

# AR-Simply

**Assembly/Disassembly of Machines  
with AR Digital Twin App**



Medialogy-VGIS 2022  
Master Thesis





# AALBORG UNIVERSITY

## STUDENT REPORT

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**Abstract:**

This project is in collaboration with PDM Technology and aims to combine Augmented Reality and Digital Twin technology to create an application that can guide users in assembly or disassembly of machines. Machines are complex and difficult to assemble/disassemble, as many things can go wrong in the process, resulting in time and money wasted for individuals or businesses. To address this problem an Augmented Reality iOS app that guides users in assembly/disassembly by using Augmented Reality and Digital Twin was built in Unity. The app was tested with users and an expert from PDM Technology. The results showed that the user experience could use improvements, but that the Digital Twin and Augmented Reality aspects held great promise and were helpful to the users.

# Preface

This Master's thesis project is a collaboration between the studies of Vision, Graphics and Interactive Systems and Medialogy. The group consists of Tobias Adamsen and Frederik Jensen. The report is made in the time period from February 2022 to June 2022.

The references in this report are cited with the use of The American Psychological Association (APA) referencing method, which means that sources will be cited as "[n]", where n is the order of appearance. In the Bibliography, they will be listed in the same manner. Illustrations will be labelled under the chapters they belong to and not the different sections they are included in. As an example, the first figure in Chapter 1 will be labelled "Figure 1.1", followed by 1.2, 1.3, etc. Tables and Equations follow the same principles.

The source code for this project can be found at the following Github repository:

<https://gitfront.io/r/user-4058053/vaDvt98pn4CE/AR-Simply3/>.

The repository contains the Unity project and all related files. The project can be build in Unity and compiled with xCode to run on an iOS device.

The authors would like to thank Jørgen and the test participants from PDM Technology.

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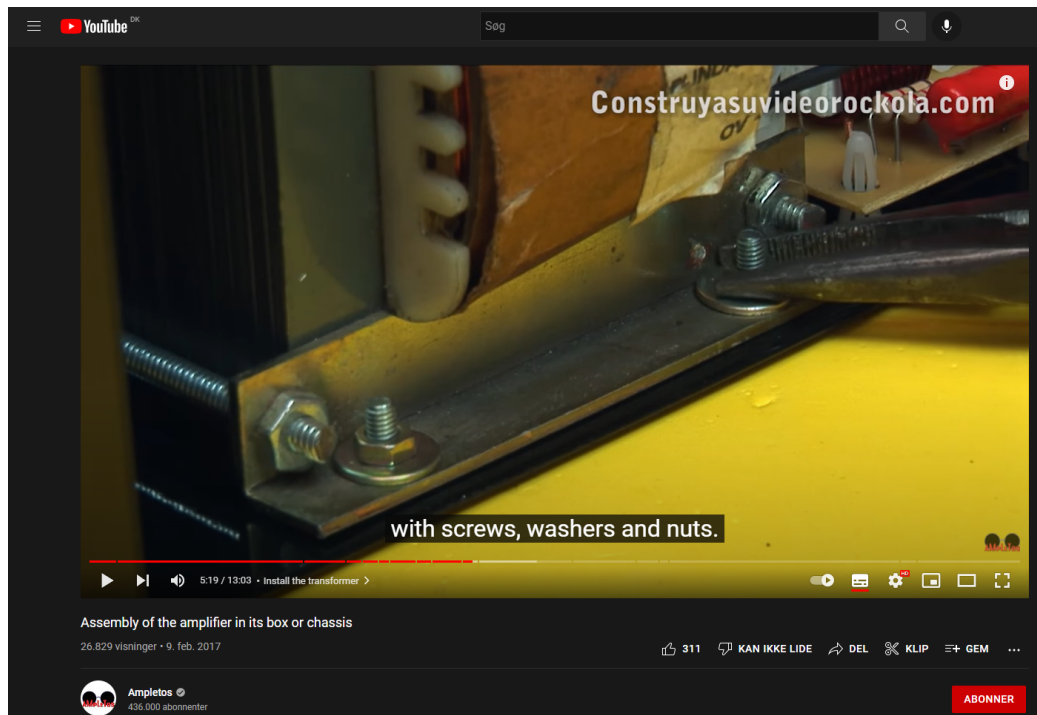
# 1 | Introduction



**Figure 1.1:** Logo of PDM Technology.

PDM Technology is a business to business software company with its primary focus on Bluestar [36]. Bluestar combines what is known as Product Lifecycle Management (PLM), systems that are used by engineers and designers to track product stages from start to finish, and Enterprise Resource Planning (ERP), systems used by marketing, sales associates and manager that integrate business processes with software technology. Bluestar is used by PDM Technologies costumers to easily get an overview of their products and all files related to projects, share them among employees and work together more efficiently.

The majority of PDM Technologies customers makes complex machines, and use the Bluestar software to keep on top of the process and track all necessary files and parts that go into their production. PDM Technologies are always looking for opportunities to expand their product range and support their customers even further. One opportunity is by making use of new emerging technology such as Augmented Reality and Digital Twin to assemble/disassemble machines.



**Figure 1.2:** YouTube video showing how to assemble an amplifier. [3]

Assembling and disassembling machines can be a difficult process. Many things can go wrong: fragile pieces can break, steps can be accidentally skipped requiring a do-over or the instructions can be unintelligible. These mistakes might be time-consuming or expensive, and in an industrial settings could disrupt the flow of business. [8]. Currently the most obvious way to ensure a mistake-free assembly of a machine is to study the manuals or instructions carefully during the process, or to watch a video of someone doing it. An example of this can be seen in figure 1.2. [31]. Combining Augmented Reality with Digital Twin technology could mean this is about to change.

A Digital Twin is a virtual representation that serves as the real-time digital counterpart of a physical object or process [14]. Digital Twin technology has the potential to transform the way we interact with objects and give the interaction another dimension, as they can make use of real-time and historical data to represent the past, present as well as simulate predicted futures. They can be tailored to use-cases, powered by integration, built on data, guided by domain knowledge or implemented in IT/OT systems. Digital Twins and their physical counterpart exists today as separate systems with a clear border of digital and physical between them. But combining Digital Twin technology with Augmented Reality could be a way to blur the border.

Augmented Reality is an enhanced version of reality, created by the use of technology to overlay digital information on top of the real world. This can be achieved by using a device, such as as a smartphone camera or head mounted display [34]. In recent years Augmented Reality has found use-cases in learning and training scenarios, games and entertainment and for visualisation especially in industry. Here Augmented Reality can be used to help workers on assembly lines, or during maintenance work and repair, to carry out required tasks.

This project, in collaboration with PDM Technology, aims to combine Augmented Reality and Digital Twin technology in order to make a system, that could support users in assembling/disassembling machines easier and with less time-cost.

## 1.1 Initial Problem Statement

PDM Technologies makes software for customers, that are in the business of assembling/disassembling complex machines. Assembling and disassembling machines can be a time-consuming and error-prone process. A proposed solution to this problem is to combine the technologies of Digital Twin and Augmented Reality to create a systems that can guide the user in how to assemble/disassemble machines with fewer errors along the way. In order to help direct the problem analysis and learn more about these technologies and how they might best be used to solve the problem, an initial problem statement and a set of resulting research question, which are to be investigated, has been formulated. The initial problem statement is the following:

*What Digital Twin and Augmented Reality technologies can be used to support users in assembly and disassembly processes?*

### Research Questions

- What types of Digital Twins exist, how are they created and which use-cases are there for Digital Twins?
- What are the platforms, use-cases, challenges and how how can Augmented Reality be implemented?
- How does current Augmented Reality or Digital Twin solutions support their users in assembly/disassembly processes?

## 2 | Preview

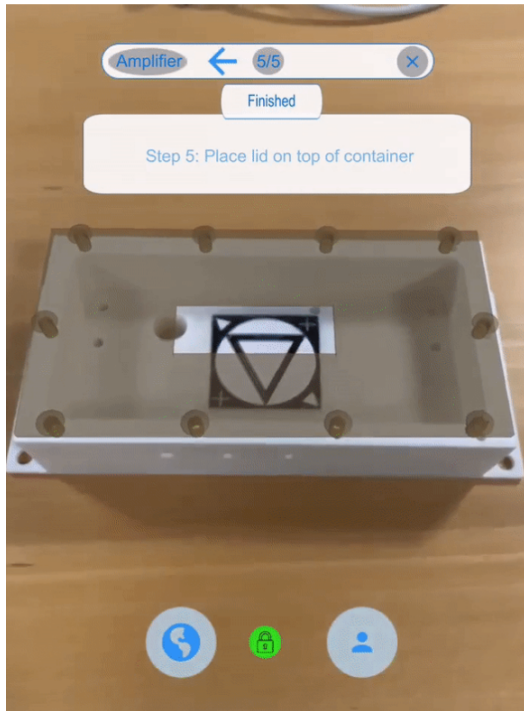
This chapter provides a short overview of the final prototype that was created in the project. The figures show a 3D printed amplifier used as example machine.



**Figure 2.1:** Digital shadow on top of real model. The app uses two different tracking methods to align the virtual and real world.

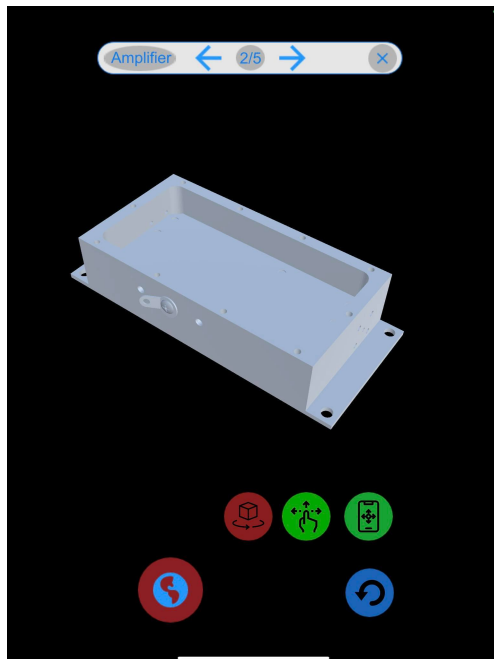
The prototype is in an iOS system and has the goal of providing a step by step approach to help users with either assembly or disassembly of machines. The application uses Augmented Reality to align the virtual world of a 3D model with a physical models world. This way, each physical component corresponds to a virtual component and a digital shadow relationship is created. In practice this is done by image tracking, where the user has to point the system at a marker on the object, or object tracking, where the user has to show the object to the application.





**Figure 2.2:** The app can be used for assembly or disassembly of machines. Outlined component is the next step.

Once the world have been aligned, the app guides the user in assembly or disassembly process via a step by step approach, where the next step is communicated via outlined components. The idea is that the user can go back and forth between steps and physically change the real life machine as they proceed in the process. A helpful tip pops-up in each step, providing the user with some more information about what to do in the step, before disappearing. The user can also obtain information about the machine itself by pressing the name button, or skip to a specific step by pressing the step counter button.



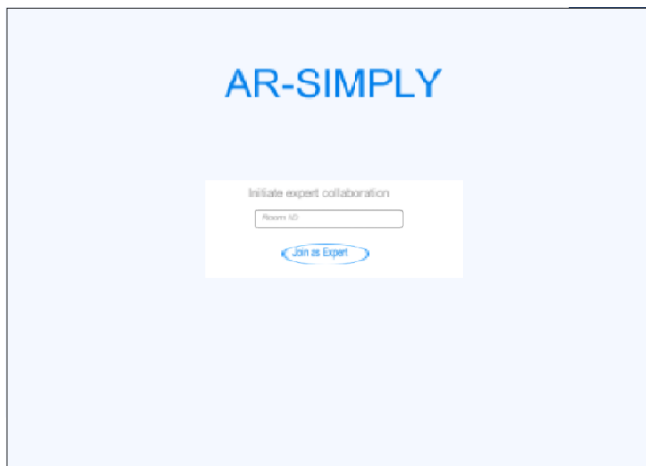
**Figure 2.3:** The app includes a digital world, where the user can interact with the machine in different ways than the real world.

The step by step approach is also applied to a completely virtual environment, referred to as the "Digital world". In the digital world only the digital shadow can be seen. The user has the options to use different interaction methods to manipulate it; they can rotate, scale, or move the model using taps and touches. The digital world is still anchored in the real world, making it possible to walk around the model. The user can go back and forth and see future steps, to learn how the machine works. Once a user goes back the real world, all changes are reset.

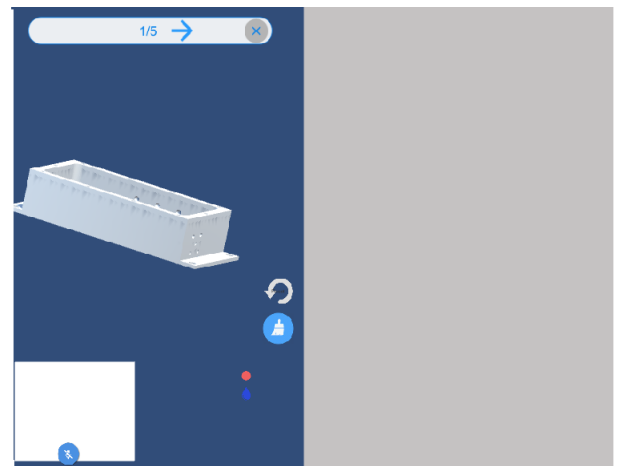


**Figure 2.4:** The app includes expert collaboration, where a user can screen-share their AR view to an expert.

Finally the application allows for collaborating with expert. The user can specify a "Room ID" and establish contact to an expert, who has entered the same "Room ID" in a companion computer program. Once the connection has been established, the user is able to see the experts camera and the expert and user can communicate via voice. The expert receives a live feed of the users screen and interact with a digital shadow of the machine next to the feed. The expert is able to change the color of any component, which is then displayed on the users digital shadow.



(A) First screen



(B) Second screen

**Figure 2.5:** The experts companion program running on computer.

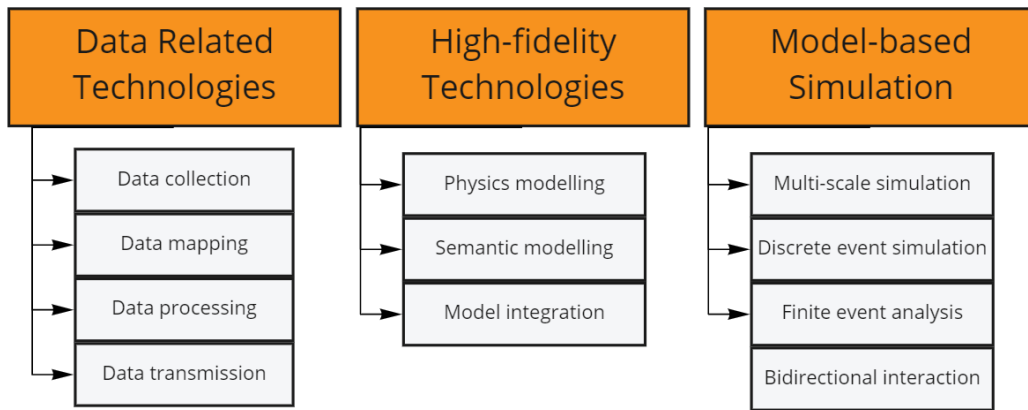
**Part I**

**Problem Analysis**

## 3 | Digital Twins

In this project the concept of Digital Twin (DT) refers to a virtual representation that serves as the real-time digital counterpart of a physical object or process [14]. The chapter will investigate what use DT has in the industry, what different types of DTs exist and how they are different from each other along with what challenges there are with using DT and how they might be solved.

