool there will still be a lot of time spent on adjusting produced measure spools. The business cases set up in chapter 4.4 also prove that this scenarios provides the most cost savings of the different scenarios.
By choosing this direction it will be important to figure out how and where the tool can best support the work done by the pipe fitters.

5.4.3

Tool development

If the decision has been made to initially only continue with the pipe fitting tool for now the advice would be to extensively research the wishes and needs of the end users of the tool as this information is not documented enough up until now. Based on the requirements that will result from this a decision should be made on if the complicated, and expensive, technologies such as augmented reality or digital 3d scanning and metrology are actually necessary for a successful tool. It might well be that a simple low-tech solution as presented in chapter 4.5 would provide the workers with more than enough information and accuracy for them to do their jobs more accurately and quickly. Let alone it being a far less expensive option to develop. Other than that a digital solution using new technologies will be prone to bugs, crashes and possible compatibility issues in the future. It will most likely also have to deal with regular maintenance and support from software developers in the first periods of usage.

Nonetheless the results from the MVP seem promising and it will be worth a try to develop this technology further into a more useable prototype utilizing smaller markers. From discussions with the software developer and the market research it showed that there are plenty of possibilities now and in the future to improve the tool and make it capable of doing more than just measuring. Being able to present the end user with a more realistic and functional prototype will

also help them see and understand the added value of developing and implementing such a new tool.
When development funds allow it ideally it would be advisable to choose to develop the current MVP further to a solution using smaller markers as presented in chapter 4.2. Alongside a low cost prototype of the low-tech solution can be made. This prototype can be built fully inhouse using the supplies of the yard. The two different prototypes can be used to present the solution to the pipe workshop. Physical working prototypes will help communicate the idea better to these stakeholders compared to presenting the idea on paper and enabling them to try and use the prototypes afterwards can potentially activate and motivate the stakeholders to help with the development.

If the decision has been made to continue with the paperless project, be it either at short or long term, the advice would be to not only try to implement the pipe fitting tool but also try to make the whole piping shop paperless. The pipe fitting tool can be combined with a smart system which utilizes the data available which can be updates instantly using measurements made with the tool. This gives the whole piping workshop access to the most up to date and correct data. Eventually smart systems might even be able to help with production planning and stock management to maximise the efficient use of materials and lower cost on material waste. The backbone of this would be having a database that is always up to date. The documentation is available digitally but there is no central system which collects and orders these documents as of now. As for the availability of 3d data this currently differs strongly between the different business units of Damen. The workboats department is engineering their vessels completely in 3d, the High Speed Craft department does not yet do 3D engineering of all details.
In this scenario the advice would be to first define and identify the goals of the Paperless project and define how the pipe fitting tool fits in with these goals before continuing with the development. This is not only to avoid doing double work but also to make sure any systems that will be developed in a later stage are able to function together in the same workflows.

5.4.4 Stakeholders

In this report the different stakeholders for this project have been identified and it has been researched which stakeholders have been included in the project and which ones have not. The advice on the stakeholders would be to try and include the end user more. As found in the research on change management in chapter 3.2.1 the pipe workshop personnel initially responded with a lot of doubt when presented with the project and the tool. This is partially because the normal reaction is to protect the status quo, but also due to the fact that they are not informed enough about why the project is existing and how they could help developing it. Apart from getting the end user on board with the project they also have to be included due to the expert knowledge on the subject. Pipe fitting is usually done by experienced workers. They gained their experience over the years by doing the work and this rationalisation of this work is difficult (Yokoyama, H., & Takeuchi, K., 2013). For any pipe fitting tool to work and deliver the required information the knowledge these employees have is important to include.
In the end they are the ones who decide to use the tool or stick to their old ways of doing things and throw the tool in the corner to collect dust. Management could force them to use the tool but this will most likely not be in favour of a positive working environment.

The most important advice to give in further development of this project with regard to the stakeholders is to make sure all important stakeholders are either included or actively informed about changes and developments in the project depending on the importance of the stakeholder. In chapter 3.4 a visual is presented giving a guideline on informing or involving stakeholders (figure 23).

Chapter 5.5

DESIGN BRIEF

For the purpose of efficient project handover a design brief has been created. This document features a very short summary of the work done so far and the aims set for the future. The roadmap is presented together with suggestions for objectives to continue with first when a new project owner continues with the project. Alongside this design brief a file folder containing all the relevant documentation about the project has been created. This documentation consists of internal development documents, business cases, presentations and summaries of the project.
This will allow any future project owner to familiarize themselves with the project and everything done so far without having to research and dig up the required documentation as was the case with the start of this assignment.
The design brief as shown in figure 40 can be found in full in Appendix A.7.

Design Brief

Project Name: Pipe Fitting Tool

Company Name: Damen Shipyards

Department: Operations Support

Project Overview and Scope

In an effort to save costs the process of manufacturing, measuring and fitting measure spools at the yards has been identified as a task that can be improved. Especially the measuring part of the job could be improved by using a tool. For this purpose Damen has developed a prototype solution in the form of an Augmented Reality (AR) pipe fitting tool utilising the camera of a tablet and two markers to be attached to flanges.

Previous work proved that this prototype was not sufficient for trial implementations on the yard. It does not meet the set requirements and there are several stakeholders that have not been implemented in the project enough.

Several development and implementation scenarios have been created and the next step is to research and decide on which direction to continue in.

Aims

- Requirements validation
- Business case input collection
- Requirement collection
- Feedback and critique collection
- Process and workflow observation and validation
- Decision making on development
- Reconsider link with project Paperless

Summary of previous work

In previous work on this project the goal was to create a minimum viable product of the tool to be used in trial tests at the yards. The creation of a functional prototype which worked in an optimal test situation was successful and this prototype was taken to the Galatz yard for a user acceptance test. The results of this test were not as hoped as it proved to be difficult to find locations on vessels where the tool would function. This was partially due to the fact that the markers of the prototype proved to be too large and the mounting of the markers was often not possible. The system was however capable of supplying production information for a pipe spool which did fit within the production margins defined by quality control.

The next step was to continue the project by assigning it to a graduate student. In this project all previous work has been evaluated and the prototype itself as well. Early conclusions were that the prototype could not be identified as a minimum viable product as it did not meet the minimal requirements defined by previous project owners. The business case of the project proved to be based on unreliable and non-representative numbers. Also the exact workflows and production processes with regard to measure spools were not known or documented.

In close contact with experts and the yard itself these workflows have been identified and documented.

Alongside an extensive market analysis and meetings with the software developer have been held to identify the possibilities for future development. From this different potential development scenarios have been created.

Next to the development scenarios several workflow implementation scenarios have been made to show what the

Figure 40, Design brief

Chapter 5.6

CONCLUSION

Due to the reasons mentioned earlier in this report the project could not be executed and finished as initially planned. As a result the desired step towards a better and useable prototype could not be realised. The fact that testing and co-designing the solution at the yards together with the stakeholders was not possible means that there are not enough substantiated input or research results to make an informed and correct decision on the right direction to choose. The purpose of this project has therefore shifted towards a more informing nature. The goal was to present the current situation and the now known information as detailed as possible to create a clear image of the current state of the project, the people involved and the workflows involved.

answering the research question "*How does the pipe fitting tool need to be developed to make it an accepted tool within the shipyards as well as it being an added value to the process of shipbuilding?*" has been partially achieved in this project and report and most of the sub questions have been answered.

Investigate
The sub questions regarding the investigation have been answered. The pipe fitting processes have been researched and visualised and the stakeholders and corresponding information flows have been found. The mayor bottleneck that has been found in the process were the additional adjustment and finishing steps together with the extra transportation moments needed for the completion of a measure spool. By placing the pipe fitting tool within these processes the results and consequences of the implementation could be presented.
The results have however not been fully validated yet. This is a step that will have to be conducted when continuing with the project.

Evaluate
The points of improvement have been validated and further identified by using and testing the tool in various situations. The initial requirements have been elaborated. The exact requirements of the end users and other stakeholders like the pipe workshop and other yard personnel still need more research. The yard workers in the Netherlands proved to not comparable to the ones in Galati Romania as the way of working is completely different. As it was not possible to incorporate these people in the project the correct requirements are not known yet and have to be identified.

Design
The design part of the research question stays relatively unanswered. This is partially because important input from testing and stakeholder research is still missing but also because there are some unknowns. Ultimately there are possibilities to improve the current AR marker. The connection to the flange can be made easier as shown in chapter 4.6. The size of the markers was one of the main issues making the tool not suitable for usage in the production area. Smaller markers are technically possible but it is unknown what the consequences will be for the accuracy of the tool or if the accuracy requirement of Damen is achievable. This can only be answered by creating the tool and testing it.
Different scenarios for development of the tool have been created and presented in chapter 4.2.
The question what the correct technology is to choose for this tool is strongly depending on the long term goals of Damen as a company and the long term goals of this tool. When the goal is to purely make a measuring tool for measure spools AR might be a little too advanced and too complicated for the job. When Damen plans on expanding similar technology to different kinds of jobs in the shipbuilding process or create a complete industry 4.0 production environment it makes the use of AR a lot more suitable because of the different possibilities of the technology.

Future
With regard to the future the question on how to continue with developing and implementing the tool and what resources and people are required in this process this has been answered in chapter 5.1 by creating a roadmap for further implementation. In the advice given in chapter 5.4 the different development and implementation scenarios and possibilities are discusses in an effort to provide Damen with the right information on what to decide to do next.
A timeline on implementation cannot be given realistically as there is no clear answer on how Damen wants to continue with the project in the future. Also the current economic situation makes for changes in the company structure that influence this project.