### 3.1 Types of Digital Twins



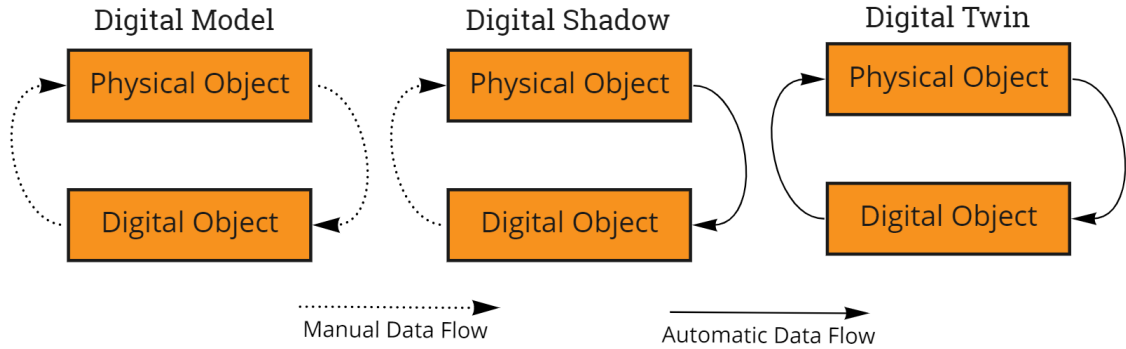
**Figure 3.1:** Three key technologies for DT.

Many attempts have been made in literature to classify different types of DT's based on different characteristics such as interactability, how they use data or their application domain. Liu et al. recently did such an attempt and discussed key technologies for DT's [33] from three perspectives: data related technologies, high-fidelity modeling technologies, and model based simulation technologies. The technologies and their use-cases can be seen in figure 3.1.

Data related technologies are all about collecting as much data as possible and using it to inform the twin. Data can be obtained from things such as sensors, gauges, cameras, scanners, etc. It is key the data should be transferred in real time, so that the twin is always updated to the environment and input. This can be a problem since DT's often require a large amount of varied data. Attempted solutions to this problem are data mapping by using XML, data fusion or preprocessing the data. Examples of studies that used this data driven approach are Ala-laurinaho [1], who explored application layer protocols and created a platform that allowed users to easier add sensors to their DT, and He et al. [22], who attempted to work with signal processing algorithms in combination with DT's.

High-fidelity technologies are all about the relationship between the models. The models can consist of semantic data models, which can be trained using machine learning methods and physical models, which are based on the actual physical properties and how these interact with each other. With this approach it is important to consider the contrast between how simplified the virtual model is compared to their complex physical object and make a decision between the computational effort needed and accuracy of the model. Examples of studies that uses this approach are Ghosh et al. [17], who build DT's that used hidden Markov models to investigate complex manufacturing problems, and Sun et al. [41], who made a DT system that created models from point cloud scanning in order to facilitate the creation of high precision products at factories.

Model based simulation technologies are different from the others in that these technologies allows the virtual models and physical models to interact with each other in real-time. This can be achieved by using data from the physical system that are collected and recorded in real-time from physical space, using techniques such as image recognition or laser measurement to understand the physical world. Another approach is attempting to control the physical world by using electrical control, programmable control, embedded control or network control technology. Most of the existing studies focus on unidirectional data flow, going only from the physical model to the digital. Models that uses bi-directional data flow are actively being explored in research at the time of writing according to Liu et al.



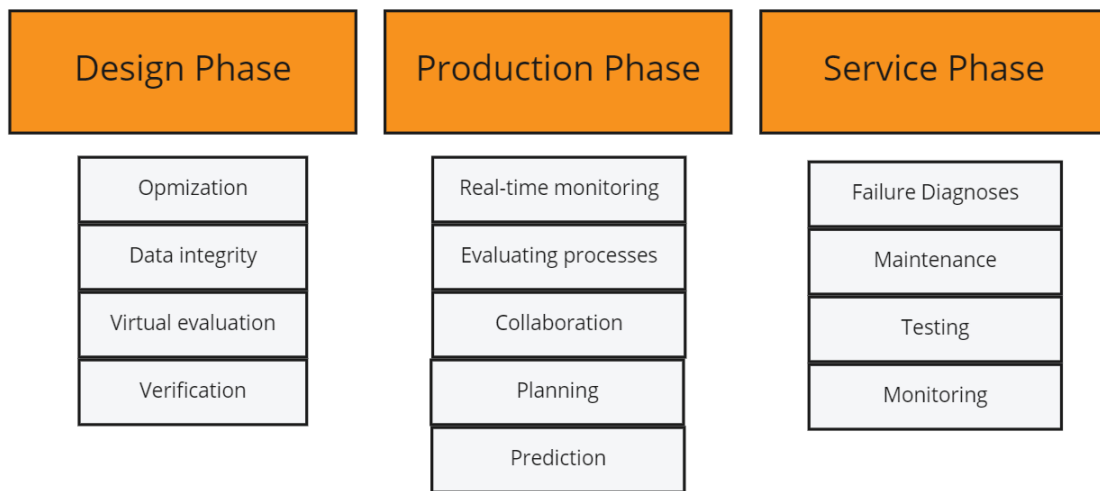
**Figure 3.2:** Digital Model, Shadow and Twin.

Kritzinger et al. classified DT's depending on the interactions between the physical object and the relative virtual object [29]. A diagram of this classification system can be seen in figure 3.2. In this system, a proper DT is a system where the data is exchanged both ways automatically, meaning the physical object sends data to the virtual object and the virtual object sends data back to the physical object. This means when the state of one of the objects changes, the state of the other object also changes. Bottany et al. used a proper DT system to work with the logistic behavior of automated guided vehicles in their study in 2017 [9]. The result of the study showed the technology could provide a strategic optimization of the plant resources and be beneficial for industry.

Another type of DT is the digital model system, where there is manual or no interaction of data exchanged between the physical and virtual object. Kumar et al. used a digital model system to optimise planning and production scheduling in industry in their case study from 2015 [30]. The results of the study showed that the business benefited from the system and saved money compared to not using the system.

In-between these two types of DT is the digital shadow system, where only the physical object sends data and updates the virtual object automatically, but the digital object sending data to the physical object is manual, or no data is send. Lindström et al. worked with a digital shadows system [32] that combined predictive maintenance and continuous quality control for maintenance. The system focused on keeping production robust, high-quality and future-proof.

## 3.2 Applications of Digital Twins



**Figure 3.3:** Applications for DTs in different phases of industry.

At the time of writing DT's main use lies in industry and fits particularly well into the notion of industry 4.0. This notion is defined as the new industrial revolution, where modern smart technology such as AI, IoT and DT's gets integrated into industry in order to improve manufacturing. Studies have shown that DT's can be useful assets in all aspects of industry: from the design phase through the production phase until the maintenance and service phase. Examples of how DTs can be used in the different phases can be seen in figure 3.3. [45]

In the design phase DTs can help designers by providing a lot of data in order to make it easier for the designer to make decisions. This was argued for in a study by Canedo [11], where they concluded that product design could be notably improved by adding data feedback from DTs. Other potential applications for DTs in the design phase include product planning, conceptual design, detailed design and quality testing. [44] [39]

In the production phase DTs main goals are making production processes more reliable, flexible and predictable. One way to achieve these goals are by making DTs that can visualize and update the real-time status of production processes. It is critical that these systems are precise, allowing humans to depend on them to make adjustments and optimizing the production process. [50]

In the service phase DTs can be useful for ongoing stability and maintenance. DTs can keep some of the functionality from the production phase, such as performance prediction, and be used to keep an eye on their physical counterparts and ensure they keep working optimally. [50]

### 3.3 Challenges with Digital Twin

While using Digital Twins during product engineering processes can provide many advantages they also provide some challenges.

One challenge is the amount of data required. The ability to update data in real-time without human interaction is a key factor and a required milestone toward creating a proper Digital Twin, however some infrastructure and a data-flow is required to facilitate this. The data itself must also be varied and expansive and include data that could potentially be used in the future, to allow the DT to evolve and expand its life-cycle. Another challenge could be the cost of implementation of a DT, which one study estimated to be around 50.000 dollars. Depending on the scale, implementing a DT could affect various parts and processes in a company and bring costs related to this disruption and change. These challenges means that DTs must be results of careful planning and consideration before being implemented. [4]

A key issue preventing DT technology from being widely adopted in industry is the lack of a standardized consistent framework for the use of Digital Twins in product development. A consistent framework could cover topics such as mutual understanding, interfaces and standardization and efficient information flow. A framework could be helpful to define boundary conditions and concepts for optimization in production processes. Another benefit is to help users become used to interfaces, affordances and expected actions related to the Digital Twins. The framework would allow for requirements of the Digital Twin to be modelled, planned and implemented in production easier and with compatibility to other Digital Twins. If standardized, Digital Twin of different domains could be linked together, enabling information flow and support for teams working across domains.[49]

### 3.4 The Grieves Tests of Virtuality

In their study from 2017 [20] Grieves and Vickers developed a testing structure that has the goal of determining how well a virtual system mirrors a physical counterpart. Based on the Turing test, the testing structure consists of a series of trials and is called The Grieves tests of virtuality (GTV). The tests consist of a sensory visual part, a performance part and a reflectively part. The tests all take place with a real person acting as a viewer. The viewer is located inside a room with two separate screens. One screen is a video feed from the room where the physical system is present and the other screen is connected to a computer and shows the status of the DT.

For the sensory visual test, the viewer can demand any 3D movement of the real system or the DT. The system could for example be rotated, lifted, and or disassembled. If the viewer can not differentiate between the real system and the DT, the test is passed.

For the performance test, the viewer can demand any action to be executed on the real system of the DT. Actions could be things such as opening a valve, have stress placed on the system or have power applied to it. If the viewer can not differentiate between the behavior of the real system and the behaviour of the DT, the test is passed.

For the reflectively test, the viewer can request data about the state of a system. This could be temperature, altitude etc. If the viewer obtains the same data from the physical twin and the DT, the test is passed.

### 3.5 Summary

In this chapter Digital Twins were investigated. Different types of twins and what defines them were defined, such as the digital shadow that only has an automatic data flow between the physical object and the virtual, but not the other way around. It was explored how Digital Twins can be useful in industry and what kind of challenges are related to implementing them. The Grieves Tests of Virtuality was discovered and has potential to be used for evaluating the Digital Twin that results from the project. In the next chapter an overview of Augmented Reality will be provided along with exploring different challenges and solutions to them.



## 4 | Augmented Reality

In this project the concept of Augmented Reality (AR) refers to the blending of the virtual and real world, where virtual elements can appear as if they exist in the real environment. The chapter will investigate what use AR has in industry, what problems there are with using AR and how they might be solved, along with examining which frameworks can be used to implement AR and on which platforms.

### 4.1 AR in Industry

Recent studies have applied AR systems in industry for tasks such as product design, production planning, development and maintenance. In product planning and design phases, AR has been used primarily for visualization and as a helping tool for designers, giving them the ability to visualize, inspect and modify 3D product models collaboratively, involving customers and evolving design processes. AR has also found uses in assembly processes in order to support faster product design phases, to make the processes more reliable and integrated and to integrate the work environment in the processes.

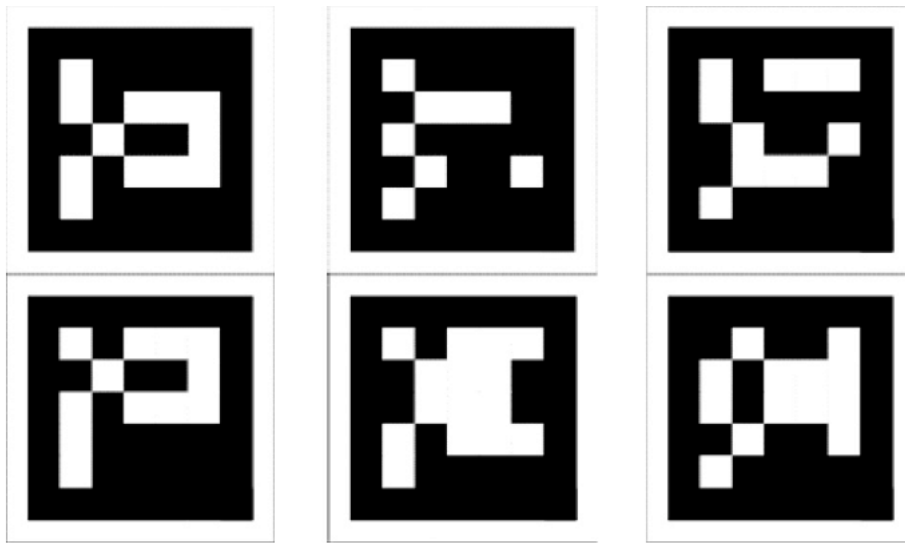
It is difficult to evaluate the impact of AR systems in the industry, because of the many factors involved in such a system and due specific requirements of the process the systems should improve. One way to evaluate is by examining technical performance.

While AR could be instrumental in industry 4.0, currently the bottleneck that is holding the technology back is the difficulty of making AR systems that can effectively communicate between individuals and production department in real-time. This communication is key for a thriving business. Phone-based AR devices could be a step to solve the problem. [16]

## 4.2 Aligning Worlds

Fusing virtual objects with the real physical environment is a big challenge in AR. The topic is important because it is key for creating immersive experiences. [28]. A number of solutions have been proposed to the problem, such as using markers, using sensors or purely camera-based approaches.

### 4.2.1 Marker-based Approaches



**Figure 4.1:** AR Markers than can be used for aligning the virtual and the real world. [43]

A marker-based approach attempts to solve the problem by using computer vision methods to detect visual markers, such as 2D bar-codes. It can be difficult to design a good marker; it should easily and reliably be detectable in different light and color environments and needs to contain enough information so that the pose of the camera can be calculated from it. An optimal marker that fits these criteria is a black and white square. Once a marker is detected, it defines both the correct scale and pose of the camera. Appendix A.2 section 1 describes a series of steps to implement a typical marker-based system. Problems with marker-based approaches include randomly jumping content if the marker is lost, inexact positions of content if the marker is not clearly visible or have blurred edges as well as limited detection distance depending on the size of the marker. [40].

Using 3D objects as markers is an option and is especially useful when working with depth cameras such as Lidar. These methods works by detecting a provided 3D model in the scene and combining methods such as feature extraction and bounding box prediction to detect objects on 3D point cloud data. Machine learning helps optimize the process. [52].

### 4.2.2 Sensor-based Approaches



**Figure 4.2:** SLAM method that shows tracked landmarks in an image and their location in a mapped view. [13]

Dedicated sensors that provides information the system can make use of to estimate the cameras pose can be very important. These methods can stand on their own but are often combined with the other approaches, to create hybrid methods that results in improved results, as traditional solutions with sensors are easily polluted by noise and drift. Various kinds of information useful for pose estimation can be gathered from sensors: an accelerometer can give the direction of acceleration, a magnetometer can give the direction of the gravitation vector and a compass can give the objects bearing. [40]

An example of a sensor-camera-based hybrid method is Simultaneous localization and mapping (SLAM). SLAM methods are sets of algorithms aimed at solving simultaneous localization and mapping problems in real time. They work by making use of the sensors on the device, such as cameras and inertial measurement units, to build a map of the unknown environment while tracking the pose of the camera at the same time. SLAM systems are beneficial for use in AR scenarios because they can handle complex camera motions, which means less accidental jittering and better handling of nausea-induction rotational motions. [28]

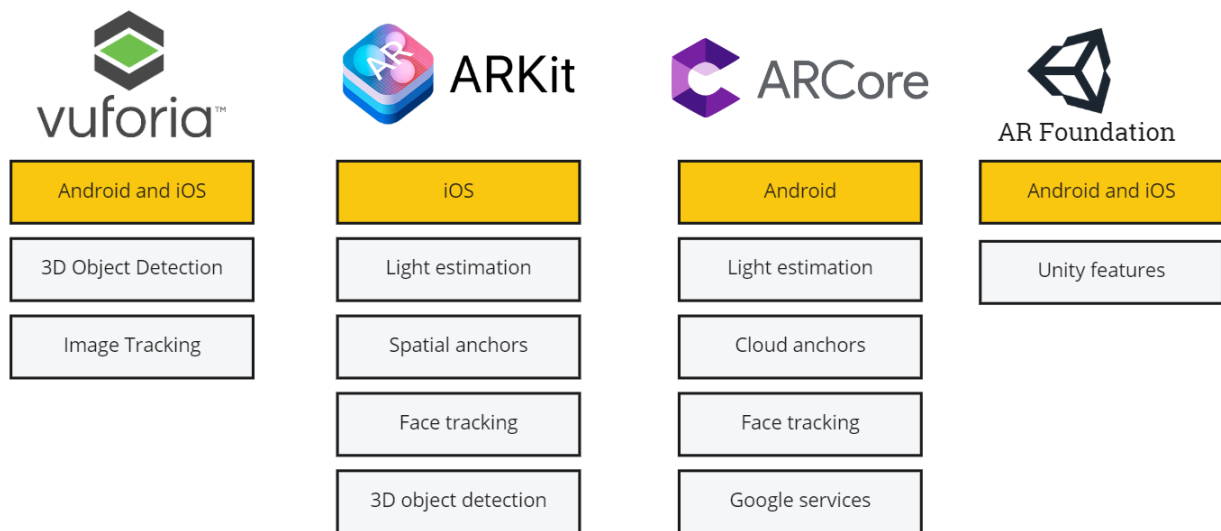
### 4.2.3 Camera-based Approaches

Camera-based approaches attempts to deduce the cameras pose based on what it sees and uses no other equipment. These methods can be used in scenarios where other methods are insufficient in some aspect or a combination of several methods is beneficial. The two main methods within this category are feature-based methods, where the cameras pose is informed by detecting features in the images, and model-based methods, where the system contains a model of the scene and then tries to detect this model in the image in order to deduce the pose of the camera. [40]

In 2016 Nuernberger et al. experimented with feature-based methods as they created an AR system that allowed users to easily position, orient, and scale AR virtual content with respect to real world constraints [35] without using markers. The system worked by extracting planar surfaces and edges from the real world as constraints and using these to allow for the virtual content to snap to real world objects. Experiments with the system showed that people moved around physically more when in the scenario with the system compared to scenarios with traditional techniques.

Another feature-based method is visual SLAM (VSLAM), a variant of the SLAM method. Different from SLAM, VSLAM uses only visual sensors to estimate the camera pose and scene structure. Information that would have been collected from other sensors is modelled using inertial navigation and machine learning. This means VSLAM in general is a more robust approach. Apple's ARKit and Google's ARCore both makes use of VSLAM methods. [12]

### 4.3 AR Frameworks



**Figure 4.3:** The different AR frameworks presented in this section along with a subset of unique features from each.

Several different AR frameworks exist. The most common ones are ARCore, ARKit, AR Foundation and Vuforia. A summary of each framework can be seen in figure 4.3. The following is a description of the different frameworks and their features.

#### 4.3.1 Vuforia

Vuforia is developed by PTC and intended for industrial use. It is a heavy-weight framework, which is more complex and difficult to use but contains extensive documentation. Vuforia offers a large variety of features such as tracking, environment scanning and object recognition. Vuforia works for both iOS and Android. [48]

A key feature in Vuforia is 3D object recognition. This feature works by making use of a companion app, the Vuforia Object Scanner, an android application that can scan 3D objects and produce a file that includes the data required to define a target object. Once a model is scanned, it must be uploaded to the Vuforia website, and be processed and approved, before it can be downloaded again and used for object detection. A limited number of models can be uploaded to the free service.

Vuforia scans objects without using a depth scanner camera such as Lidar, but just using computer vision. To get the best result, objects should be scanned in moderately bright and diffuse lighting. Its important to avoid direct lighting on objects with reflective surfaces as this can result in areas with no tracking points. This surface of the object should be evenly lit and not contain shadows caused by objects or people to optimize the tracking.

### 4.3.2 ARCore

ARCore is developed by Google and offers three key features in the form of motion tracking, environmental understanding and light estimation. it supports a wide variety of Android devices, along with a host of features from Google service. The framework is well-documented and easy to use. [18]

### 4.3.3 ARKit

ARKit is a framework for AR on iOS devices, developed by Apple in 2017. ARKit contains many of the same features as the other frameworks, such as facial and world tracking, however it also contains some unique state of the art features that fully takes advantage of the hardware in the newest iOS devices, such as Lidar. Among other features, the Lidar allows ARKit to do object detection. This is done in the same way as Vuforia, by using a companion app to scan an object, however there is less overhead as the model doesn't need to be uploaded to an online service, but can be used right away. [5]

### 4.3.4 AR Foundation

AR Foundation is a lightweight cross-platform framework developed by Unity Technologies that supports both iOS and Android devices. It functions as a layer on top of another framework, such as ARKit or ARCore, and allows for developing for both at the same time in Unity. It is very new and has a limited set of features and documentation. Its main features include tracking, plane detection and raycasting. [46]

## 4.4 AR Platforms

Several platforms exist for AR: Desktop displays, Head-mounted displays (HMD'S) or mobile phones. Modern mobile displays are an ideal platform for simple AR applications because they feature good cameras and have the processing power needed without the need for wires and additional technology. [23]. Another benefit for using a phone-based AR system is that the ease of which it allow users to interact dynamically and share information with and from their real environment, especially useful in industry [16].

## 4.5 Summary

This chapter investigated uses of Augmented Reality in industry and the major challenge of how the real world can be aligned with the virtual world. Three different approaches to solve the problem were found. Finally existing AR frameworks were found, and the difference between features they provided were discussed, along with a description of different AR platforms. In the next chapter an overview of current commercial apps and studies that uses DT or AR for assembly purposes will be explored.

## 5 | Current Solutions

This chapter will go over various studies and application that utilise AR or DT for assembly or disassembly related purposes. The main focus will be to investigate what the solution does to support the user in assembling/disassembling, which platforms they use and how the application uses AR or DT.

### 5.1 Commercial Apps

This section investigates AR and DT applications that are currently available and used in industry or by consumers.

#### 5.1.1 IKEA Place



**Figure 5.1:** Placing a virtual sofa in the room with IKEA Place [25]

IKEA Place is an AR app for iOS developed by IKEA in 2017. The app helps consumers to visualize true to scale IKEA products, as they can place furniture in their real environment and see how it would fit, as can be seen in figure 5.1. Special care is taken in the app to ensure realism, such as realistic lighting and careful consideration of product size. [25]. In 2020 IKEA announced a new update to the app. The update is called "Studio Mode" and makes use of the depth camera in the newest generations of iPads in order to enhance the realism in the app. The 3D depth information would be used to digitally furnish walls, ceilings, seats, table tops and other previously hard-to-reach places and to increase the quality and fidelity of the 3D models. [24].

The app is build with ARKit and appears to make use of SLAM methods, as it requires scanning of the environment, before being allowed to place objects. The app is interesting because it can be said to make use of the digital twin concept, with the expectation that the physical part of the twin would be in the digital twins place in the future. So for that reason its very important that the twins are near-identical. The app could also be thought of as a pre-step to a potential furniture assembly process.

### 5.1.2 Inspect AR



**Figure 5.2:** Inspect AR app in use. [26]

Inspect AR is a comprehensive, scale-able enterprise AR solution made by Augment IT. The solution works for several platforms: Hololens 2, AR glasses and Android. The solution offers a wealth of features to support industries during various stages of production:

- Creating and customize step-by-step instructions with AR overlays through a web browser or directly in the app. The instructions can be enriched with images, videos or AR overlays.
- Real time overview of maintenance tasks. Defects are reported in real time and documented at the push of a button.
- Knowledge integration; instructions and related materials can be found right next to the machine in the app.

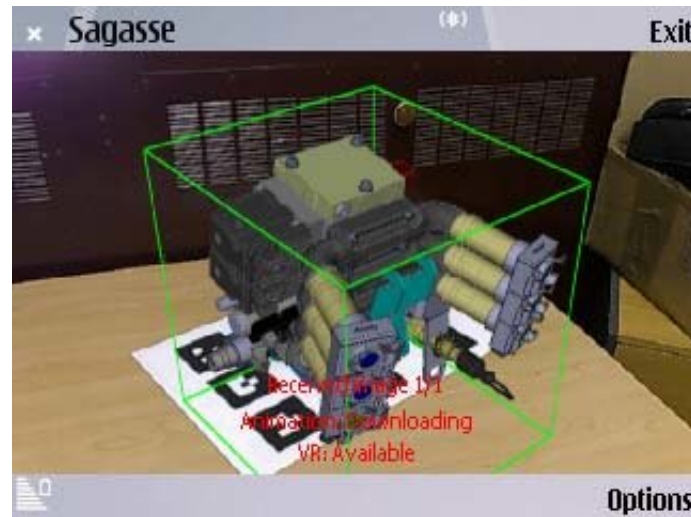
Augment IT claims that using the app resulted in business having 32% fever errors, 15% faster reporting and 28% less downtime. [26].



## 5.2 Prior Studies

This section investigates prior studies into AR and DT assembly/disassembly applications.

### 5.2.1 Augmented Assembly using a Mobile Phone



**Figure 5.3:** AR assembly system by Hakkarainen et al. [21]

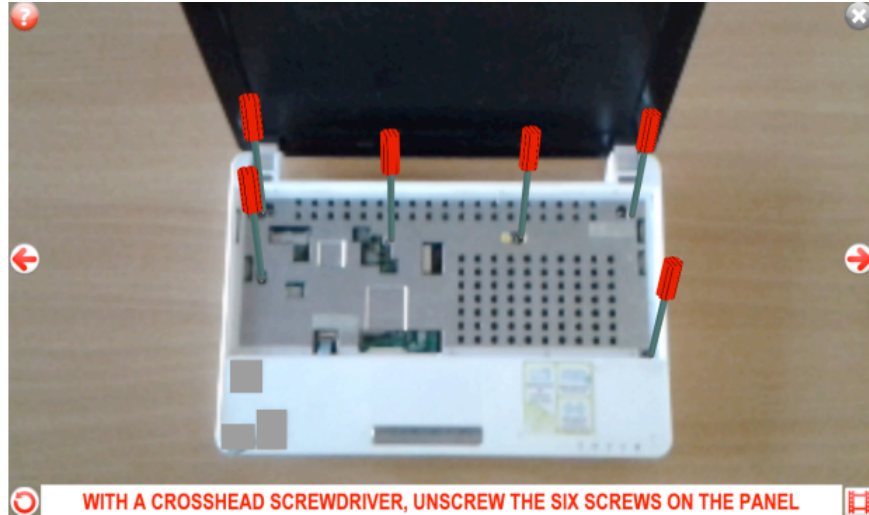
In 2008 Hakkarainen et al. created an AR system that enabled users to view complex models on their mobile phone and see a step by step guide for a real world assembly task [21]. The app uses a client-server architecture, where complex model information is located on a PC. It is built using ARToolkit, an open-source stand-alone AR framework, and uses a set of markers attached to the assembly side to align the virtual and real world. The AR guidance system was not in real time, but worked by having the user take a picture and sending it to the server, which would process it and tell the user what to do next by sending a picture back. User studies of the app showed that people felt the interface was intuitive and very helpful in supporting the assembly task. The interface can be seen in figure 5.3. The system is primitive compared to today's standards, it is however worth mentioning because it appears to be the first attempt of using mobile and AR for assembly purposes and because Hakkarainen et al. also aimed for assembly of complex models such as machines.

### 5.2.2 Co-assemble: A collaborative AR cross-devices teaching system for assemble practice courses

Zhang et al. created a multi-user cross-device collaborative system for assembly practice on mobile devices in their study from 2021 [51]. The goal of the system was to help students understanding the models structure and assembly activities and help teachers easily teach or monitor classes. The system was for iOS tablets and was created using Unity Engine and Azure Spatial Anchors, a cross-platform developer service with which users can create mixed-reality experiences, and place objects that persist in their location across devices over time. User tests showed the system had potential as a learning tool as it was more intuitive and contained context awareness different from a traditional CAD system. This system is very interesting for this project because it includes learning from experts as a significant part of the system.



### 5.2.3 Using Handheld Devices to Support Augmented Reality-based Maintenance and Assembly Tasks



**Figure 5.4:** Screenshot of the UI from the system proposed by Sanna et al. [37]

Sanna et al. studied the opportunities coming from the use of consumer devices like smartphones and tablets to perform maintenance and assembly procedures with AR in their paper from 2015 [37]. Sanna et al. created a system that helped users in assembling a machine step-by-step. Each step is recognised and activated automatically when a well-defined configuration of the object to be assembled is found in the scene. The application can recognise objects and align the virtual and digital world in two ways: by images, where the app has been trained with photos of the real object and local feature descriptors are exploited to describe a matching with the scene, or by CAD models, which looks for a models specific geometry in the scene. The system can be seen in figure 5.4. The study showed that AR tools aimed to support maintenance and assembly tasks can be valuable and that the lower the skill level of people in charge to perform the task, the greater the advantage they could get by using AR-based procedures.

### 5.2.4 Visual Assembling Guidance Using Augmented Reality

In 2015 Syberfeldt et al. studied the use of AR for supporting assembly line workers in carrying out their task optimally and can be said to make use of digital twin concepts by overlaying virtual information on top of real world objects. [42]. The study created an app using Unity Engine for a modified version of the Oculus Rift VR headset, turning it into an AR headset. In the app, the user would receive guidance as to how to assemble a 3D cube puzzle. The study concluded in a set of guidelines for what could make AR systems become more adopted in industry. In particular Syberfeldt et al. assess that the complexity of the assembling task must be high enough for the user to feel that it is worth using the AR system and that it must be proved that the AR system makes the user more efficient, otherwise the user will see no meaning in using it.

### 5.3 Assembly/Disassembly Features Comparison

	Ikea Place	Inspect AR	Augmented Assembly using a Mobile Phone	Co-assemble	Using Handheld Devices to Support AR-based Maintenance and Assembly Tasks	Visual Assembling Guidance Using AR
<b>Platforms</b>	Mobile	Mobile, Smart glasses, HMD	Mobile, Computer	Mobile	Mobile	HMD
<b>Assembly Item</b>	Furniture	Machine	Machine	Machine	Machine	3D puzzle
<b>DT related visualisation</b>						
<b>Step-by-step instructions</b>						
<b>Object persisting</b>						
<b>Automatic recognition of steps</b>						
<b>Expert collaboration</b>						
<b>Integrated knowledge</b>						

**Table 5.1:** Overview of the assembly/disassembly related features that the different systems presented previously in this chapter provide. Red means the feature is not present, green means the feature is present.

Table 5.1 aims to summarise and compare the different solutions that were presented in this chapter. Since the goal of the project is to combine Augmented Reality and Digital Twin technology in order to support users in assembling/disassembling machines, the focus is on previous research and commercial applications that strive towards the same goal. From the different solutions, various features that supports the user in assembly/disassembly processes were identified based on trying out the applications if available, or otherwise reading or watching the solution in action. From the table, it can be seen that the most common features are step-by-step guides and DT related visualisations. No solution offers all features.

Since the majority of existing solutions are mobile apps, and are mostly interacted with by using touch gestures, it becomes important to get an understanding of touch gestures and to establish some rules for how they should be used in the design of an app.

### 5.4 Apples Human Interface Guidelines

Instead of developing a set of rules that defined the best way to interact with apps, a well known design convention for working with apps can be used instead. Apple’s Human Interface Guidelines (HIG) is a set of design recommendations, that has the goal of enhancing the user experience of apps and other interactive media by making interfaces more consistent and intuitive. Opposed to Google’s Material Design guidelines, Apple sees mobile devices as windows into another world, embracing infinite depth in their applications, where Google instead has been inspired by the flat design movement and believes that humans should interact with components as if they were stacked on top of each other; users should feel as if they are holding the screen in their palms, where Apples aims for more integrated and immersive experiences. For these reasons, the HIG were selected. The goal with using established design conventions is to better convey information to the users, by using established commands/gestures, the user should know the expected outcome of each of them. HIG defines a set of standard gestures and their expected actions along with a set of rules. The standard gestures and actions are the following:

- **Tap:** Activates a control or selects an item
- **Drag:** Moves an element from side-to-side or drags an element across the screen.
- **Flick:** Scrolls or pans quickly.
- **Swipe:** When performed with one finger, returns to the previous screen, reveals the hidden view in a split view controller, reveals the Delete button in a table-view row, or reveals actions in a peek. When performed with four fingers on an iPad, switches between apps.
- **Double tap:** Zooms in and centers content or an image, or zooms out if already zoomed in.
- **Pinch:** Zooms in when pinching outward, zooms out when pinching inward.
- **Three-finger pinch:** Copies selected text when pinching inward, pastes copied text when pinching outward
- **Three-finger swipe:** Initiates undo when swiping left, initiates redo when swiping right.
- **Touch and hold:** When performed in editable or selectable text, highlights the text under the fingertip and displays an edit menu.
- **Rotate:** Rotates an image or view.
- **Shake:** Initiates undo or redo.