Usability of results
In the end questions can be asked if this assignment

and the results in only relevant to Damen or if it is applicable for the whole industry. And in short the answer is that the results could also be of interest to the whole industry. The way how this development process has been conducted and the resulting roadmaps and advices can be easily translated to different industries looking for technological improvement projects. This project can be of use to learn from and be prepared for different setbacks and incidents that can happen during such a project.
The tool itself could also be of interest to different industries in which piping systems are designed and manufactured. Production plants and oil rigs often run into the same issues as Damen. When Damen succeeds in rationalizing the work of pipe fitting and realise a reduction in repeated work while still being able to measure accurately they have created a valuable tool that can be of interest to other industries (Yokoyama, H., & Takeuchi, K., 2013).

Concluding the end result of this project is still an open book. It is key for Damen to decide for themselves what their short and long term goals are with the Pipe fitting tool and the project Paperless yard as well. Only when this is known strategic choices can be made to benefit the development of either of those projects. And once decided the roadmap will provide a guideline on how to continue, which steps to take and which people to involve to get to the desired result.

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A.a

APPENDIX

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Appendix A.1 – Business case tables

[redacted]

Appendix A.2 – Lelea Table Stakeholder Analysis

Issue	Goal(s)	Questions to be addressed
Power	Examine power differ-ences between actors that may be important for the issue/problem to be addressed	• How does the actor influence other actor's role and scope of action? • How is the actor influenced by other actors with regard to his/her role and scope of ac-tion? • What is the actor's authority in terms of: § Setting objectives and norms? § Allocating or denying resources to other actors? § Defining others' tasks and responsibilities? § Controlling access to knowledge/information? § Allocating rewards/recognition/sanctions? § Channelling messages to superiors and external bodies?
Interest	Describe the actors' interest(s) in relation to the problem/issue the project focuses on	• What is the actor's interest in the issue/problem? • What prior experience does the actor have on the problem/issue to be addressed? • What potential benefits and risks arise for him/her if the issue is addressed/the problem is solved? • To which degree are the actor's interests coherent or conflictive with other actors' inter-ests? • What options exist to increase the actor's interest and engagement, or to dismantle obsta-cles?
Resources	Identify material and non-material resources different actors possess or have control over	• What relevant resources does the actor have at his/her disposal (e.g. knowledge, exper-tise, skills, material resources)? • What potential contributions could arise from this? • Which resources are missing that may be needed to effectively address the issue/solve the problem?
Relationships	Describe the relation-ships between actors, e.g. with regard to distance, degree of trust and/or conflict	• Which actors cooperate with each other? • Which actors compete with each other? • Which actors tend to be disconnected from other actors? • Which degree of trust/mistrust is there between the various actors? • Which conflicts exist and how explicit are they?
Social difference	Identify differences in actors' power, interest, resources and rela-tion-ships that relate to social categories they belong to	• How are differences in power, interest, resources and relationships related to age, gender, ethnic group, educational background or wealth? • Are any strategies necessary to avoid exclusion of certain groups of actors? • Which empowering measures may be required?

Appendix A.3 – Stakeholder Analysis

A.3.1 Power and interest of stakeholders

Operation Support Manager
Power:
- Power to approve (improvement) projects for the yards
- Tied to budgets and policy from higher management
- Responsible for the improvement agendas of the yards

Interest:
- Significant interest in delivering a successful project to show the effectiveness of the improvement agenda

Recourses:
- Extensive experience in project management
- Extensive with yard improvement projects
- Knowledge on budgeting and testing

Operation Support Project Manager
Power:
- Main project owner of the Pipe Fitting Tool
- Responsible for primary decision making in the project
- Has to answer to the Yard Support Manager

Interest:
- Developing a successful solution and deliver a project that will improve yard efficiency

Recourses:
- Contacts with specific and detailed knowledge on parts of shipbuilding

R&D Engineer
Power:
- Currently no power on the issue as the project is owned by the Operation Support department

Interest:
- The project could potentially deliver insights or results that can help with other developments with regard to new technologies and tools

Recourses:
- Extensive knowledge in researching new technologies and techniques
- Potentially have similar issues or questions
- Might have knowledge on useful technologies
- Research budget for promising ideas

Yard Management/Director
Power:
- Responsible for processes, management and regulations on the shipyard
- Authority to set objectives and norm and defining tasks and responsibilities of employees
- Authority to allocate budget to specific projects
- Does to an extend answer to the EB of the Damen group

Interest:
- Has an interest in creating time and cost saving solutions for their yard
- Creating a solution that will keep employees happy and interested

Recourses:
- Extensive knowledge on the functioning of the yard and employee relations
- Ability to find the correct people to help develop the project

Job Planner
Power:
- Has little to no power on the issue.

Interest:
- Interest in solutions allowing for more time efficient planning

Recourses:
- Can provide insight in current ways of production planning
- Can help expose bottlenecks in production planning

Production Manager
Power:
- Influence on how processes are ran within the yard
- Can set objectives and tasks for the yard/project in production
- Influenced by higher management, the EB and operations support

Interest:
- Interest in improving project efficiency and decreasing of (human) errors

Recourses:
- Able to supply relevant feedback on implemented solutions
- Able to communicate issues, requirements and wishes for improvement on the yards

Pipe Fitter
Power:
- No direct power on the issue or the development of the project
- Does have a power in rejecting or refusing solutions
- Can have an influence on co-

workers and their opinions

Interest:

- No direct interest in the issue other than that this tool could make their jobs easier and less prone to errors
- As this issue does concern the daily activities of a pipe fitter they do have an interest in the final outcome of the project.
- Potential risk that they will feel that their expertise and skill will become less valuable to the company and that they might become obsolete when less workers are needed for the same job

Recourses:

- Extensive arsenal of knowledge, expertise and skills on pipe measuring and fitting
- Valuable insight in understanding the difficulties of the job
- Can identify areas that need improvement
- Can provide valuable user input on proposed solutions

Pipe Workshop

Power:

- No direct power in the issue other than that they can reject the solution if it does not deliver usable data or information

Interest:

- Potential interest of the pipe workshop can be that they could manufacture first time right
- Cost, time and material savings

Recourses:

- Can deliver input on desired way and form of information transfer

Repair, Maintenance, Refit Yards

Power:

- For now do not have power in the issue as the focus is on new build yards for now

Interest:

- They can have an interest in creating a useful solution to the issue as this can deliver valuable time and cost savings
- Repair and maintenance yards come across lots of custom pipe work for which such a solution can be very useful

Software Developer

Power:

- No power in decision making
- Can have an indirect power in decisions based on feasibility of ideas

Interest:

- Interest in building a long term relation with Damen Shipyards
- Research and Development potential for new technologies and solutions

Recourses

- Knowledge on possibilities and potential of software and technologies
- Can give advice on potential future developments and techniques

Hardware Supplier

Power:

- No power other than that hardware with the required or optimal specifications might not be available (yet)

Interest:

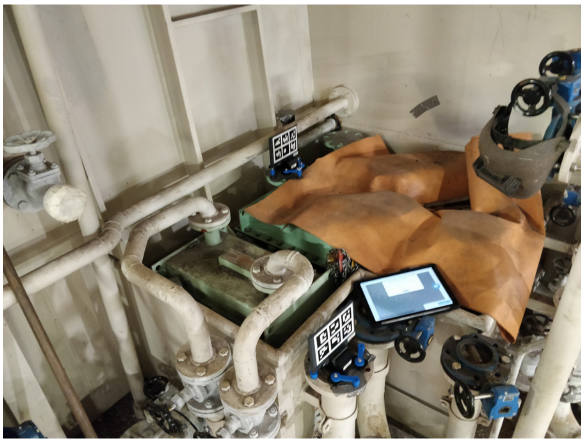
- Potential interest in creating a long term relationship with Damen Shipyards

Resources:

- Source of information on technologies that are supplied
- Can give advice based on real world results of applications of technology

Appendix A.4 - Notes Test session DSGO 28-10-19

Test 1



Testdsg001
Test setup:

Test notes:
- Pictures from 6 angles is possible
- Start-marker fits the flange, the end-marker also fits in this orientation
- There is a lot of distance needed between the camera and the markers to get both markers in view at the same time, in a more tight engine room this will be difficult
- Based on what workers working on the ship said this was an engine room with a lot of space available to work in. In other ships there is significantly less space
- No obstructions in the field of view

Scan result: Error, Image quality not sufficient.

Processing result: Processing not possible due to failed scan.

Testdsg002
The setup and notes are the same for this test as they were for Testdsg001. The only difference was that the images were taken with more care with regards to sharpness and illumination.

Scan Result: Error, Image quality not sufficient

Processing result: Processing not possible due to failed scan.

The errors in both scans are probably caused by insufficient illumination in the machine room or too much distance between the markers.

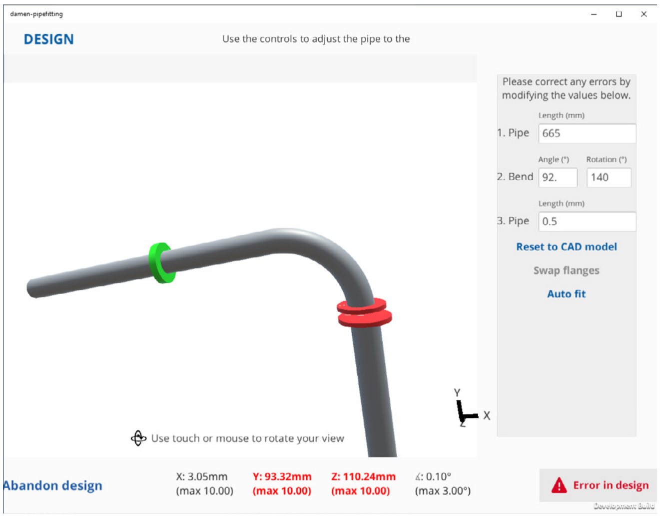
Test 2

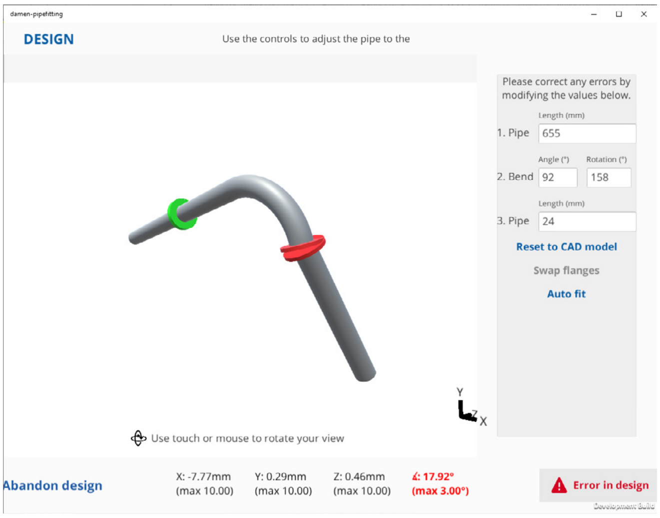
Testdsg003
Test setup:

Test notes:
- End-Marker does not fit on flange due to another pipe limiting the space
- Difficult to find six different angles to take pictures
- Making picture from the left angle is not possible due to other piping and the wall of the ship
- App freezes after taking pictures and clicking the ‘ok next step’ button

Scan result: Scan successful

Processing result: The processing finished in 25 minutes. The images process correctly but the software is not able to create fitting pipe with the current setup as the angle of the end flange cannot be adjusted.





Test 3

Testdsg004

Test setup:

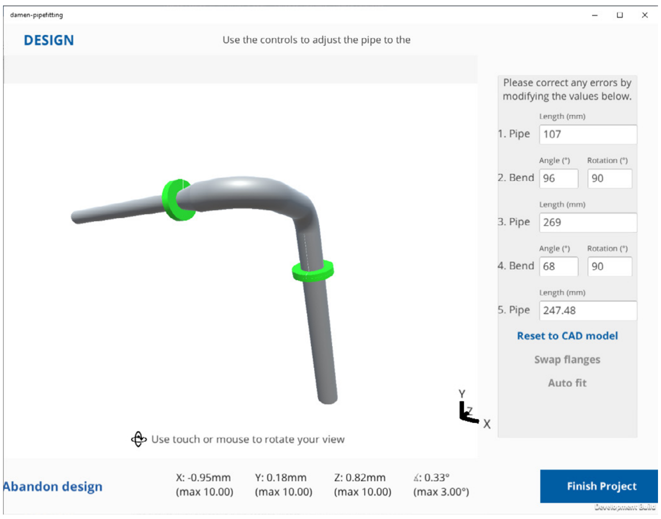
Test notes:

- Six different angles was possible with some effort
- The user needs to put himself in some rather difficult positions to get enough different angles

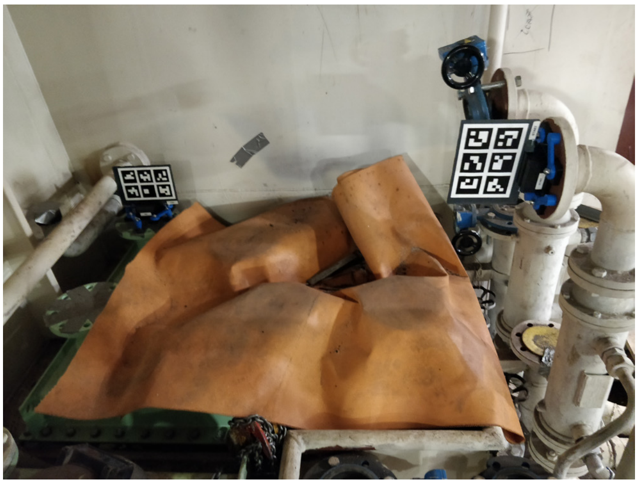
Scan result: Scan successful

Processing result: Processing failed at first attempt. The software says the preprocessing on the tablet has not been finished, but on the tablet the scanning was successful.

Retry of processing: After copying the files again the processing does finish. However on one picture the point cloud is misaligned and not placed on the marker correctly. This might cause errors in the dimensions. The processing finished in 28 minutes.



Test 4



Testdsg005

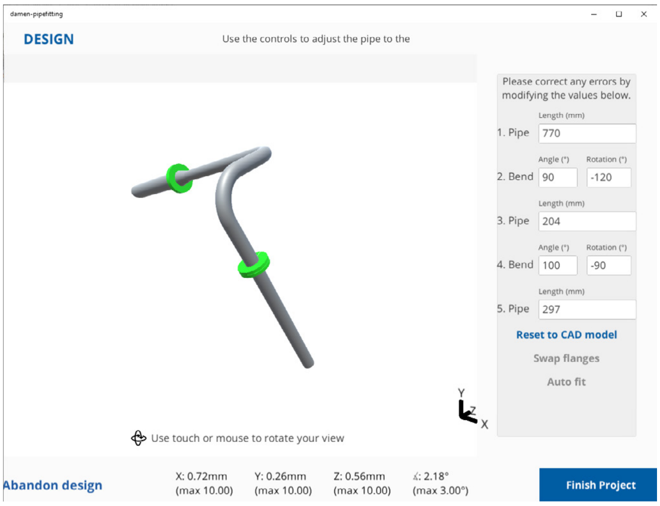
Test setup:

Test notes:

- Difficult to get six different angles
- Flanges are relatively far apart (1,5-2 meters)
- Another pipe is in the way of the End-Marker so this one cannot be fitted to the flange correctly
- Pipe obstructing the view of the markers in some pictures
- App crashes when evaluating the processed images

Scan Result: Scan successful. The setup of this test is similar to the first test, but this scan did pre-process correctly.

Processing Result: The processing finished in 21 minutes. A pipe design within margins could be generated with the software.



Test 5

Testdsg006

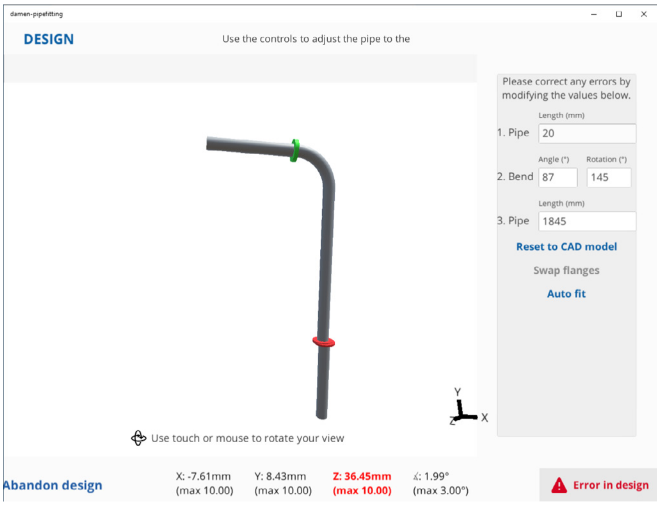
Test setup:

Test notes:

- Big distance between flanges (205cm)
- Almost 4 meters distance needed between the camera and the markers to get both of them within view

Scan Result: Scan successful

Processing Result: The processing finished in 29 minutes. The software could not create a fitting pipe as the angle of the flange could not be adjusted.
8.10



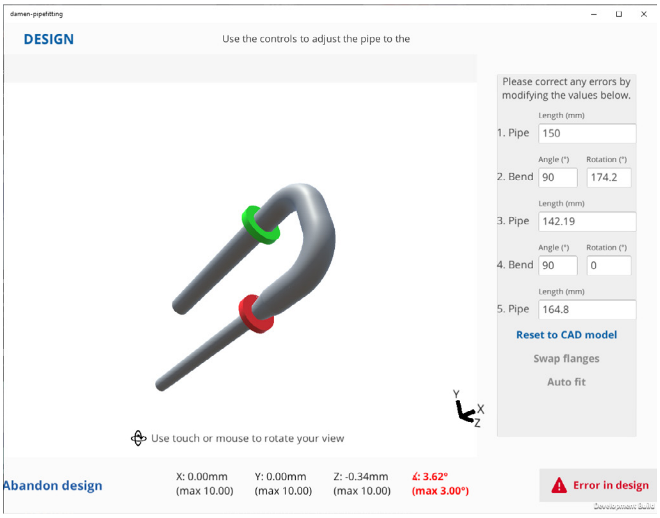
Test 6

Testdsg007
Test setup:

Test notes:
- Start-marker does not fit bolt holes of flange because of the paint on the flange
- Lots of angles to take pictures possible due to small distance between flanges and the room around the markers
- Not a lot of distance needed between the marker and the camera as they are close to each other

Scan result: Scan successful

Processing result: This scan processed in 45 minutes, which is the longest of all the tests in this session. A fitting pipe design could almost be created, but only the angle of the end flange was outside of the margins with 0,62 degrees. This pipe is a good example of obstructions in the path of the pipe design. The scan does not take into account the pipe in between the markers. The generated pipe design would be feasible for fabrication, but cannot be mounted.