The idea is that these gestures elicit a close personal connection with the content and enhances the sense of direct manipulation of onscreen object. It is important to combine the standard gestures with their expected actions, as to not confuse users and add unnecessary complexity. Whenever possible there should be visible way to navigate or perform an action, even if it means an extra tap or two and shortcut gestures should not replace them but supplement them. Lastly multi finger gestures should be used sparingly and could be replaced with onscreen controls in some cases.

## 5.5 Summary

This chapter investigated several commercial applications and previous research that used AR or DT for assembly/disassembly related purposes. A set of features were identified from the different solutions, and no solution provided all features. Since most current solutions used mobile, it was deemed important to investigate and understand touch gestures and their expected outcome. A set of recommendations for how to use touch gestures in apps were found in the form of Apples Human Interface Guidelines, which will be used and serve as a baseline during the design phase of this project.

## 6 | Problem Analysis Conclusion

### 6.1 Final Problem Statement

Based on the findings of the problem analysis the scope of the project has been established. This project aims to create a mobile app that can assist the user in assembling or disassembling machines by using Augmented Reality and Digital Twin. The project will be realised on iOS using ARKit and using Apples Human Interface Guidelines to create the best possible user experience. Going forward it must be determined how the app will assist the user with assembly/disassembly visualisations and the specific interaction options must also be established. This has lead to the following final problem statement:

*How can the Digital Twin and Augmented Reality technologies be used to develop an iOS application that can assist users in assembly/disassembly processes?*

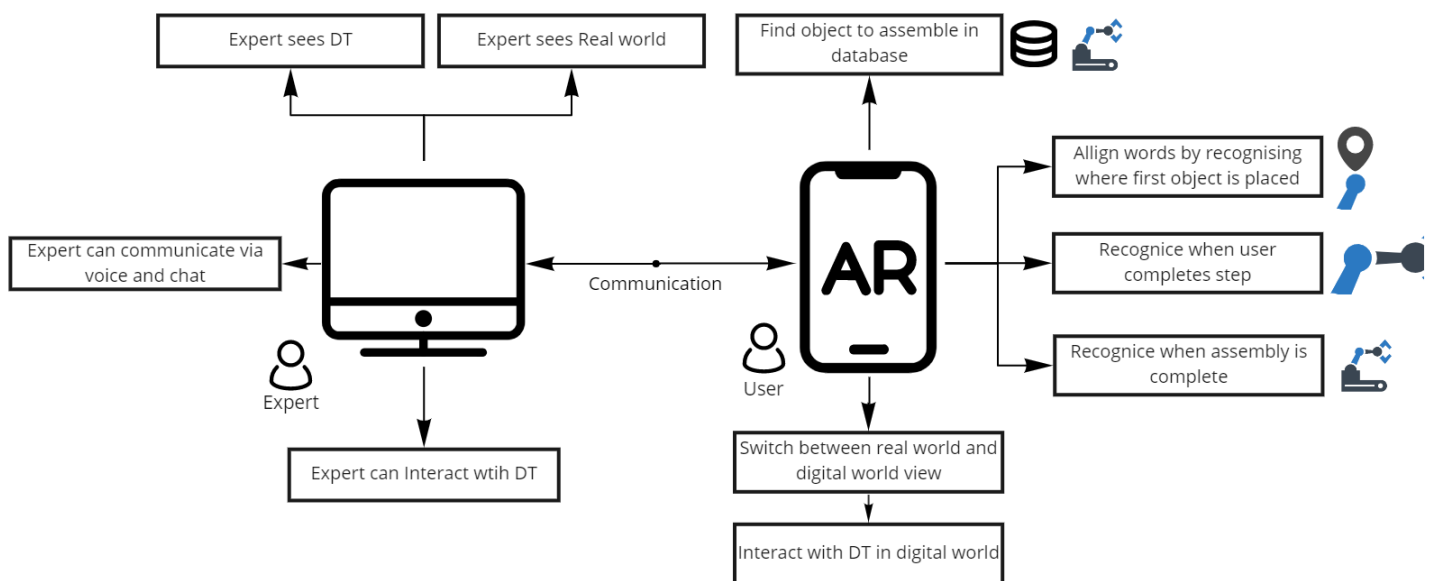
# **Part II**

# **Design**

## 7 | Proposed Solution

This chapter provides an overview of the ideal solution as well as the delimitations of the project and the requirements for success. The ideal solution assumes the solution is sold by PDM Technology to customers and customised to fit the specific customers need in terms of what should be assembled. Ideally the solution is envisioned to be a complete package containing all the features and functionality described in this chapter.

### 7.1 Ideal Solution



**Figure 7.1:** Overview of the different features in the ideal solution.

The ideal solution should be an app running on iOS devices and using ARKit as framework for Augmented Reality. The ideal solution and its features can be seen in figure 7.1. The app contains four core sets of features: AR, DT, assembly/disassembly support and expert collaboration. The following subsections describe each set of core features.

### 7.1.1 Augmented Reality

The app should use AR to visualise the next step in the assembly/disassembly process. In the app the user should be able to switch off the AR view and camera and switch to a purely digital view, where they see only the digital part of the twin. In this view, the user can interact with the twin by rotating it, tapping it to move it or scale it. When the user switches back to AR view, the twin resets. This is to keep the relationship between the digital and real world objects intact.

### 7.1.2 Digital Twin

Based on the types of DTs found (see section 3.1) a model-based simulation digital shadow should be created. The shadow should represent the object to be assembled/disassembled and be aligned with it in the real world. Aligning should be done by using 3D object detection, and using the first component in the model to be assembled/disassembled as the marker. The digital shadow should be informed and updated automatically by changes to the real model, such as moving it around, rotating it or assembling it. If a user closes the app, the shadow should persist in the same location upon opening the app the next time.

### 7.1.3 Assembly/Disassembly Support

The main feature of the app is the ability to support the user with assembly or disassembly processes. These features of the app are based on the features identified in section 5.3. The assembly/disassembly process should function in the following way: The user should be able to choose a model to assemble/disassemble from a database within the app and is then prompted to align the worlds. The app should inform the user about the next step by updating the shadow with the next component and highlighting it. When a user has correctly placed or removed a component, the app should automatically progress to next step. The user should be able to have control over the process and be able to turn off the automatic progression or go back steps. The app should recognise when the model is fully assembled or removed and inform the user.

### 7.1.4 Expert Collaboration

A major feature in the solution is the ability to connect to an expert and receive guidance on how to proceed with an assembly task. The experts would be employees from the company that PDM Technology has sold the solution to. The expert would use a desktop version of the solution, and have access to some special features, that could help them guide the user. A user can connect to an expert in the app at the press of a button, and the expert would then be connected with audio and screen-sharing. The expert would get the AR view through the camera of the phone and the digital view, where they can see the digital twin only. The expert can select a components in the twin to highlight them for the user, allowing for communication in three ways: through interaction, audio and visually.

## 7.2 Expert Interview

In order to limit the scope of the project, get feedback on the ideal solution and ensure the group had a united vision with PDM technology, an expert interview with the CEO of PDM Technology, Jørgen Schiønning Larsen, was carried out. Jørgen was presented with figure 7.1 and an explanation of the different features in the ideal solution, before being asked his thoughts about various parts of the solution.

### 7.2.1 Methods and Procedure

The interview followed a semi-structured pattern, where the questions were not set in stone and the interviewer could branch out into interesting directions based on the experts answer. A script was made to provide a rough outline for the interview. The script can be seen in appendix A.3. The interview was conducted with two interviewers, the primary interviewer being in charge of the main session and the secondary interviewer doing the first introduction and the warm up, as well as looking out for interesting branches to follow in the line of questioning during the main session. The interview was conducted online using Microsoft Teams, due to time-availability.

The interview was split into distinct sessions following each other:

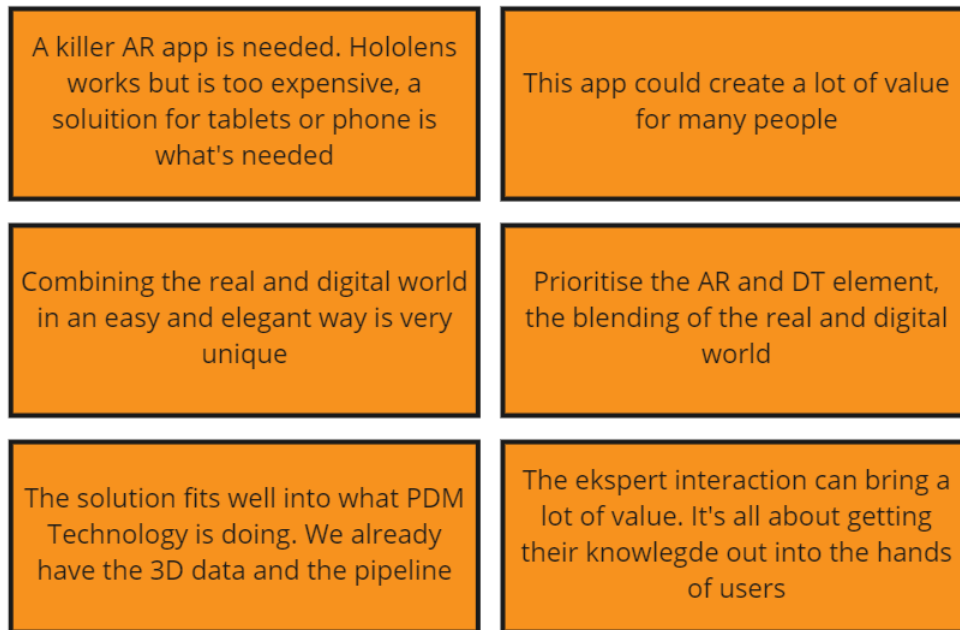
1. **Introduction part 1:** Informing the expert about the structure of the interview and getting permission to record the interview.
2. **Warm-up session:** Easy-going questions to get the expert talking and breaking the ice.
3. **1 Minute thinking break:** The expert get to observe and understand the diagram on their own without explanation from the interviewer.
4. **Introduction part 2:** Showing the expert the diagram and explaining the different features in the ideal solution.
5. **Main session:** Hard hitting questions to the expert about the diagram and the ideal solution.
6. **Cool-down session:** Easier questions and giving the expert a last opportunity to provide comments.

### 7.2.2 Pilot Study

A pilot study of the expert interview was carried out using a group member as participant. This was to measure the length of the interview and to determine if the questions in the script were sufficient and answered the goals set for the study. The script was considered sufficient following the pilot study.



### 7.2.3 Results



**Figure 7.2:** Key findings from the expert interview.

The most important findings from the expert interview can be seen in figure 7.2. In general the expert was positive and enthusiastic about the proposed ideal solution. When asked in general about the solution, the expert could see a lot of value for their customers and users in it. The expert found the core of the project to be about aligning the virtual and real worlds, and saw it as a stepping stone to understand more about how to use AR in the future. As such, the expert would prefer the project to prioritise features related to AR and DT over expert collaboration or assembly features.

When asked questions about expert collaborating features, The expert was also very positive, and suggested several ways the communication could be expanded, such as sending 3D files and videos over the system. The expert remarked that the way the solution is split between an app and a computer was a good way to integrate the expert and can support both parties by giving them what they need to succeed. The proposed solution would also fit very well into what PDM Technology does and be of great benefit to their customers.

### 7.3 Delimitations

This project will focus on creating an iOS application for assembly/disassembly of machines. As such, integrating the app with other platforms, such as Android phones or HMDs, is out of scope for the project. It is seen as possible to extend the solution to additional platforms but the iOS functionality takes priority during implementation, due to the features included with ARKit. (see section 4.3 )

The core principle of the solution is to focus on assembly of machines. This means other types of assembly/disassembly, such as furniture or 3D puzzles (see section 5.3), will not be included. The application will however be made with potential future expansion of assembly/disassembly types in mind.

While DT technology is an important aspect of the project, creating a model-based simulation full digital twin that has automatic data flow both ways (see section 3.1) is not feasible nor in scope of the project, as it is not seen as necessary to support users in assembly. Instead the group will focus on making a digital shadow, where information from the real model informs the digital model.

Several limitations must be made regarding the features of the application to keep the development focus on the core of the project. The features described in section 7.1 were put into three different categories depending on their implementation priority, as seen in table 7.1.

	AR & DT	Assembly	Expert Collaboration
<b>Core Features</b>	<ul style="list-style-type: none"> <li>- Aligning the environment</li> <li>- Aligning the objects</li> <li>- Switching between real and digital world</li> </ul>	<ul style="list-style-type: none"> <li>- Step by step assembly/disassembly guidance</li> <li>- Virtual outline of physical model</li> </ul>	<ul style="list-style-type: none"> <li>- Contacting expert with screen-share</li> </ul>
<b>Quality of life improvements</b>	<ul style="list-style-type: none"> <li>- Interacting with model in digital world</li> </ul>	<ul style="list-style-type: none"> <li>- Undoing steps</li> <li>- Choosing object from database</li> </ul>	<ul style="list-style-type: none"> <li>- Contacting expert with audio</li> <li>- Contacting expert with chat</li> </ul>
<b>Nice to have</b>	<ul style="list-style-type: none"> <li>- Objects persists in the world</li> </ul>	<ul style="list-style-type: none"> <li>- Automatic recognition of completed steps/finished model</li> </ul>	<ul style="list-style-type: none"> <li>- Expert can switch between real and digital world</li> <li>- Expert can interact with twin</li> </ul>

**Table 7.1:** Features of the system put into different categories depending on the implementation priority.

Features in the top row are core features, and must be implemented first, as these are needed for the core of the system to work. These consist of the alignment of the digital and real world, along with assembly/disassembly supporting features and contacting an expert with screen-sharing. Features in the second row are quality of life improvements and add on to the core features and improve them in different ways, but are not key for the system to function. Features in the bottom row are nice to have and would be implemented if there is more time after all the other features are completed. These features are not crucial to the system but would improve it. The focus on the project is on AR and DT features, as the expert found these features to be the most interesting part of the project and suggested to focus in that direction. Expert collaboration features, while still being important, are not the focus of this study and are thus not prioritised highly.

## 7.4 Core Requirements

The following set of requirements serve as project goals in regard to implementation of the application. Rather than a strict set of requirements to be implemented, they serve as goals for the design and the implementation of the application. The goals are listed in order of priority and will serve as a guide while implementing the solution.

### 7.4.1 Feature Requirements

These requirements detail the specific features which should be implemented. These requirements are ranked in a decreasing priority according to the core features described in figure 7.1.

1. The virtual environment must align with the physical environment.
2. The virtual overlay should fit on top of the real world model.
3. The user must be able to view a virtual overlay of the physical model.
4. The user must be able to advance the assembly/disassembly to next step and the overlay should adapt.
5. The user must be able to screen-share with an expert.
6. The user must be able to switch between the real world and a purely digital world.

Apart from these requirements the solution needs to fulfil basic functionalities of modern smart-phone applications, such as functional UI and stability of the app.

### 7.4.2 Application requirements

The requirements below describe the general features which must be considered when designing and implementing the application.

1. The application must utilize the design conventions described by Apples Human Interface Guidelines (see section 5.4).
2. The application should be implemented in augmented reality.
3. The application should run on iOS for phones and tablets.

Having established the requirements needed to design the application it is possible to begin the design process. In the next chapter the final design of the application will be described along with the methods and techniques used in the design process.

## 8 | Design Concept

This chapter aims to develop a design concept for the proposed solution. This is accomplished by using a Google Design Sprint. The methods from the sprint were applied in order to create a design concept for how to present features in the app and the graphical user interface. The design focuses on what is needed for the ideal solution, however only the app and not the experts view on the computer.