Test 7

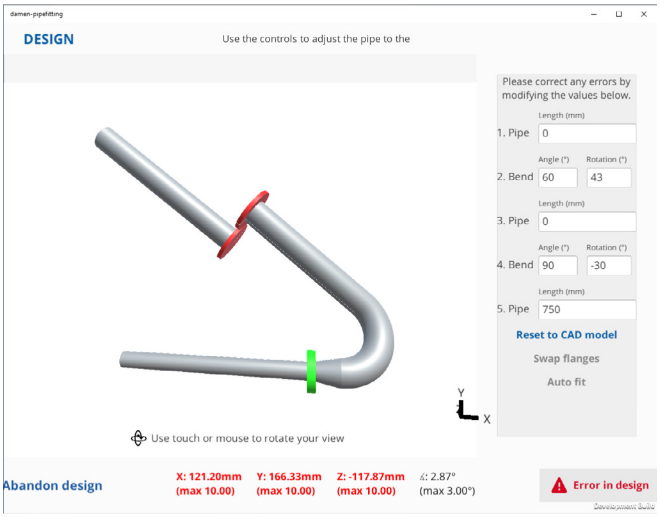
Testdsg008

Test setup:

Test notes:

Scan result: Scan successful

Processing result: Processing successful in 29 minutes. A pipe design could not be made. The reason for this is that the bending radius of the pipe is too large to connect both flanges. Using a smaller pipe diameter the design should be possible, but this is not possible with the current software.



9.10

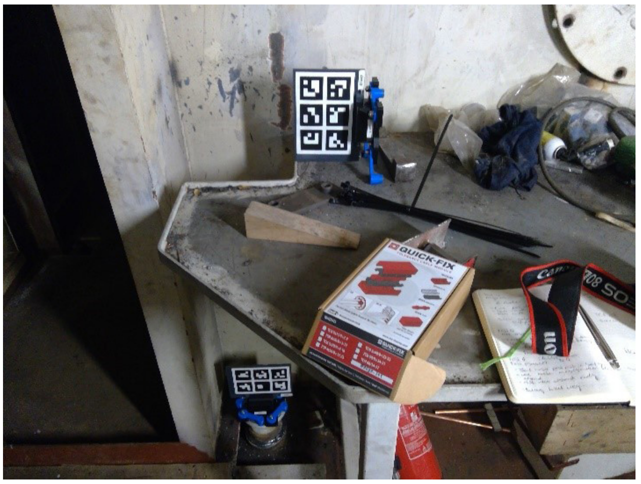
Test 8

Testdsg009

Scan setup:

Scan notes:

- In some pictures the view on one of the markers was obstructed by other components in the ship



Scan result: Scan successful. Although in some pictures one of the markers was not completely visible to the camera. The processing did however recognize it correctly.

Processing result: Processing failed at both attempts after 18 minutes due to image quality. What is weird is that the pre processing on the tablet did finish correctly and all the markers were recognized correctly.

Test 9

A final test conducted was meant to test a theory. To overcome the issue of needing too much distance to get both markers in the frame a Dslr camera with an extreme wide angle lens was used to take pictures. These pictures were put in the project folders on the tablet to be processed. It was tried several times with different pictures but the processing failed with the error 'quality of images insufficient'.
This method of taking pictures with another camera to process them later should be feasible, but has to be developed and implemented to function properly if there is a need for it.

Appendix A.5 – Email with yards

A.5.1 Email conversation production Galati

Black: Questions asked

Yellow: First answers

Red: Follow up questions

Green: Follow up answers

Blue: Follow up questions

Purple: Follow up answers

1. Is there a DSGa measure spool work instruction or process flow available? No we don't have For both possibilities below (found in DSGa pipefitter manual on page 155)
    a. Classical measure pipe outfitting process (mainly DN<25mm)

> For the pipelines manufactured classically (esp. the thin pipes) the mould of those pipelines shall be as an isometric drawing delivered to the prefab shop in order to be manufactured subsequently.

Our target it is all pipes to be made in Pipe Workshop . This is the aim, fully agree. So this type should not be the focus of this project, correct?

> The pipeline delivered by the semi finished product manufacturing shop is of two kinds: certain and uncertain. Uncertain pipelines are those made with material additions and are fixed in welding points. They shall be fitted at ship and then sent to the shop to be welded and physically/chemically protected, and then final mounting follows.

Yes it is correct

2. Outfitting engineering / Job preparation adds overlength to measure spools (spool XML and drawing available)
    a. Is this added to the XML, Pipefab (spool drawing and sawing list) or on paper? It is added in XML file
3. Are measure spools included in the normal mounting work packages (albums) or in separate packages? In a normal package

So if I understand correctly there are albums / work packages for:

- Per section
    - Inside tanks à where can be measure pipes? (for example one measure pipe per line in a tank? After coupling of section (tank) **Yes Correct , after coupling the sections , inside the tank**)
    - In skids à where can be measure pipes? (preferably not, right?) **Yes , preferably not**
    - Outside tanks, per system à where can be measure pipes? (for example after coupling of sections and blocks **Yes Correct , after coupling the sections and / or blocks** ? Or are these compartment albums?)
- Per compartment

- o Per system à I think here are most measure pipes, correct? Mainly between equipments and lines? **Yes Correct**

4. Are measure spools planned/handled differently compared to ready spools? If yes, how? No
5. How many measure spools are fitted and/or measured at the same time?
   a. Is this done one by one or in batches? one by one

   So if I understand correctly, for example a pipe fitter on board has mounted all ready pipes of one line, and now the final pipe is measure pipe. Is the sequence as below?

   1. He takes measurements between the two flanges **or two sleeves or free two ends pipes** What is the (approximate) ratio of measure pipes with flanges / sleeves / free ends? Around 60/20/20? Or depends on shiptype? Can you please fill in below:

      O&T vessel: 50/30/20

      DSNS: 60/20/20

      Yacht: 40/30/30

      Tug: 50/30/20

      If you have no data on this subject, just experience estimation is sufficient. For us it's very useful to know, since the tool is now only applicable for measure pipes with flanges.

   2. If adjustments are needed, he grinds loose tack weld and adjusts spool by removing over-length (or something else?)**only remove the overlength because the fittings it is complet-ed welded on measured pipes only flange or sleeve to the ends of the pipes it is only tack welded**

      So, just to verify, generally speaking a measure pipe has overlength and tack welded flanges/ sleeves on both ends, correct? **YES CORRECT**

   3. Fitter tack welds adjusted spool and sends individual spool back to workshop? **Yes Correct** How long does transport take (approximately)?**Between 10 - 20 minutes** Transport arranged per foreman phonecall - spool, group of spools? **Yes by phonecall on group of spools** - or daily transport? Generally speaking, does pipe mounting foreman arrange trans-port for group of measure spools one time a day for all his pipe fitters (his pipe fitters can be divided over multiple projects, right?)? **YES CORRECT** Or section by section, compartment by compartment (location where team of his pipe fitters are)? **YES CORRECT** Just to estimate how many transports are needed per day.
   4. In workshop, adjusted spool is put at welding station by logistical worker? **Yes Correct** Welding and quality control according to normal process **Yes Correct** If the group of spools arrive at the workshop, what happens then? Gabriela or foreman arranges that they are brought with priority to welders? Or logistical worker gets a phonecall and he makes sure the measure pipes are put near welder's workstations? **YES CORRECT logistical work-er makes sure the measure pipes are put near welder's workstations are brought with priority , DEPEND OF THE STAGE OF THE VESSEL**

5. Treatment according to normal process (for example included in galvanizing batch) Yes Correct

6. Sorting – how is it done? Album container (with album checklist) is located on board, right? Yes Correct Or is this list going back to pipeshop together with measure pipe? no What if there are multiple measure pipes per album? I not understood How does the sorter know which finished measure pipes go together and where they have to go? **by phonecall between foreman and sorter**

   How is finalized measure pipe going on board again? **Spool by spool** Spool by spool or per album? How long does transport take (approximately)? **Between 10 - 20 minutes** Transport arranged per foreman phonecall - spool, group of spools? **Yes by phonecall on group of spools** - or daily transport?

b. Are the measure spools fitted, transported and adjusted one by one? Yes

6. Is measuring, fitting and adjusting of measure spools done by the same pipe fitter? No Only on board, or partly in workshop (adjusting, e.g. sawing)? In Work Shop and also on board .

7. How often are there "problematic" pipes? 10 % of pipes

   1. Pipes unable to be fitted without stress

   2. Piping prone to failure due to incorrect fitting/measuring

   3. Difficult routing or shapes

6. Do piping spools smaller than DN25 also have measure spools (in case they have spool XML/drawing)? In the majority of cases we don't have anything : spool XML/drawing

7. How fast do the measure spools have to be finished? 2 days Within week after measurement?

   1. Lead time per work package or per spool? per spool

   2. Is lead time or man-hours per spool more important for measure spool? Yes

6. What is the working area for measure spools? (e.g. biggest measure spool)between coupling of the sections and coupling with equipment's

   1. What is the maximal distance between flanges? No limit . Limit is maximum length of measure spools, correct? Yes Correct We will check some engineering data.