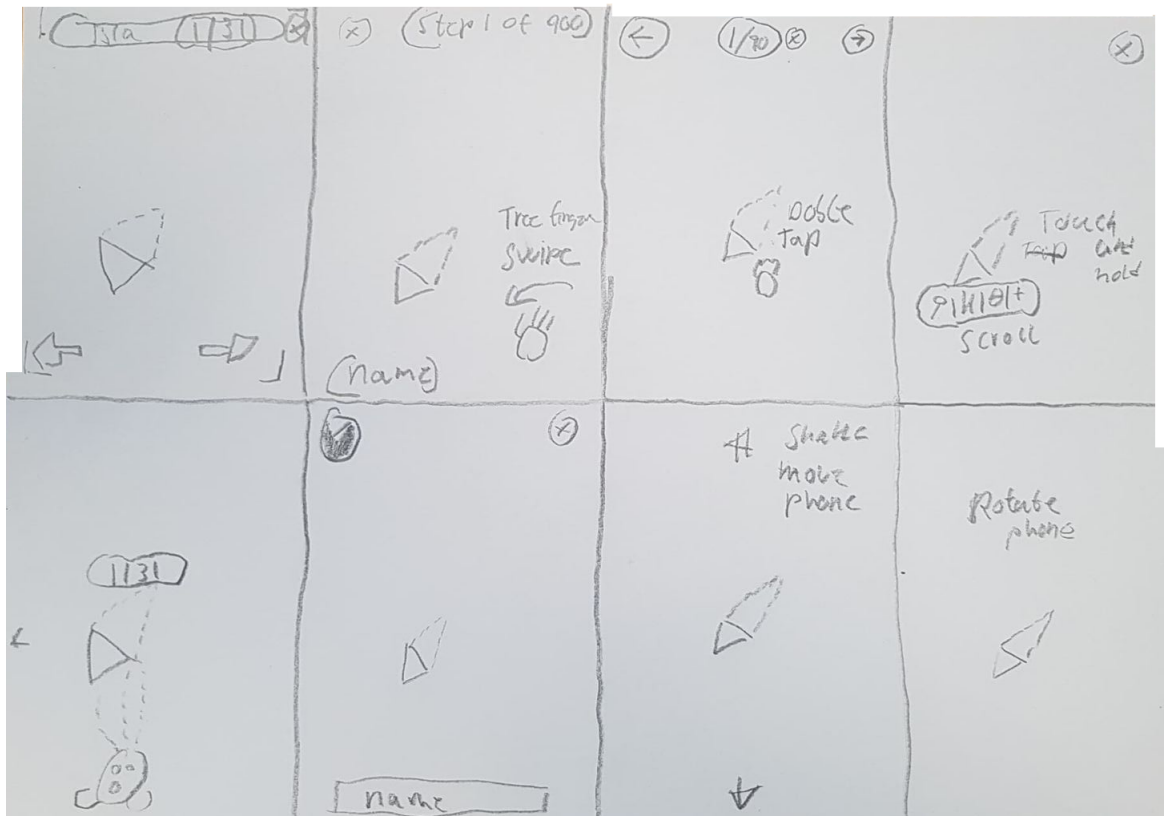
### 8.1 Design Sprint

A Google Design Sprint [19] consists a variety of methods with the purpose of intensively outputting a huge amount of ideas over a short amount of time. From the resulting ideas, the best candidate solution can be derived. The sprints in this project took place by using the following methods in order:

1. Prior discussion: The group discusses the problem to solve for 20 minutes. This step makes sure that everyone is on the same page about the goal of the sprint.
2. Sketching with crazy8: Over eighth minuets each member of the group creates eighth sketches of a potential solution to the problem.
3. Discussion of sketches: Each group member explains their sketches and discusses pros and cons with the group. Results in an agreement on the best sketches and ideas.
4. Further sketching and discussion: Step 2 and 3 are repeated to iterate on the best idea until a final concept has been generated.

### 8.2 Sketching

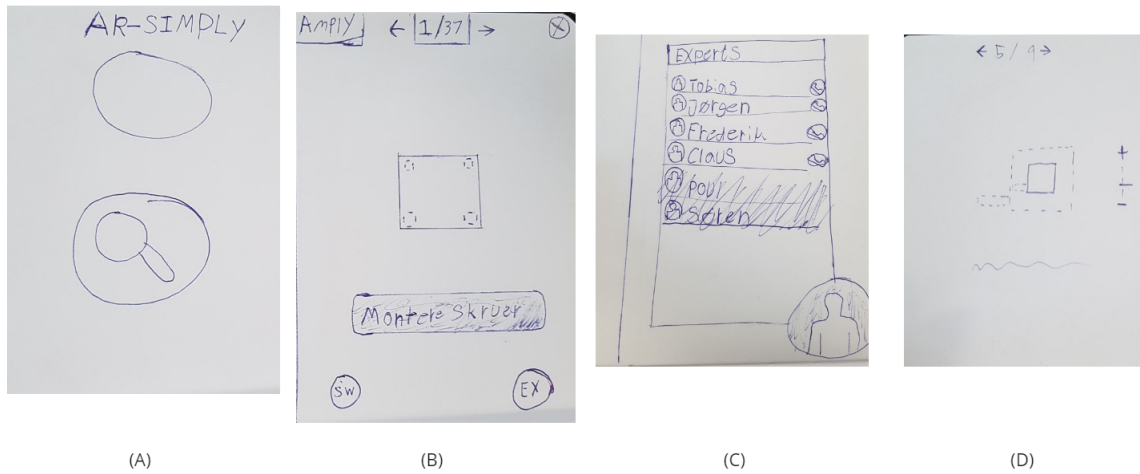
The sketching process was done individually with a modified version of the crazy8 method, where two minutes was used per sketch contradictory to the one minute that the normal crazy8 method uses. The reason for this was the group only consisting of two people, and it was decided that a longer sketching period could be beneficial to the discussion in order to gain more from each iteration. The crazy8 method was done a total of 2 times before the group determined a mid-fi design. The result of the first iteration was an agreement on which screens to include in the prototype. The result of the second iteration was how to include the different features on the screens.



**Figure 8.1:** Sketches showing different iterations of a user should be guided for assembly

A selection of the sketches, that resulted from the sketching process, can be seen in figure 8.1. These sketches focuses on investigating the assembly/disassembly process. They experiment with using the different gestures described in section 5.4 to affect the process. As a result from the sprint, it was decided to include the following screens in the system:

- **Front page screen:** The initial page the user sees as they open the app.
- **Finding object screen:** Used to align both the digital and real object and worlds.
- **Assembly screen:** Guides the user trough the assembly/disassembly process. Also allows for contacting expert and switching between digital and real world.
- **Assembly complete screen:** Informs the user that the assembly/disassembly is complete.
- **Digital world screen:** AR mode is disabled and the user can see the Digital Twin and interact with it in a different way then in AR.
- **Expert collaboration screen:** Allows the user to select and expert and get in contact with them.
- **Different pop-ups:** Appearing on top of other screens to allow for easier navigation, expand information or ask for confirmation.



**Figure 8.2:** Sketches of first iterations of some of the screens in the app.

In figure 8.2 the first iterations of some of the screens described above can be seen. (A) is the front-screen, (B) is the assembly screen. (C) is the expert screen. (D) is the digital world screen. The focus was on exploring what elements could be on the screen and how the user should navigate and interact with each screen.

### 8.3 Final Design

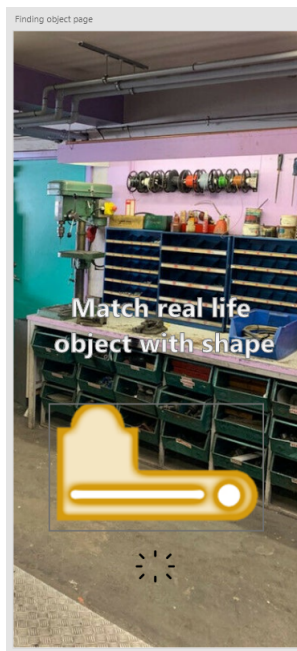
The final design was realised using Adobe XD to create an interactive mockup. A plugin to Adobe XD allows for the design to be exported and used in development software. The following is an depth discussion of each screen in the application:



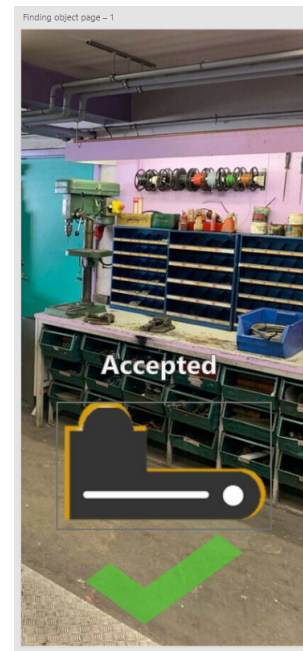
**Figure 8.3:** The front page of the system, the first page the user sees.

The front screen can be seen in figure 8.3. It mainly consists of the view from the camera on the phone, as AR is immediately activated. This is represented by a stock image of the environment the app could be used in. The screen also contains the name of the app and a logo, that can be interacted with to continue.



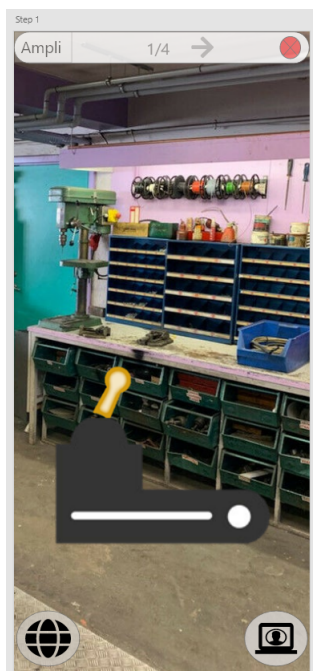


**Figure 8.4:** User being prompted to align the real world object with the digital object.

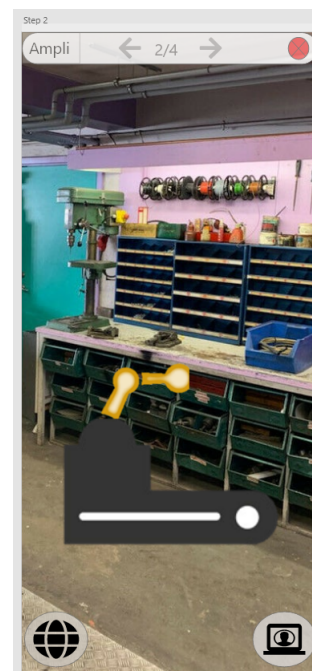


**Figure 8.5:** Object has been recognised and the worlds are aligned.

Once the user interacts with the logo, the finding object screen is the next screen the user sees. This screen can be seen in figure 8.4 and 8.5. On this screen an outline of the first component of the object to be assembled can be seen. The user is prompted to match the real object with the outline, so that the system can use that information to align the digital and real worlds. Once this is achieved the user gets a check-mark and the assembly/disassembly process can start.

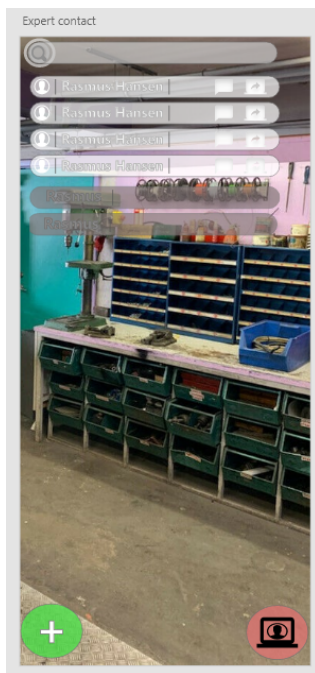


**Figure 8.6:** Outline shows which step to complete next.

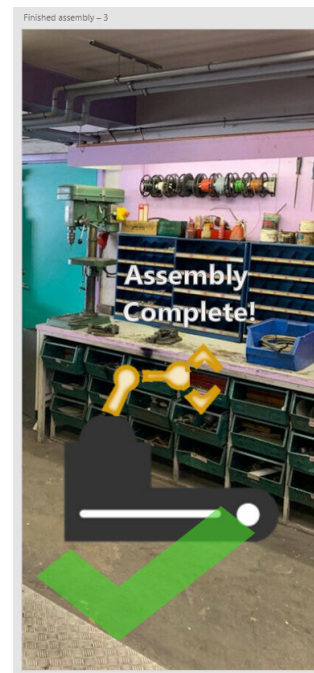


**Figure 8.7:** User has progressed to step 2.

The assembly screen is the main screen the user will interact with in the app. The screen can be seen in figure 8.6 and 8.7. In the screen the user can see an outline of the next part and how it should fit in the assembly/disassembly. The page contains a bar at the top, that tells the user about the name of the object they are assembling/disassembling, a quit assembly button and a step counter that shows which step they are on and how many steps the assembly/disassembly consists of. The bar also contains two arrows, allowing the user to progress to the next step or the previous step if these exists. Tapping the name of the object opens a pop-up that contains more information about the object, such as full name, model number and model year. Tapping the step counter opens a pop-up menu that allows the user to skip to any step and also get a short explanation of what the steps consists of. Tapping the quit assembly button open a pop-up that asks the user to confirm. If the user confirms, they are taken back to the front screen, otherwise the pop-up just closes. Buttons at the bottom of the screen allows the user to switch between the real world and digital world view (left button) and to contact an expert (right button). If the contact expert button is pressed, a connection is established to an expert, and the screen is shared. The process of choosing an expert can be seen in figure 8.8. A graphical effect along the sides of the screen alerts the user that this is happening along with the button changing color. Pressing the button again disables sharing and the effects.



**Figure 8.8:** Selecting an expert to contact in the app.



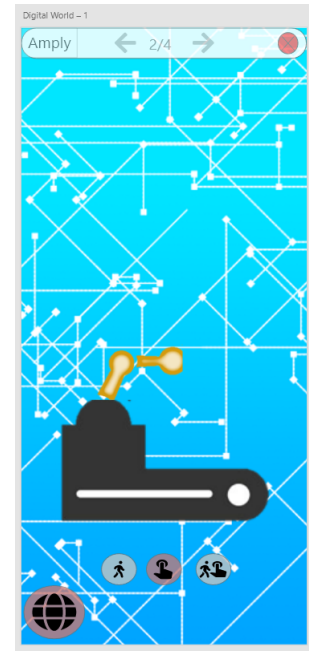
**Figure 8.9:** Assembly has been finished.

Once all the steps are completed, the user is greeted with a check-mark and the text "Assembly/disassembly completed" after which they will be taken to the front screen. The completed assembly screen can be seen in figure 8.9





**Figure 8.10:** In the digital world the user can interact with the model in different ways.



**Figure 8.11:** User has progressed to step 2 in the digital world.

The digital world screen can be seen in figure 8.10 and 8.11. It can be accessed through the assembly screen by pressing the corresponding button. When the button is pressed it turns red. In this world AR is disabled and the user can only see the digital twin in a virtual environment and not the real object. The user can interact with the digital twin by moving individual components around, scaling them or rotating them. Tracking is still active behind the background, so the object continues to be anchored. This can be disabled with a button in the digital world. If the user presses the switch world button again they will be taken back to the real world view.

## 8.4 Summary

The design of the system was completed by using a design sprint and sketching the different proposed screens of the system. In the end, the group arrived at a final design concept and used Adobe XD to make an interactive mock-up. Now that the design is complete it is possible to begin the implementation of the application.

# Part III

## Implementation

## 9 | Implementation Methods

In this chapter the methods and tools used in the implementation of the prototype is identified and described. A system architecture is selected. Finally the 3D model and real life machine used for testing is described.

### 9.1 Agile Development and Design Patterns

The prototype was implemented using the agile development framework known as extreme programming. In extreme programming, development consists of multiple shorter and intense cycles, rather than one long. The goal was to respond to changes in requirements and design quickly along the implementation process, with the philosophy that changes are a natural, inescapable and desirable aspect of software-development projects. After a coding cycle, it was important to share and explain the code to group-members and give feedback.

When appropriate the singleton design pattern was used in different classes. This pattern involves restricting the instantiation of a class to a single instance. Is it useful when creating manager-type classes, where there should only ever exist a single instance anyway. In Unity singletons allows for easier flow of data between the singleton and other classes, as other classes don't need a reference to singletons, but can instead identify them from a global scope. Examples of classes that were implemented with the singleton design pattern include SceneSwitcher and AugmentedManager.