   2. What is the maximal measure spool length? No limit

A.5.2 Email conversation production Song Cam

Black: Questions
Red: Answers

1. Is there a Song Cam pipe fitting manual available? (At DSGa there is a comprehensive pipe fitting manual available) No. we have a production handbook.

2. Is there a Song Cam measure spool instruction or process flow available? No, but our process is pretty similar with the ones from Galatz.

3. Is there a Song Cam general piping process flow available? No, but our process is pretty similar with the ones from Galatz. Pease consider the differences in our bussinness model.

4. How does engineering / job preparation at Song Cam handle measure spools?
    a. What information is used / received from DSGo by the job preparation team?
        i. E.g. which files/file extensions used (DSGo uses XML spool information to import in Pipefab), what type of information is prepared for the pipe workshop We are not using Pipe Fab in work preparation. All ISO sketches are exported from CADMATIC and WP make the demarcation Hull yard – DSCS. WP make the MTO for Supply chain as well.
    b. Do they add overlength to the measure pipe design information received from DSGo? If yes, how and where do they do that (DSGa uses pipefab for example) We receive all neccessary informations on ISO sketches.
4. Can you explain in short how the production, fitting, measuring and adjusting process for measure spools at Song Cam works? Is this comparable to the attached workflow from DSGa? What are differences? Yes is comparable with DSGa.

as a starting point you have to know that our business model is completely different than Galatz one. We are building hull ++ in partner yards and we do only the outfitting, painting, commissioning, trials and delivery. Consequently, 90% of our piping production consists of measured pipes. In these circumstances would be very interesting for me to figure it our how the savings for DSCS were determined.

Appendix A.6 – Plan of Approach research Galati

The pipe fitting tool

In a quest to make the pipe fitting process in the production of Damen more efficient a concept for a so called Augmented Reality Pipe Fitting tool has been developed. This tool is meant to assist pipe fitters and fabricators to measure and create perfectly fitting measure spools quickly and first time right without transporting the spool to and from the vessel multiple times for test fitting and adjusting.
Research and evaluation of the current solution proved that the current tool is not sufficient enough the be called a Minimal Viable Product yet. It performs well in the test setup but it will fail when used in the production at the yards. The main reasons for this are unclear requirements and insufficient understanding of the relations and influences of all the aspects of the piping production process.
To get a better understanding of the piping process and the needed requirements for a successful implementation of a pipe fitting tool some field research at the yard is necessary.

Goals of field research

1. Mapping the current pipe fitting process from start to finish at Damen Galati/Checking with current view on production flow
2. Understanding the process and how everything influences each other
3. Creating an extensive business case for the pipe fitting tool/validating the original business case
4. Collecting the requirements, wishes and ideas of the actual end user of the pipe fitting tool
5. Collecting requirements based on the current pipe designing, routing, fabrication and fitting processes
6. Collecting requirements linked to the working area in which the tool has to function
7. Validating if and how a pipe fitting tool will influence and fit it with the current processes of Damen

What has been done

Evaluation of previous work

- Business case; Potential annual savings of 160.000 euro at Galati and 105.000 euro at Song Cam
    - Based on time savings for measuring on board and adjustment times
    - Unclear if transport between workshop and vessel is included
    - Source of said time savings unclear
- UAT and sign off docs
    - Unsuccessful UAT; only one pipe measured in three days of testing
        - Markers are too big to fit the working environment
    - Technology works in optimal testing environment
    - Unclear what the agreed requirements were upfront
    - Although signed off, the project has not met the initial requirements

Evaluation of current pipe fitting tool solution

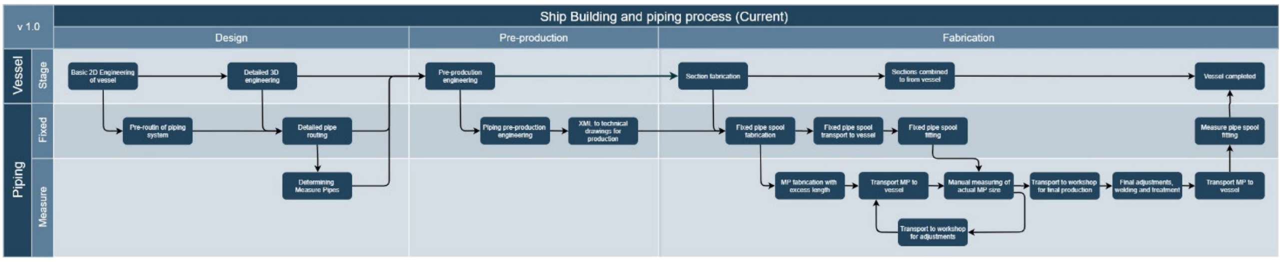
- Markers are difficult to attach to flanges
- Scanning process is slow, long waiting and processing times
- Flanges on the test setup are incorrectly placed
- Flange/bolt hole rotation/position is not takin into account

Market analysis

- Lots of promising new technologies available
- Successful implementations are found in reverse engineering applications
    - Uses 3d data and 3d modelling after scanning, no direct adjustments based on scan result
- 3D scanning seems promising
- Technology is 'not there yet' but will be soon

Research conclusion

- The tool that has been developed is NOT an MVP
- The current tool is NOT ready for production testing



Plan of approach for collecting requirements

Working area

1. Exploring the yard and pipe workshop
2. Exploring different vessels in production
3. Measuring spaces and rooms inside vessels
4. Documenting the working area's for future reference

Pipe design and fabrication processes

1. Empirical research
2. Observing the current processes
    a. Following and watching people in doing their regular job
3. Possibly doing measurement on production and/or process times

Interviews/questionnaires

1. Talking with the different people involved in all stages of the piping process
2. Trying to find out what obstacles, bottlenecks and irritations they experience while doing the job
3. Trying to find out what they think will make the job more efficient or more enjoyable

Questions

Business case

1. How many pipe spools are fabricated/fitted annually?
    a. How many of those are measure spools?
2. How many man hours are currently spent on fabricating, adjusting and fitting measure spools?
    a. How many of those hours are transportation?
    b. How many of those hours are adjusting measure spools?
    c. What is the production time of a single pipe spool?
    d. How long does a measure spool adjustment take?
3. How long is the transport time between the workshop and the vessel?
4. What percentage of measure spools are first time right?
5. What percentage of measure spools are second time right (or more?)?

General Process questions

1. How is does the current piping process work at Damen Galati from start to finish?
2. Are measure spools handled differently compared to fixed pipe spools?
3. Is pre-production for piping done by job preparation or by the pipe workshop? Or somewhere else?
4. Are pipes produced one by one, by diameter/tube type or in batches (cutting/bending all components and welding afterwards)

5. Is measuring, fitting and producing piping done by the same person?
6. How much time does it cost to transport a pipe from the workshop to the vessel?
7. How often are there "problematic" pipes?
    a. Pipes unable to be fitted without stress
    b. Piping prone to failure due to incorrect fitting/measuring
    c. Difficult routing or shapes
8. How is piping production planned?
    a. How many hours are planned per pipe/section?
    b. Is the planning realistic, are the deadlines met?

General questions current situation

Information

1. Where do you get your information?
    a. From who do you get your information?
2. How is the information provided and presented?

Work (using the information)

1. Can you describe your work?
    a. Which steps does the work consist of?
    b. How/where does it start?
    c. What do you need to do/finish the work?
    d. When is your work finished?
2. What information is required to do your work
3. Do you get all the information you need?
    a. Do you get all the information on time?
4. How long does your work take on average?
    a. How long does each step take?
5. What bottlenecks do you experience doing your job
    a. Are there times waiting on information and/or other people?
6. What problems do you run into doing your job?
7. What irritations/annoyances do you run into doing your job?

Work output

1. What is the output/end result of your work?
2. Who continues with your work?
    a. To who do you hand over the output/result of your work?
3. Are there any questions or uncertainties by others about your output?

General questions future situation

1. How do you want to receive your information?
2. What would help you doing your job?
3. What would make your job more efficient?
4. What would make your job more fun?
5. What would you change about your job?

Job Preparation specific questions

Current situation

1. What file formats are used in piping job preparation?
2. What file formats do you receive for piping job preparation?

Future situation

Pipe Fitter specific questions

Current situation

1. How long does it take to fit a spool?
2. How long does it take to measure the correct dimensions of a measure spool?
3. Do pipe spools get lost or misplaced in transport?

Future situation

1. What would make fitting a pipe more easy?
2. What would make measuring a measure spool more easy?

Pipe bender/fabricator specific questions

Current situation

1. How long does it take to produce a pipe spool
2. How long does it take to adjust a measure spool to fit
3. Do pipe spools get lost or misplaced in transport?
4. How is the orientation of the flange to the pipe determined?

Future situation

1. How can the efficiency of piping production be improved according to you?
2. How would you handle the fabrication of a measure spool?