### 9.2 Development Tools

It was decided to use Unity Engine [47] to implement the prototype application. Unity is fast and easy to create prototypes with, as it contains in-built features and libraries that will help the project. Group members also have copious amounts of experience in using Unity from previous projects. Unity is a game engine, which means it has lot of features for interaction and simulation of 3D objects. A key factor is support for ARKit through AR Foundation. Another benefit is the Unity asset store, that contains many free assets such as plugins, 3D models and functionality, for use in projects. Through the Adobe XD plugin "XUID Unity Exporter" [27], the design created in the previous chapter can be imported and used in Unity, significantly simplifying the process of making a UI, which Unity is notoriously not great for.

Unity version 2021.2.18f1 was used in the project. This was the latest official long term support release from Unity during the project and was used due to dependencies in AR Foundation limiting the version to 2021.x or errors would occur. A Unity internal version control system called Plastic SCM was used to share code among the group members and keep track of changes

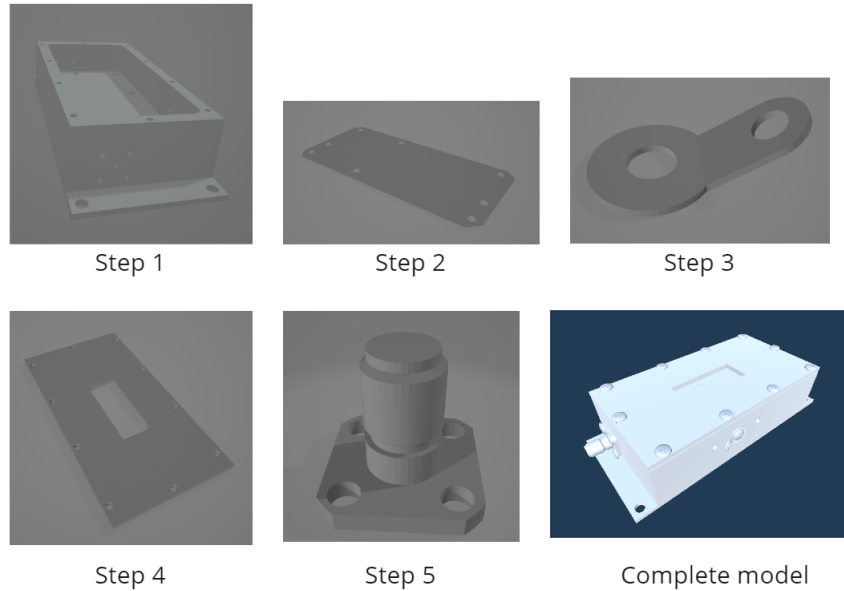
during the project. By using Plastic the need for third party version control was removed.

Since the project is an iOS app, a Mac computer is needed in order to create builds in Xcode from Unity. Creating these builds are a cumbersome process that involves switching between the Windows machines used for development and the Mac computer. A plugin from the asset store that was helpful for the project was "iOS Project Builder for Windows" [7], which could be used on Windows to replace Xcode. The plugin used the Unity build as input and took care of building and signing the code, before outputting a QR code, that could be scanned by the device in order to deploy the application. Using the plugin greatly simplified the build process and reduced the time it took to develop and test the build on an iOS device. As for iOS devices used, the project used a 4Th generation 12.9-inch iPad Pro and an iPhone Xs both running on the newest version of iOS version 15.4.1 for testing the app.

### 9.3 System Architecture

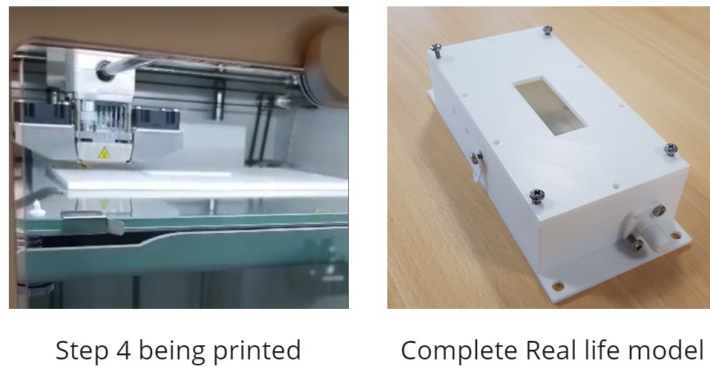
As Unity uses a component-based development (CBD) system, that is the method by which the prototype will be implemented. In CBD functionality is split between separate components, so that all data and functions within each components are semantically related. Components should strive to be reusable, independent and should lack context specification. Unity allows for editing components directly from the editor using the inspector window, without having to dive into the code. The benefits of CBD is that it is modular and cohesive. Building the system as different components can be efficient and easier to maintain than using traditional inheritance-based architectures. Using CBD also makes it easier to split the work-load between the group members and progress on implementing more components at once. Disadvantages of CBD can include making it difficult to analyse and compare components for trustworthiness and quality certification or identify different requirements for different components. A figure showing how different classes belong to different scenes can be seen in appendix A.1 figure A.1.

## 9.4 Testing Machine



**Figure 9.1:** Machine used for testing while implementing the prototype.

In order to ease development of the prototype, a simple machine was required to test out the features. Since the project needs both the real world machine and a 3D model counterpart of every component, it was decided to 3D print a model provided by PDM Technology, an amplifier for industrial machinery consisting of five unique components. The assembled model and its individual components can be seen in figure 9.1. 3D printing the testing machine provided both advantages and disadvantages. The printed machine was quite featureless and difficult to use for the object recognition system to recognise. The model also consisted of flat surfaces, which made it easier to put a marker on it and use image tracking. While the model was useful for testing during the development, it did not provide a very realistic scenario for how the prototype would be used in the real world. The real life model can be seen in figure 9.2. The group spent around 25 hours printing all individual components.



**Figure 9.2:** The model being printed and the assembled real life model.

## 9.5 Summary

The prototype was implemented in Unity using AR Foundation with ARKit. The group used a component-based system architecture and strived to make components reusable, independent and lacking context specification. A 3D model of an amplifier was 3D printed and used as testing machine during development.

## 10 | General Implementation

In this chapter it is described how the different features that makes the prototype flow together were implemented. This includes how the UI functions, how the prototype supports assembly and disassembly and how the digital world and expert collaboration were implemented.

### 10.1 User Interface

The UI was implemented in the prototype by loading different scenes depending on which screen the user should see. A scene in Unity is an assets that contain a specific part of a game or application. The UI was implemented using different scenes in order to keep the application light and simple with only the necessary elements in each scene. It also made it easier to split the workload, as several scenes and their corresponding functionality could be worked on by the group-members at one time. The prototype contains the following scenes:

- **Loading scene:** The first scene upon opening the app, loads in a few key objects that persist trough the scenes and then goes to front scene.
- **Front scene:** Allows the user to select between assembly and disassembly as well as which model to work with.
- **Finding scene:** Allows the user to select between object tracking, image tracking and simply placing a model in the world by tapping. Activates the selected tracking system.
- **Assembly scene:** Allows the user to assemble or disassemble their model by going through the different steps.
- **Digital scene:** Allows the user to interact with their model by rotating, scaling or translating individual components. Disables the AR camera.
- **Expert scene:** Allows the user to communicate with an expert via screen-sharing and voice.

In addition to loading new scenes, a few key objects were marked as "DontDestroyOnLoad" and thus persisted between scenes. In some cases this was done to preserve knowledge of the users interaction, such as keeping track of which assembly step the user was at, when switching between the real and digital world. In other cases it was to keep the prototype smooth as the user navigated to different scenes, and would otherwise need to load an object still in use again. An example of this is the AR-session and related cameras. If these objects were re-loaded between scenes, the user would experience a jarring lag and their 3D model flying away for a second, as the AR-session had to re-calibrate. The DOTween library was used to create animations when switching between pages, or to give the user feedback for interactions.



**Figure 10.1:** Help message that was added into the implementation.

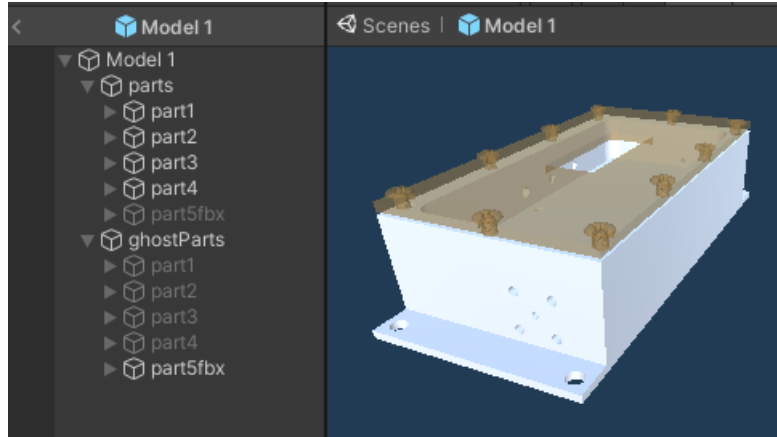
While implementing the prototype and trying out the different features, the group discovered some errors in the design or missing features, that would enhance the users experience. Examples of this includes a help-box that fades in and informs the user of what to do in the coming step and using the front page to select between assembly and disassembly and switch machines. The help-box can be seen in figure 10.1. Additionally some design compromises were had in order to save time, such as using a room-code system to join an expert session, instead of building a lobby system, where the user or expert could see and join active rooms. Apples Human Interface Guidelines were kept in mind when implementing the UI. It was important that interactions were kept simple and that each screen brought something new and unique to the user, that users could use the entire display and that text was minimised.

## 10.2 Assembly and Disassembly

Assembly is handled in the prototype by simply toggling visibility of different child components in a parent model based on the current assembly step. The parent model is pre-set and prepared in the editor before building the app, as the system is not generic and requires some tuning for different models. This was done for time-saving purposes, and would change to become more generic in future iterations of the system. The transparent outline that guides to user as to what is the next step was archived by placing a copy of the model to be assembled on top of the normal model. The material of this model was then changed to have the transparent outline, and the visibility of the next component to be placed is toggled depending on the current step. Disassembly is handled by arranging the child components under the parent model in the reverse order and toggling their visibility depending on the current step the same way as

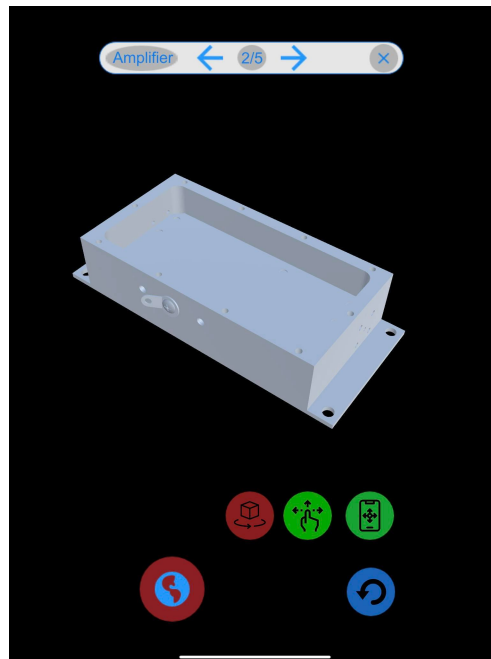


assembly. Figure 10.2 shows a model during assembly, where four steps has been completed and the last step is being hinted with the outline.



**Figure 10.2:** Assembly of the model. Four steps has been completed and step five is being hinted with an outline.

### 10.3 Digital World



**Figure 10.3:** Screenshot of the digital world

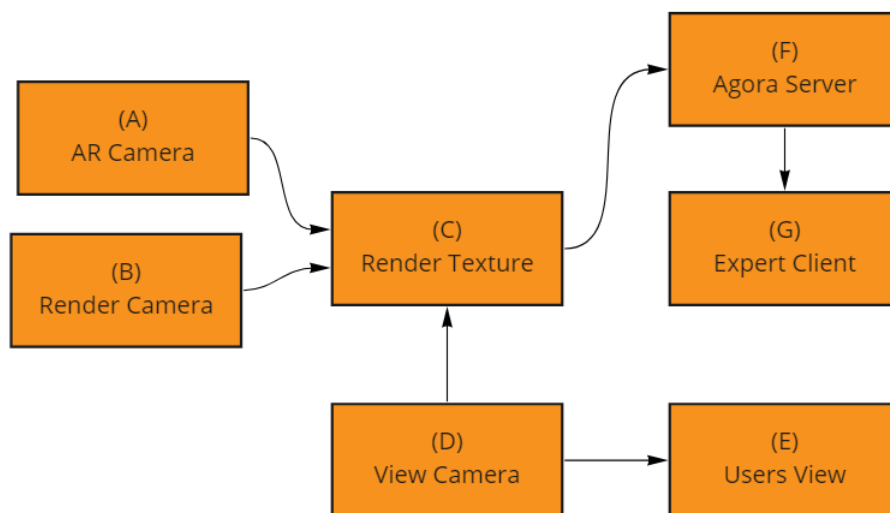
In the digital world the user can rotate, translate and scale individual components of the 3D assembly object by tapping and dragging them. The user also has the option to disable the background tracking, and not have the model move when the devices moves. The AR camera background is disabled in the digital world. The intention with this world was to allows the user to interact with the 3D assembly object in other ways than the real world. It was important to maintain coherence between the digital and the real world with regards to the 3D assembly

object and how the user perceives it, while at the same time creating a useful tool, that would support the user in assembly or disassembly processes. Several different iterations of environment or methods were tried in order to create a digital world, such as using a sky-box, putting the camera inside a sphere with an environment, or creating a room around the camera. However it was found that these methods were not conducive to a good experience, as the user could walk away from the environment, the environment would simply not display or the switch between worlds would not maintain the coherence. As such it was decided to go with a black background and keep tracking the assembly object in the background. The digital world can be seen in figure 10.3.

## 10.4 Expert Collaboration

Expert collaboration in the prototype is achieved by making use of the Agora framework. Agora is a customisable and flexible package, that allows for easy integration of feature such as live-streaming, voice and video calling and real time messaging. Agora works across platforms and is free to use for 10.000 minutes per month. No minutes are consumed by the functionality from the prototype, as it is used for testing purposes only. The framework was integrated into Unity using the asset store.

While Agora supports screen-sharing the entire screen out of the box, a bit of setup was required in order to capture 3D objects from the users view without capturing UI elements. This was necessary to accomplish, because the UI elements would clutter up the screen and the expert did not need to see them or be confused by them. The expert did need to see the 3D model being assembled to see what the user is doing and help. The more screen real estate the expert could see the better.



**Figure 10.4:** How the different objects work together to allow for expert collaboration.

The screen-sharing works by making use of three different cameras and a render texture. Figure 10.4 shows the relationship between the cameras and the clients. The AR Camera uses the

physical camera from the back of the device as input and sets each frame as output to the render texture. Since the AR camera does not capture the 3D elements in the scene the Render Camera is needed. It is placed at the same position as the AR Camera and it is also outputting to the render texture. Since both cameras output to the render texture, this means their images are not rendered to the screen itself. The View Camera is the camera that provides the users view. The camera is looking at and parented to a quad (A primitive object that resembles a plane but its edges are only one unit long), which is using a material generated from the render texture, providing the combined view from the other cameras to the user. The View Camera has a different position than the other cameras, so that the quad doesn't appear in the other cameras view. The render texture is also sent to the Agora server and fetched by the expert client.

### 10.4.1 Users View



**Figure 10.5:** Users view

From the users side, they are able to see the experts camera and toggle their microphone, as well as exit the collaboration session. The users interaction options are very limited in this screen, as the focus is on the expert helping and guiding them. The users view can be seen in figure 10.5. The white square represents the experts web-cam, but no expert was connected in the figure.

### 10.4.2 Expert Client

While the expert client was not the focus of this project, a preliminary design and implementation was put together for it in order to show how it could work. The result can be seen in figure 10.6.