AGENDA GALATZ PIPE FITTING TOOL VISIT

Sunday

Flight to Bucharest in the Evening

Monday

Day Schedule:

1. Travel from Bucharest to Galatz in the morning
2. Yard Safety briefing
3. Introduction to Management
    a. Technical Director
    b. Production Director
    c. Yard Director
4. Yard tour

Tuesday

Project introductions and brainstorms

Day Schedule:

1. Focus group session with Job Preparation and Engineering
    a. Focus on production planning, information flows and file management
2. Focus group session with Pipe fitters and Pipe workshop
    a. Focus on pipe fitting and measuring process flow
    b. Focus on preferred adjustment information methods
    c. When possible, focus on time estimations
3. Focus group session with Foreman
    a. Focus on process flow and time estimations

Process observations may also include timing of process steps as input for the business case

Wednesday
Business case creation and validation

Day Schedule:

1. Pipe fitting process observations
    a. Scenario of pipe fitting in tanks
    b. Scenario of pipe fitting between sections
    c. Scenario of pipe fitting between components
2. Pipe manufacturing observations

Process observations may also include timing of process steps as input for the business case

Thursday
Business case validation and

Day Schedule:

1. Continue observation of processes
2. Crash course pipe fitting and measuring
3. Process and summarize collected insights and information

Friday
Wrap up and travel back

Day Schedule:

1. Wrap up with interested people
2. Travel back to the Netherlands

Appendix A.7 – Design Brief

Design Brief

Project Name: Pipe Fitting Tool

Company Name: Damen Shipyards

Department: Operations Support

Project Overview and Scope

In an effort to save costs the process of manufacturing, measuring and fitting measure spools at the yards has been identified as a task that can be improved. Especially the measuring part of the job could be improved by using a tool. For this purpose Damen has developed a prototype solution in the form of an Augmented Reality (AR) pipe fitting tool utilising the camera of a tablet and two markers to be attached to flanges.

Previous work proved that this prototype was not sufficient for trial implementations on the yard. It does not meet the set requirements and there are several stakeholders that have not been implemented in the project enough.

Several development and implementation scenarios have been created and the next step is to research and decide on which direction to continue in.

Aims

- Requirements validation
- Business case input collection
- Requirement collection
- Feedback and critique collection
- Process and workflow observation and validation
- Decision making on development
- Reconsider link with project Paperless

Summary of previous work

In previous work on this project the goal was to create a minimum viable product of the tool to be used in trial tests at the yards. The creation of a functional prototype which worked in an optimal test situation was successful and this prototype was taken to the Galatz yard for a user acceptance test. The results of this test were not as hoped as it proved to be difficult to find locations on vessels where the tool would function. This was partially due to the fact that the markers of the prototype proved to be too large and the mounting of the markers was often not possible. The system was however capable of supplying production information for a pipe spool which did fit within the production margins defined by quality control.

The next step was to continue the project by assigning it to a graduate student. In this project all previous work has been evaluated and the prototype itself as well. Early conclusions were that the prototype could not be identified as a minimum viable product as it did not meet the minimal requirements defined by previous project owners. The business case of the project proved to be based on unreliable and non-representative numbers. Also the exact workflows and production processes with regard to measure spools were not known or documented.

In close contact with experts and the yard itself these workflows have been identified and documented.

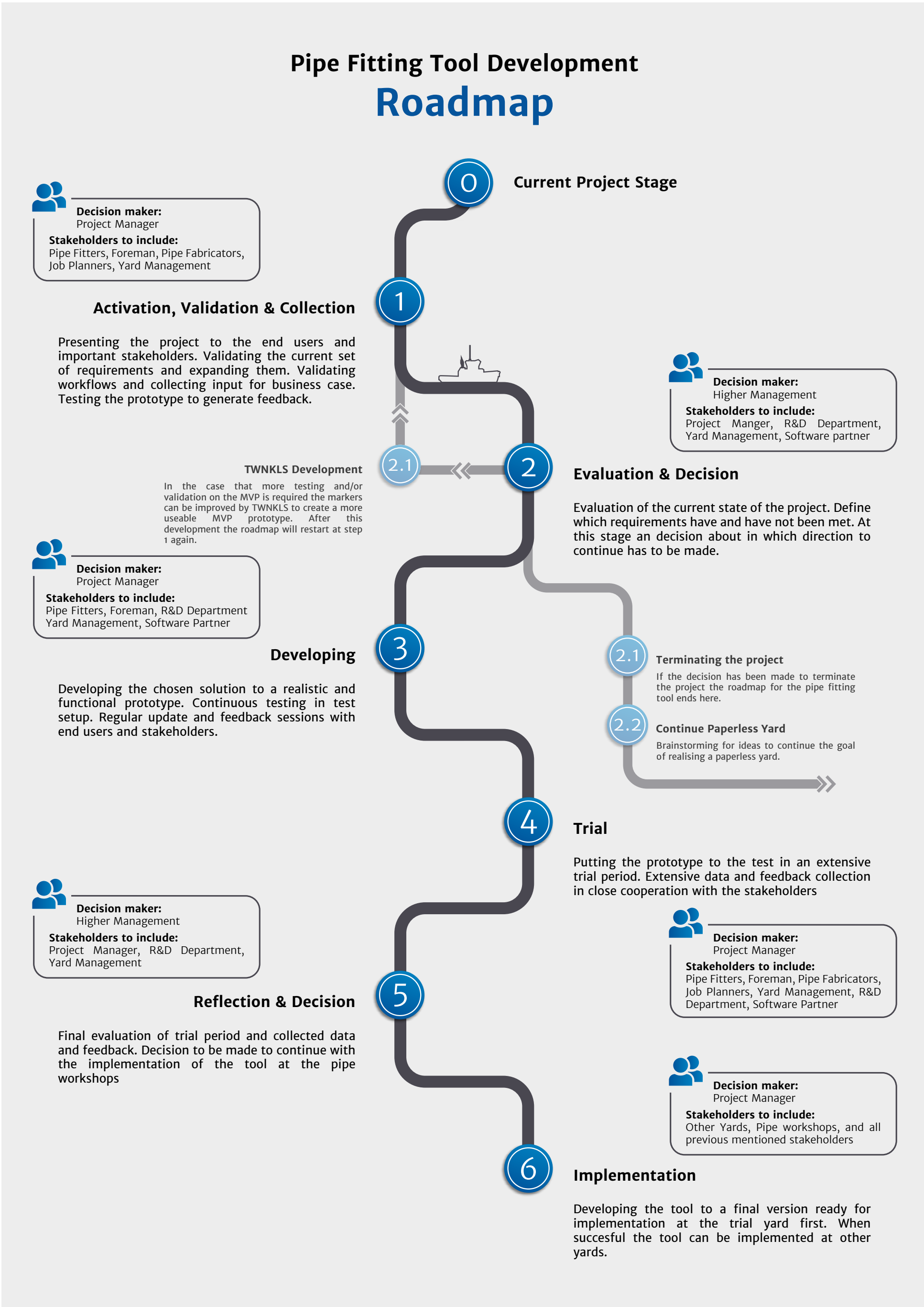
Alongside an extensive market analysis and meetings with the software developer have been held to identify the possibilities for future development. From this different potential development scenarios have been created.

Next to the development scenarios several workflow implementation scenarios have been made to show what the impact of implementing the tool in different manners will be on the existing workflow. Business cases based on these different scenarios have been roughly calculated using the existing non representative numbers. This does not give an accurate business case with regard to the actual savings but it does enable Damen to compare the potential of the different scenarios.

Finally the result of the project is an advice on how to continue and a roadmap on further development. This Design brief is part of the result to help the next project owner to get started.

Roadmap

A roadmap for further development has been created containing the potential steps to follow in continuing this project.

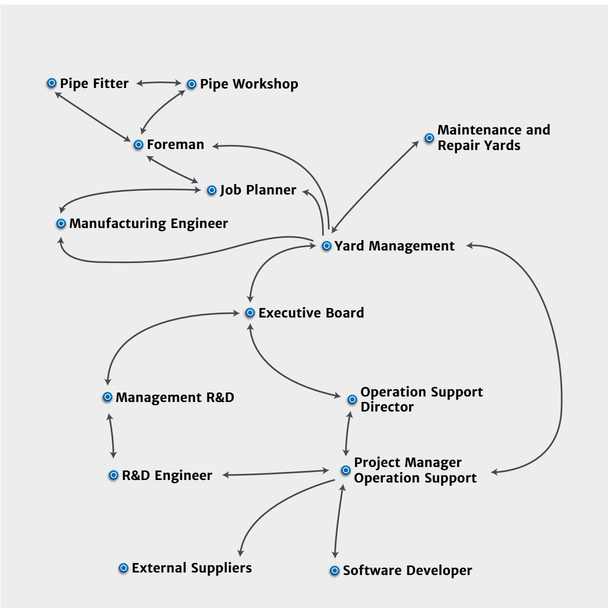


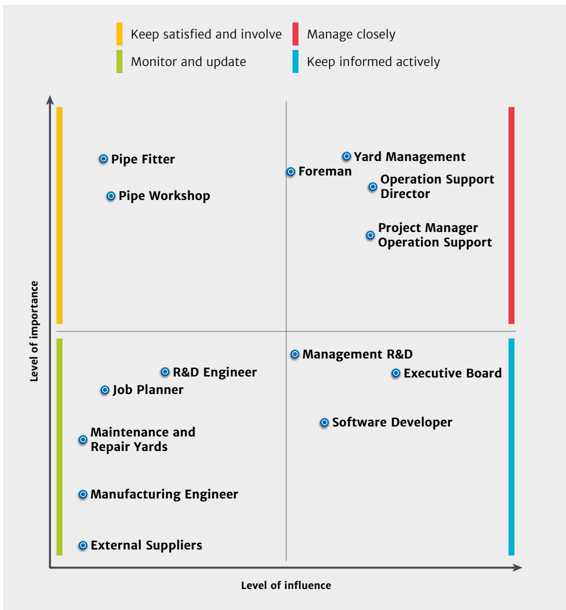
Stakeholders

The stakeholders and their relation and importance to the project are shown in the image below. Also the current information flows between those stakeholders in this project has been visualised. The most important stakeholder to actively incorporate in the project from now on are the workers of the pipe workshop and the foreman. This are the people who actually have to work with the tool once ready and thus will have not only a lot of knowledge of their trade but also a certain power to refuse to use the tool as Damen intends. It will be in both Damen's as the pipe fitters interest to create a tool that pleases the requirements of either party.