The expert client runs on a computer and consists of two screens. The first screen (A) allows the expert to input a room-code and join a session. The expert is then taken to the second screen (B), where they can see a users that joined the same room screen-share. The screen is gray in the figure because no user has joined. The expert and the user can interact via voice, and the experts front-camera is sent to the user and visible to the expert themselves. The expert has a view of the item being assembled next to the screen-sharing view from the user. Here the expert can rotate and move the object, go trough assembly steps as well as select individual components of the object and mark them in a chosen color. This action is then communicated to the user via Agora, and the corresponding object changes color for the user too. The intention with this feature was to give the expert a tool to communicate and interact with the model in front of the user. The expert can also reset colors for both parties and reset transformations of the model.



**Figure 10.6:** The screen in the expert computer prototype.

## 10.5 Summary

The chapter described how the UI was implemented with different scenes and retaining some elements between the scenes. It was explained how assembly and disassembly were done by toggling child objects corresponding to the current assembly step under a parent object. Finally it was discussed how the digital world provides different interaction options and how the expert collaboration was implemented using the Agora framework.

# 11 | Augmented Reality Implementation

This chapter describes how AR was setup in Unity and how two different tracking methods were implemented along with AR anchors. For the AR implementation AR foundation together with ARKit was used as a basis for aligning the real world with the digital world.

## 11.1 Setting up AR

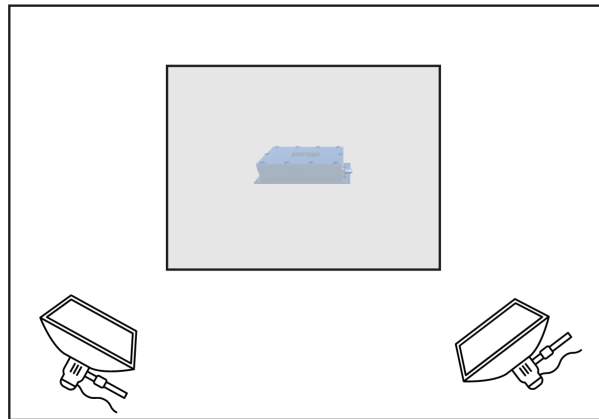
AR Foundation is designed as a set of subsystems. A subsystem is a platform-agnostic interface for surfacing different types of information. Each subsystem handles specific functionality. For example, **XRPlaneSubsystem** provides the plane detection interface. This allows for splitting up functionality and only using what is necessary in a specific AR application and saving computing resources. There are three key component objects to setting up AR in a scene: **AR Session**, **AR Session Origin** and **AR Camera**.

**AR Session** is the core object that handles everything from initiating, configuring and running AR on a device. When it is disabled, the system will no longer track features in the environment. An **AR Session** object needs an **AR Session Origin** object to function. The purpose of **AR Session Origin** is to transform trackable features like planar surfaces or feature points, into their final position, orientation and scale in the Scene. **AR Session Origin** is also responsible for transforming between coordinate systems, as AR devices provide their data in **session space**, which is an unscaled space relative to the beginning of the AR session, and must be transformed into Unity space. The final object needed in the setup is **AR Camera**, which is a special type of camera that is a child to **AR Session Origin**. The combination allows detected trackables and the camera to move together.

## 11.2 Object Tracking

The group's first method to align virtual and real worlds were using object tracking. The idea of object tracking is to scan spatial features of real-world objects and then use the results to find those objects in the user's environment and trigger AR content. The first step of object tracking was scanning the object to be tracked.

### 11.2.1 Scanning real life object



**Figure 11.1:** An example of a setup used for scanning

The group used the scanning and detecting sample app provided by Apple [6] to scan the 3D printed amplifier. In order to obtain the highest quality scan possible, the group used the following scanning environment guidelines:

- Light the object with an illuminance of 250 to 400 lux, and ensure that it's well-lit from all sides.
- Provide a light temperature of around 6500 Kelvin (D65)—similar with daylight. Avoid warm or any other colored light sources.
- Set the object in front of a matte, middle gray background.

Figure 11.1 shows a diagram of a setup used for scanning the amplifier. The setup consisted of a table with the amplifier on, along with two dim-able studio lights and plenty of space to walk around the object. The scanning process consisted of several steps. The first step involved positioning the object and configuring a bounding box around it in the sample app. The bounding box defined what region of the world contained the object that should be scanned. It was important that the bounding box only contained features of the object that should be scanned and not features from the environment it was in. The next step was to move around and look at the object from different angles. The app highlighted parts of the bounding box to indicate the object had been scanned enough to be recognized from the corresponding direction. The object should be scanned from all sides that users of the app should be able to recognize it. The final step was adjusting the object's origin, the anchor point relative to the object. The finished scan could then be tested and exported as an **ARReferenceObject** for use in Unity. Figure 11.2 shows the process of scanning the amplifier in the app.

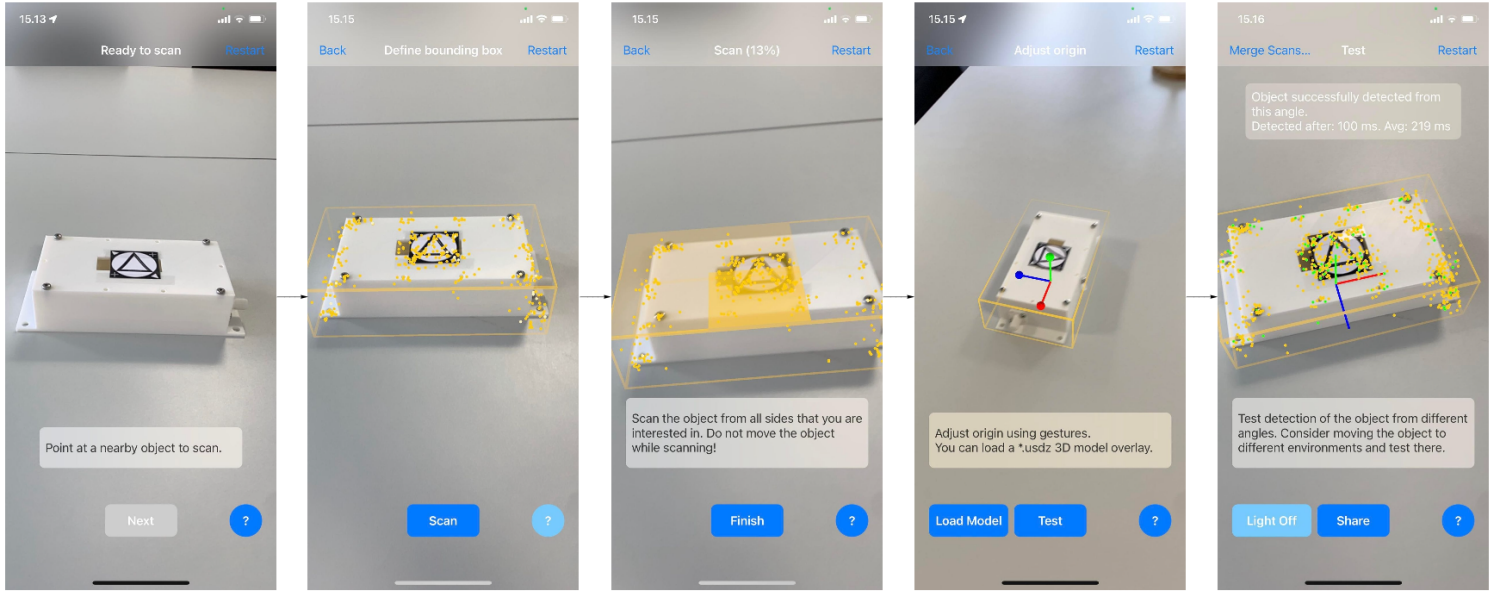


Figure 11.2: Each step in the process of scanning.

### 11.2.2 Object tracking in Unity

AR Foundation supports object tracking by using an AR Tracked Object Manager. The AR Tracked Object Manager functions by using a reference library. The library contains **ARReferenceObjects** that the manager should look for in the environment. Upon detecting it, the manager will create a pre-defined object at that location, such as the amplifier. The manager will then continue to track and update the position over time.

### 11.2.3 Tracking performance

Several different scans of the real life amplifier in different environments were implemented in Unity. However the group discovered the tracking performance of the system was very poor, as the amplifier would rarely be recognised and tracked. This might be due to the real life amplifier model not being a very good object tracking subject: it has very few identifying features, very little geometry and is of a solid white color. The model contains holes, from which the surface under it can be seen. This means the surface potentially has been picked up by the scanner too and contributed to poor performance in other environments. Due to these reasons, it was decided to look into another tracking method.

### 11.3 Image Tracking

Due to object tracking not showing great results, it was decided to test out image tracking with a marker. A suitable marker was found by searching online. It was important the marker fit the criteria for a good marker described in section 4.2. The marker used in the project can be seen in figure 11.3.



**Figure 11.3:** Marker used for AR in the project. [2]

Image tracking functions similarly to object tracking in terms of implementation in AR Foundation. Image tracking is achieved by using an AR tracked image manager coupled with a reference library, that contains the marker. The reference library also must know the physical size of the marker in order to track it. Once a marker is recognised in the scene, the AR tracked image manager places the 3D model at the location.



**Figure 11.4:** Image tracking, Digital shadow is on top of real life model.

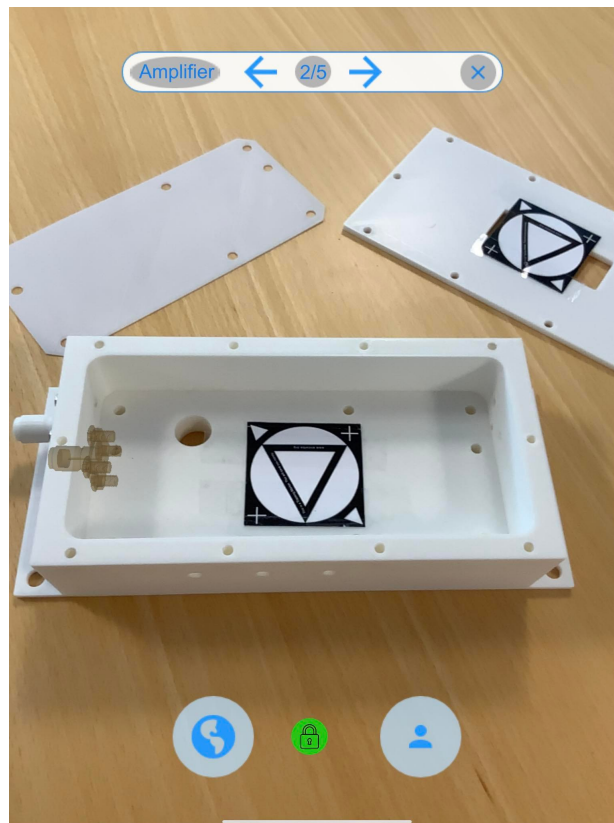
Since the markers have a specific position on the real life object, a script was created to offset the 3D model according to which assembly/disassembly step the user is currently on. This allowed the offset of the 3D model to correspond to a specific offset for a marker on a specific components and thus align the worlds across different assembly steps. The offset script works by responding to an event called **trackedImagesChanged**, which is called whenever the AR tracked image



manager detects, updates or removes tracked images. The offsets that fit the individual marker components were found using trial and error and measuring the real life object. The end result was a tracking system that worked much better than object tracking. It was decided to support both systems and allow the user to switch between them on the finding objects screen.

### 11.3.1 Tracking performance

The image tracking combined with the offset proved great performance. Figure 11.5 shows the marker on different components. The group did discover tracking would get lost sometimes in different assembly steps, and added a locking features to compensate. Pressing the lock button freezes the 3D model in place and disables tracking, ensuring that the model does not move around. This means that the 3D model and the real model should be equal unless the real model is moved around. Pressing the lock again unfreezes the model and enables tracking again.



**Figure 11.5:** Marker on different components.

## 11.4 Anchors

An addition to placing the 3D model amplifier by tracking methods, it was decided to allow the user to simply tap and place the model at an AR plane. This functionality is referred to as placing anchors and it is implemented in AR Foundation through the AR Anchor Manager. An anchor is a particular point in space that the user wants the device to track. Anchors are attached to AR planes, that the app is constantly identifying from surfaces in the environment.

Once an anchor is placed, the AR Anchor Manager makes sure to keep its position in space in relation to the device. The reason for including this feature is to provide the user with more options. A user might not want the 3D model to appear on top of the real model in every use-case. For example if the device that should be assembled is not completely identical to the digital model. The feature was mostly used for testing purposes. Figure 11.6 shows the 3D model has been placed next to the real model.



**Figure 11.6:** Model has been placed as an anchor.

## 11.5 Summary

In this chapter it was discussed how object tracking was implemented. The real life amplifier was scanned and turned into a **ARReferenceObject**, which an AR Tracked Object Manager can identify in an environment. The performance of the tracking was very poor however and it was decided to also implement image tracking. Placing a marker on the object and applying an offset to the 3D model resulted in worlds very close to being aligned. In addition to tracking methods, the user is also given the option to simply place the 3D model on an AR plane in the environment.

# Part IV

## Evaluation

## 12 | User Evaluation

This chapter describes how the prototype was evaluated with users, which methods were used and what it resulted in.

### 12.1 User Evaluation Goals

The goal of testing the prototype on users is to test the usability of the developed application. The following are the fundamental goals the application must meet:

- **Application functionality:** Testing if the application lives up to the core requirements described in section 7.4.
- **UX of application:** Feedback on the users experience of the application is important in order to learn if the application is appropriate for the target group.
- **Aligning worlds and digital twin:** An important goal is to determine if the user feels the alignment of the digital and real world object and the methods used for tracking are appropriate and useful for assembly/disassembly.

Testing the functionality of the application revolves around having the user interact with the app and trying out the different features. This includes assembly and disassembly, aligning worlds and switching between the digital and real world and expert collaboration. Furthermore, stability of the application and potential errors are important to investigate.

The goal of the users experience tests are to determine if the UI fits to the users preference. This includes the location and shape of the UI elements and buttons properties such as name, size, location and visibility as well as the different interaction options on the different screens.

Testing the world alignment and Digital Twin functionality are at the core of the application. Testing these features involve trying out the two different tracking methods, tracking while moving the device around and tracking while on different assembly steps. Unfortunately only image tracking was working at the time of the use evaluation, resulting in users not being able to use object tracking.

In general the goal with user evaluations are to get as much feedback as possible, so that the application can be improved in order to become a better solution to the problem and be more useful to the end user.

## 12.2 Methods

The following methods were used in the user evaluation:

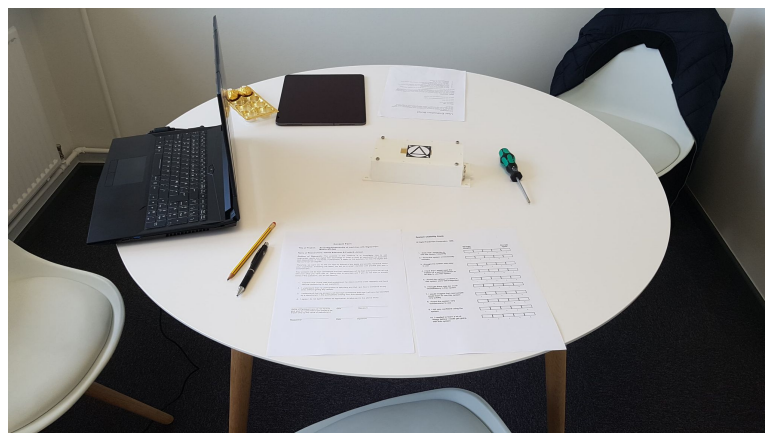
- **System Usability Scale:** The System Usability Scale (SUS) is a standardised tool to measure the usability of applications. It was decided to use SUS to evaluate the prototype usability as it allows for a measurable and comparable way of determining the users experience.
- **Interview:** A short introductory interview is conducted prior the test. The participant is asked a few questions about themselves and they are briefed about the purpose of the test. Another interview is conducted after the the test in order to gather feedback from the participant.
- **Think-aloud:** The user are given a list of tasks to do and asked to voice their thoughts out-loud while performing them. Users can ask questions regarding the tasks, but are not provided with assistance on how to solve them; they are encouraged to figure out how the system works on their own.