The following list of stakeholders have a relation to the pipe fitting tool project:

- Operations support (Project manager and Director)
- Shipyard management (Galatz)
- Piping workshop
- Pipe fitters
- Foreman
- Job planners
- Production Engineers
- R&D Department (Project manager and Director)
- External suppliers (Software and Hardware)
    - TWNKLS Rotterdam is the current software partner of the project





Requirements

Technical Requirements

1. The tool has to be able to scan a measure pipe within a working area of **1,5x1,5x1,5** meter
2. The tool has to have an accuracy of +/-1mm and 1 degree
3. The tool has to work with pipe flanges of size DN25 to DN250
4. The tool has to work with flanges of max 40 mm thick
5. The tool should function in anything between day light and no light (inside tanks)
6. The tool needs to collect shape and dimensions of the pipe and the **rotation of the flange and bolt holes**
7. Any needed marker needs to be max 100x100x100 mm in size
8. Output file should be PDF, xml or TeZet
9. Changes to initial xml file should be possible on the tablet or pc
10. Should work in panel- section- and hull building phase
11. Adjustments to mounting angle of flange to pipe should be possible in the application

Pipe Design Requirements

1. Steel or stainless steel pipes
2. Predrilled flanges with gaskets
3. Flange connected pipes only
4. Flange is assumed to be mounted on a 90 degree angle to the pipe, deviations are assumed to be absorbed by the gasket
5. Supported pipe designs; Straight, one 90 degree bend, two 90 degree bends, S-shaped pipe with two bends

Workflow requirements

1. The tool and the scanning process has to self-explanatory and can be learned without prior knowledge of 3D scanning with a manual
2. Maximum space processing time is 5 minutes, as long as the next job can be started and processing will be done in the background
3. The tool has to be able to create correct pipe design by itself
4. *The process has to be XXX% faster compared to the existing process**
5. The application has to name the files in sequence with the naming used in engineering and production departments

General Requirements

1. The scanning tool needs to be moveable by one person
2. The tool has to be understandable for all the pipe fitters working at any of the global shipyards of Damen

Whishes

1. The tool is incorporated with the 3D environment used by Damen Shipyards Group
2. Object/surface recognition for collision detection
3. Automatic pipe routing without engineering xml

**As the current process time is not known this will have to be determined in a later stage*

Objectives

The following objectives are relevant to the successful continuation of the project:

- Presentation sessions with stakeholders
    - Yard management (business case)
    - Pipe workshop (tool and workflow)
    - Foreman (workflow)
- Workflow observations
    - Empirical research
    - Bottleneck detection
    - Process step timekeeping (business case)
- Prototype demonstration
    - Try prototype in real environment together with pipe fitters
- Data summarising and evaluation
    - Summarise findings
    - Evaluate data usability
    - Draw conclusions
- Decision making
    - Decide if to continue with project
    - Decide which direction to choose
        - Workflow direction
        - Tool technology direction

Deliverables

The deliverables of the project can be as following:

- Extensive and validated list of requirements
- Documentation of stakeholder and end user needs and wishes
- Validated and complete business case
- Decision on if and how to continue with the project

Tools

To help with starting and continuing with the project the following "tools" have been collected:

- Presentation material
    - Tool introduction and previous work
    - Tool demonstration video
- Development and workflow scenario's
- Graduation Report
- Roadmap
- Collection of relevant documentation of previous work

Appendix A.8 – User Acceptance Test

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validation protocol

DAMEN SHIPYARDS GROUP

Pipe Fitting In AR

User acceptance test 2

Title:	Validation Protocol Document
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Datum	December 21th, 2018
Version	1.1
Pages	5

Introduction

On December 12-13th the project teams of Damen and TWNKLS conducted a field test of the Minimum Viable Product (MVP) of the Pipe Fitting in AR application in DAMEN shipyard in Galati (Romania). The purpose of the test was to ensure that the measurements and pipe design adjustment are useful in the real target scenario. This document captures the performed experiments and the findings under field condition during new ship construction.

Conducted work

The field test was carried out on a **Road Ferry 8117** vessel which was in production at Galati.

1.1 Day 1

Attended with 2 meetings with the shipyard directors and the team with piping division
Searched for a set of suitable measure pipes in engineering group
Encountered an issue with importing pipe XMLs in the app because of small difference to the format used in UAT1. This was initially resolved by manual modification of XMLs. Later the app was adjusted to ingest the different XMLs.
Short visit of pipe workshop
Inspection of 6 pipe fitting locations for the selected set of pipes
2 cases (A, B) – survey with the app was performed (up to data verification)
1 case – marker adaptor could not be attached because of galvanisation of bolt holes
1 case – too long pipe beyond 1x1x1m working volume
1 case – very short pipe, not enough space to place both markers
1 case – a pipe under ceiling, out of reach
Processing of 2 scanned locations (off the vessel)

Case A – a pipe with a single 30deg bend (technically out of scope with terms of shape)
Two successful measurements made
Input pipe design was adjusted for both of them and new XMLs were exported from the app
Case B – S-bend pipe with problematic access under the ceiling
Additional torch light necessary for taking pictures, limited space to take images from different viewpoints
Incorrect choice of the flange with the start marker on the spot (opposite routing of the pipe). This was fixed later during reprocessing.
Manual survey was done by a pipeline engineer for both pipe locations scanned by the app
Case B – incomplete isometric drawing because one bend angle was hard to measure and it would have to be checked with a tack-welded pipe on the location

1.2 Day 2

Searched for another set of suitable pipes with engineering group
Mixture of measured and ready pipes
Inspection of 5 pipe fitting locations for the selected set of pipes
1 case (C) – survey with the app was performed (up to data verification)
Existing pipe had to be removed
1 case – one 90 degrees bend
3 different measurements made (original illumination and a changed better lighting)
3 cases – marker apdaptor could not be attached because of the marker hitting nearby steel structures or pipes
1 case – pipe flanges under floor level with limited visibility because of other steelwork and temporary materials
Processing of 1 scanned location (off the vessel)
Case C – a pipe with a single 90deg bend (DN125)
One successful measurement was used to adjust the pipe design.
Manual survey was done by a pipeline engineer of 1. Case
Both connecting flanges and existing pipe were measured
Conversion of adjusted XMLs exported from the app. PipeFab was used to produce isometric drawings.
Case A from Day 1 was passed to the pipe workshop
Case C from Day 2 was just converted to see isometric drawing.
Pipe workshop manufactured 2 pipes for Case A
One based on the app output – cut pipe shape with free flanges
One based on manual survey – fully made pipe with welded flanges
Both manufactured pipes were successfully fitted on the location
Flanges were tack-welded on the pipe from the app after fitting
Both pipes were remeasured in the pipe workshop for comparison

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Findings

The app was able to measure accurately in a situation with a good access and illumination. The pipe design was adjusted with sufficient precision to manufacture a measure pipe. This pipe could be fitted with loose flanges at the location as intended.

Comparison between the pipe manufactured according to the app and the pipe manufactured according to manual survey shows a noticeable difference. However, both pipes can be fitted to the location.

Ship building site has challenging conditions at pipe fitting locations
A pipe is out of reach without scaffolding (under the ceiling)
Many occluding objects which obstruct views of the visual markers
Limited space around the location to take images from different viewpoints
Marker design is not suitable in a number of field situations
Marker plate is too large for smaller flange diameters (e.g. DN50) and collides with neighboring pipes, support steel.
The marker plate after mounting on the flange has often 'diagonal' orientation which often causes collisions. It will be better to have horizontal or vertical orientation (potentially positions in between as well).
Arms of flange adaptor do not fit into shrunk bolt holes after galvanization.
In some cases, a connecting flange is made of two pieces, so the total thickness is above 2cm of a standard flange.
Pipe shape should be represented in a single plane if possible (now defined by marker orientation). This will lead to simpler isometric drawing generated from the output XML of the app.
Flange bolt hole rotation is given by two(one)-hole up rule in the workshop at the moment. There is a need to find a right way to deliver the flange rotation information from the app to the pipe engineer.
For some pipe shapes it is difficult to tell the location of start marker by looking at the 3D shape. Adding flip option of pipe start/end in the design adjustment should solve this issue.
Significant number of measure pipes is a bit outside of 1x1x1m working volume (expansion to 1.5x1.5x1.5m might include more pipes). The guidelines for measure pipes could be more strictly enforced during design.
Scanning obstacles within working volume will be useful for correct routing of a pipe when additional structures are placed (often different to ship design).
Pipe workshop personnel is skeptical about the new approach because they can measure as fast by hand and have a very low failure rate with their current way of working.
However, there is no official statistics about failure rate or accuracy of measured pipes.
They have a full production schedule and prefer to work with a stable application which works well in most cases. There seems to be a limited space for much experimentation.
The app needs to be brought to a next development level tackling its current limitations before they would trial it.
Pipe division had thoughts about extending the scope of the app and whole pipe manufacturing process.
Larger DN flange range – DN25-300
Support for more complicated measure pipes with multiple branches/flanges.
Automatic adjustment of pipe design between as-built poses of flanges. But retaining option of manual adjustment to change the routing because of unplanned obstacles.
Standardization of pipe types and connection types to reduce variability in Damen ship design.

Commented [AB1]: Good argument to do a proper validation & test phase in Schiedam on a proper steel test bed.
How many cases? Food for thought!

Propose optional work to Damen however not strict requirement of MVP Upgrade.

Commented [MK2R1]: The steel test bed should have similar pipe scenarios as the current wooden one. If the technical scope expands soon (range of flange diameters), this should be included in the new testbed scenarios.
You probably want to measure and manufacture a pipe several times for each pipe scenario.

Commented [AB3R1]: Thanks Martin. Have made a client task in Jira for both Steel Test Bed as well as new markers / flange sizes.

Commented [AB4R1]: Test Bed:
https://twnkls.jira.com/browse/DS-330

Marker holders redesign:
https://twnkls.jira.com/browse/DS-331

Flange Size range
https://twnkls.jira.com/browse/DS-332

Commented [AB5]:

Commented [AB6]: Damen has an internship program to redesign the Markers (with minimum guidance / advice from TWNKLS)

Commented [MK7R6]: Lex had different ideas how to go forward. So he should be able to prevent bad ones ...

Commented [AB8R6]: That's good. Will make sure the ...

Commented [AB9]: What needs to happen in MVP ...

Commented [AB10R9]: Placed in Back Log as a Task ...

Commented [AB11]: sss

Commented [AB12]: Will discuss with Martin. I do not ...

Commented [MK13R12]: This is possible only for pipe ...

Commented [AB14R12]: As discussed this is a highly ...

Commented [AB15]: Design by who...? Damen or ...

Commented [MK16R15]: Damen internal guidelines fo ...

Commented [AB17R15]: Will note as client HIGH RISK ...

Commented [AB18]: Is this where the Dense Point Clo ...

Commented [MK19R18]: that's correct.

Commented [AB20R18]: Great. Understood! I don't se ...

Commented [AB21R18]: Placed into project under ...

Commented [AB22]: This doubles the importance of ...

Commented [AB23R22]: TASK: ...

Commented [AB24]: We can definitely do this.

Commented [AB25]: Have agreed with Cristiaan to pu ...

Commented [AB26]: Action for Damen!?

Commented [AB27R26]: YUP! For the client. Could ...

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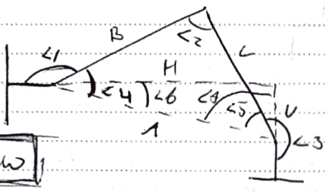
Appendix A.9 – Formula low tech solution

Formule Armen oplossing Dammen Pipe Fitting



Side view

$\angle 4 = \angle 5 = \frac{180 - \angle 2}{2}$

$\angle 6 = \angle 1 + \angle 4 - 180$

$\angle 7 = \angle 3 + \angle 5 - \cancel{180}\ DA$

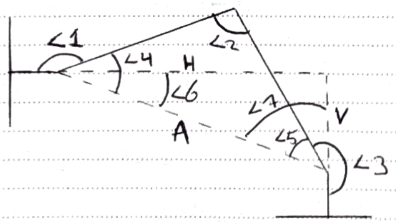
$DA = \angle 1 + \angle 4 + \angle 5 + \angle 3 - 360$

$A^2 = C^2 + B^2 - 2 \angle B \cos \angle 2$

$A = \sqrt{A^2}$

$H = (A / \sin 90) \cdot \sin \angle 7 + H1$

$V = (A / \sin 90) \cdot \sin \angle 6 + V1$



TOP View

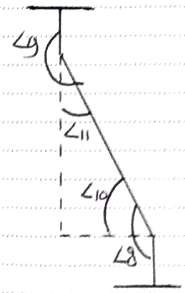
~~VH = (H/sin 90) · sin ∠10~~

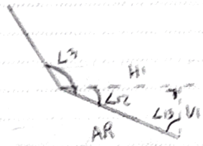
$HH = (H / \sin 90) \cdot \sin \angle 10$

$VH = (H / \sin 90) \cdot \sin \angle 11$

$\angle 10 = \angle 8 - 90$

$\angle 11 = \angle 9 - (180 - (360 - (\angle 8 + \angle 9)))$



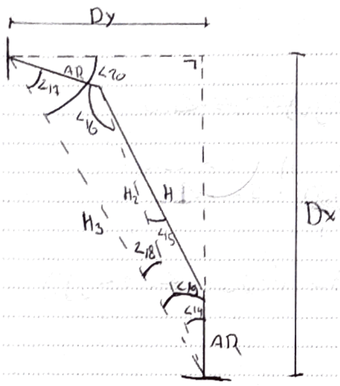


$\angle 12 = \angle 1 + \angle 4 + \angle 5 + \angle 3 - 360$

$\angle 13 = 180 - 90 - \angle 12$

$H1 = \sin \angle 13 \cdot 2AR$

$V1 = \sin \angle 12 \cdot 2AR$



X AnD Y deviations

$H2^2 = H^2 + AR^2 - 2H \cdot AR \cdot \cos \angle 8$

$\frac{H}{\sin \angle 14} = \frac{H2}{\sin \angle 8} = \frac{AR}{\sin \angle 15}$

$\angle 14 = \sin^{-1}\left(\frac{H}{\frac{H2}{\sin \angle 8}}\right)$

$\angle 15 = \sin^{-1}\left(\frac{AR}{\frac{H2}{\sin \angle 8}}\right)$

$\angle 16 = \angle 9 - \angle 15$

$H3^2 = H2^2 + AR^2 - 2\ H2 \cdot AR \cdot \cos \angle 16$

$\frac{H3}{\sin \angle 16} = \frac{H2}{\sin \angle 17} = \frac{AR}{\sin \angle 18}$

$\angle 17 = \sin^{-1}\left(\frac{H2}{\frac{H3}{\sin \angle 16}}\right) \quad \Big| \quad \angle 18 = \sin^{-1}\left(\frac{AR}{\frac{H3}{\sin \angle 16}}\right)$

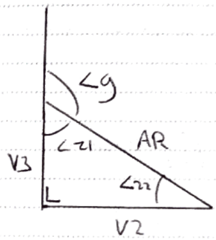
$\angle 20 = 180 - 90 - \angle 19$

$\frac{H3}{\sin 90} = H3 = \frac{Dx}{\sin \angle 17} = \frac{Dy}{\sin \angle 19}$

$Dx = H3 \cdot \sin \angle 20$

$Dy = H3 \cdot \sin \angle 19$

Z Deviation

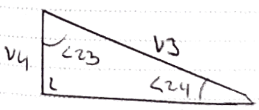


$\angle 21 = \text{IF } \angle 9 < (180 - \angle 9)$ ELSE $(\angle 9 - 180)$

$\angle 22 = 180 - 90 - \angle 21$

$\frac{AR}{\sin 90} = AR = \frac{V2}{\sin \angle 21} = \frac{V3}{\sin \angle 22}$

$V3 = AR \cdot \sin 21$



$\angle 24 =$ Flang Angle

$V4 = V3 \cdot \sin \angle 24$

$Dz = V + V4$

Appendix A.10 The Lighthouse Festival user tests 19-09-2019

User 1:
- User is missing a back button
- User is missing feedback on how the process is going
- The application needs a more clear explanation and/or guiding within the app

User 2:
- Needed to explain to the user that both markers should be on every picture
    - *Live marker recognition?*
    - *Only enable the user to take a picture when both markers are recognized by the app*

User 3:
- User notices that the flanges in the test setup are not how they are in real situations
    - The bolt holes on the flanges are not in the correct position
- User asks if the application measures the rotation of the flange
- User asks if it can design appendages or end caps?
- User suggest small laser in heart of the tube could help detect the center of the flange

User 4:
- Needed to explain to the user that both markers should be on every picture
- User is standing too close to the markers
- User asks if it can do collision detection with 3D data of the other parts inside the ship or with existing parts recognized by the scanning application?
    - *Combination with 3d scanning?*
- User suggests the tool should use the center of the pipe to attach and align the marker
- Why not use a base point in the ship and measure everything relative to that point?

User 5:
- User asks if you need to do the whole process for each pipe spool
    - *User means the calculation part and waiting for the app to finish before you can continue*
- User suggests using a universal claw for the inside of the pipe as a marker holder
- User asks if it is necessary to put one measure pipe in before the next one can be measured
- Suggestion that the app could calculate based on parameters like the least amount of material used for the pipe, or the least amount of bends in the pipe
- User asks if the application can calculate weight?
    - *Could be useful for High-Speed Crafts*

User 6:
- User is standing too close to the marker
- Needed to explain to the user that both markers should be on every picture
- *Application gave an error: Insufficient quality of images*
- User asks if the tool would work in dark environments due to image quality error
- *App crashes and images are not stored*

User 7:
- User asks if the application can store pipe designs with correct names
    - *Makes production easier, allows for keeping track of the pipes designed*
- Can the app create technical drawings automatically?
- User suggests combination with Cadmatic (or any cad software being used)
- *Application recognizes event poster as a marker in each photo (project_test62)*
- User suggests that measure pipe designs could have a one bend only criteria
    - *Would be a criteria for the engineering department to only design measure pipes with one bend*
- Measure pipes can be relatively complex with this tool as they do not have to be measured by hand
- User suggest adding a spirit level to the marker to make sure the flange is aligned correctly

User 8:
- Number and/or name pipes in sequence