## 12.3 Setup and Equipment

The following is a list of equipment used to conduct the tests:

- iPad with the prototype installed
- 3D printed real life amplifier outfitted with markers along with screws and a screwdriver
- Consent form
- Interview script
- SUS survey
- Computer for note-taking

The tests were carried out by two group members, one as interviewer and one as note-taker. The setup for tests can be seen in figure 12.1.



**Figure 12.1:** The test setup.

## 12.4 Participants

While it only requires five participants to discover most user usability issues [10], it was decided to use ten participants, in order to find rare issues. Participants consisted of employees at PDM Technology. The participants consisted of 40% males and 80% Danes. The participants were between 18 and 53 years of age. When asked what participants do if a machine in their home breaks, the majority answered they try to fix the machine themselves using Google and YouTube videos or otherwise give up and throw it out.

## 12.5 Test Procedure

The following describes the full procedure of each test. A pilot study was conducted using a team-member as participant prior to testing with real users in order to determine if the tasks and questions appropriately answered the goals set for the test.

### 12.5.1 Warm-up Session

The test started with an initial interview. The participant was briefed about the purpose of the test and a short introduction to the prototype. The questions were the following:

- Where are you from?
- How old are you?
- What is your professional background / study?
- What do you do if a machine you own breaks?

### 12.5.2 Main session

The main session of the test consisted of having the participant going through a list of tasks while using the think-aloud method. The participants feedback was written down while the test was taking place. The note-taker would act as the expert and use the expert computer program, when the participant arrived at that task. Audio between the expert and user was disabled. The task list was the following:

1. Start the disassembly process of the amplifier
2. Align the real and virtual world using the marker on the real life object and lock it in
3. Use the digital world to move the lid and see inside the amplifier
4. Finish disassembling the amplifier
5. Start the assembly process of the amplifier
6. Align the real and virtual world using the marker on the real life object and lock it in
7. Assemble 1 step of the amplifier
8. Contact an expert for help
9. Finish assembling the amplifier

## Interview

The participant was asked some questions about their experience:

- Do you feel an app like this could be a useful tool for you in assembly or disassembly processes?
- How could the app be more useful for assembly/disassembly processes?
- Would you use the app over watching a YouTube video or looking at instruction manual?
- How do you feel about the tracking method, using the marker?
- How closely aligned do you feel the digital and real versions of the machine were?

### 12.5.3 Closing session

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

**Figure 12.2:** The system usability scale questionnaire.

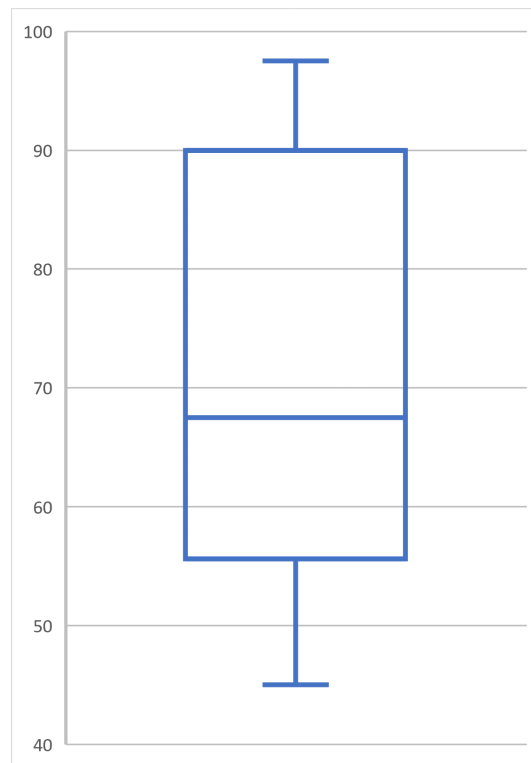
After completing the tasks, the participant were asked to rank the prototype according to the SUS. The scale can be seen in figure 12.2. The participant were asked if they have any additional comments or feedback.

## 12.6 User Evaluation Results

Participant ID	Q1	Q2	Q3	Q4	Q5	Q6	Q7	Q8	Q9	Q10	Score
1	4	2	4	1	4	2	3	2	5	1	80
2	4	2	4	2	4	2	3	2	3	3	67.5
3	4	3	3	4	3	2	4	2	3	3	57.5
4	4	3	2	5	5	1	2	2	3	5	50
5	4	3	3	2	4	2	3	4	3	3	57.5
6	3	2	3	3	4	2	5	2	3	2	67.5
7	2	4	2	4	4	4	5	4	2	1	45
8	5	1	5	1	5	2	5	1	5	1	97.5
9	3	1	4	1	4	1	5	1	4	1	87.5
10	5	1	5	1	5	2	5	1	5	1	97.5
<b>Average</b>											<b>70.75</b>

**Figure 12.3:** The results of the SUS questionnaires for each participant and each question.

Figure 12.3 shows the result of the SUS questionnaire. In the figure each participants answer to each question can be seen along with the calculated SUS score. The average SUS score the participants gave the prototype was 70.75. The SUS scores have been calculated by following the principles presented in the original paper on the SUS scale by John Brooke [10]. As such the direction of the scale in every second question changes, meaning that a positive answer in the odd numbered questions equals a high score and in the even numbered questions a positive answer equals a low score.



**Figure 12.4:** Boxplot showing the median values of the SUS scores.

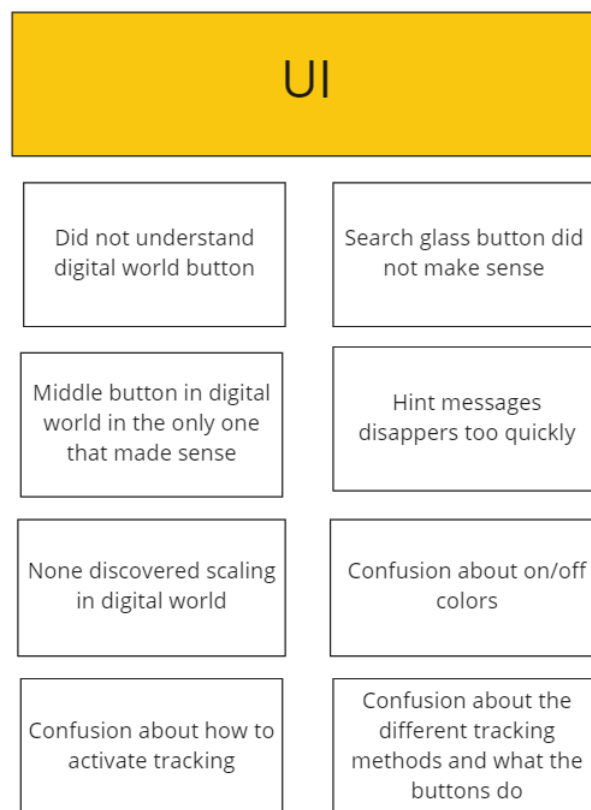


Figure 12.4 shows a box-plot of the SUS scores. The plot shows minimum, maximum and median values from the SUS scores and allows for visualisation of the distribution of the results. The plot shows the lowest score was 45 and the highest score 97.5. 50% percent of participants gave a SUS score higher than 67.5. There is a high variance in the scores, which can be seen from the length of the box.

Observations and statements from participants were analysed and put into several different categories in affinity diagrams. The categories were:

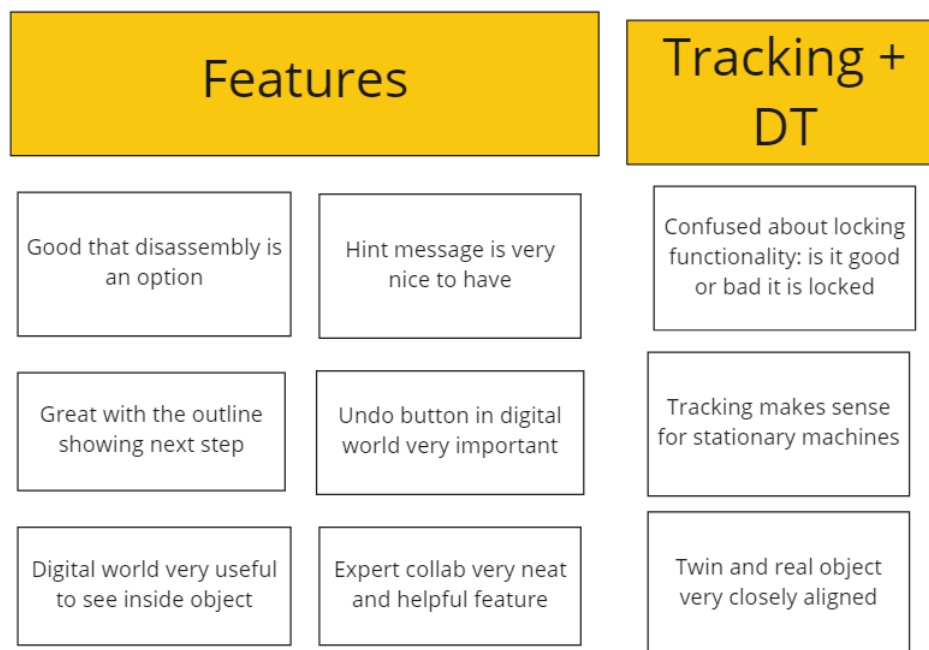
- **UI:** Comments about the UI and general user experience.
- **Features:** Comments about the different features, such as assembly/disassembly, digital world and expert collaboration.
- **Tracking + DT:** Comments about tracking and the digital twin.
- **Bugs:** Bugs found by participants.
- **Suggestions:** Suggestions about how to improve the application.
- **Other:** Comments that did not fit into other categories.

The following is a description and breakdown of each category.



**Figure 12.5:** Affinity diagram showing users' comments about the UI.

In figure 12.5 the users comments about the UI can be seen. From observing participants solving tasks and the resulting interview, it was clear the application had major problems in terms of communicating to the user what the different buttons and functions did. This was especially clear in the "Finding Object page" and with the different tracking methods. In this page, the participant did not understand the icons on the buttons, the functionality of the buttons or if a tracking method was on or off. The participants also struggled a lot with the locking functionality, as they did not understand what it did, when it was on, and if locking was a good thing to do. The confusion about button icons and functionality extended to the digital world screen. In the digital world screen participants understood the middle button allowed them to move the object, however the rotate button and stop tracking button were only understood after being pressed and tested. In the assembly screen participants liked the outline of the next step, and understood what it meant. The hint message was very helpful for understanding as well, but disappeared too quickly. The buttons at the top of the assembly page were rarely discovered by participants without being hinted. In general the UI needed a lot of work for the user to be able to understand how to use the app.

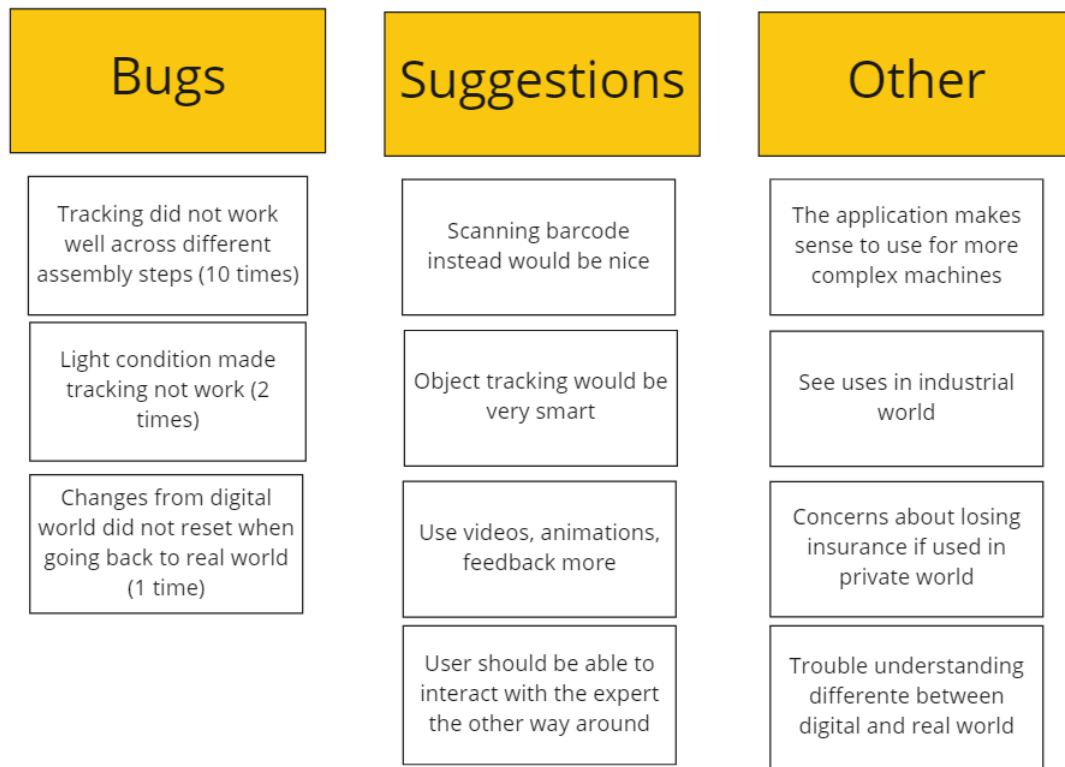


**Figure 12.6:** Affinity diagram showing users comments about features and tracking + DT.

Figure 12.7 shows an affinity diagram concerning comments about features, tracking and DT. In terms of features, participants felt both the digital world and the expert collaboration were great features that could be very helpful for helping with assembly/disassembly processes. It was observed several participants made use of the digital world un-prompted to support them in assembling the amplifier. Participants liked how assembly and disassembly worked in the app, and had no problems understanding the outline displayed the next component to add/remove. The hints that would pop up after every step were very helpful in increasing understanding.

For tracking and DT, the majority of participants had to receive hints to figure out how to use the image tracking, as the marker would be too small or the participant did not understand how to use it or to point the camera at it. Participants were also very confused about the possibility of different tracking methods and how they worked. The locking feature was

very difficult to understand and required explanation from the interviewer. Once participants managed to activate the tracking, they felt it worked well and the digital twin resembled the real life model at a very high degree. Three participants said the twin was 1 to 1 identical with the real life mode. Participants had no problems activating tracking the second time, after they had figured out how it worked. While there was a general problem with losing tracking during the experience, the feedback from the participants were that the tracking worked well and was useful.



**Figure 12.7:** Affinity diagram showing participants suggestions, other comments and bugs found.

Figure 12.7 shows an affinity diagram about participants suggestions, other comments and bugs found. In terms of bugs it was a general problem for every participant that tracking did not work well across different assembly steps, as components would obscure the marker, or the component with the marker would be taken away (disassembled). The group was aware of this problem prior to the tests but were unable to fix it in time due to time constraints. To mitigate the problem, the group had implemented the locking features (see section 11.3). However it was difficult for participants to understand the locking feature, and thus participants ran into many problems with tracking. Apart from the tracking, a few other minor bugs were noticed during testing. Two participants lost tracking due to the lighting conditions of the room and one participant experienced the 3D assembly model not resetting from components being moved around in the digital world when coming back to the real world. Overall the application was a crash-free experience with only few bugs.

Participants were in general excited about the app and its possibilities. They felt the application made sense to use in combination with assembly or disassembly of a more complex machine. Participants had many suggestions for use cases and industries it could be applied to, but were

cautious about using the app privately, as it could mean invalidating insurance. A reoccurring idea was using the AR more, for example animating components or having videos above them that showed how they should be removed. Participants also had suggestions for tracking, such as using a bar-code as marker, or using object tracking. Participants wanted to interact more with the expert, such as by drawing or using AR markers to communicate. Lastly, some participants had difficulty understanding the difference between the real and virtual worlds, and would have like the real world features, such as help messages, to appear in the virtual world as well.

## 12.7 Summary

10 employees from PDM Technology tried out the prototype in a think-aloud test followed by an interview and SUS questionnaire. The goal with the test was to find out if the prototype had a good user experience, discover bugs and crashes and find out if participants liked and found the tracking and digital twin aspects helpful for assembly/disassembly. The results of the tests showed the app had a SUS score of 70.75, one major and few minor bugs were discovered and participants in general liked the tracking and digital twin aspects and found them very helpful.

# 13 | Expert Evaluation

The chapter describes how the prototype was evaluated with the expert Jørgen Schiønning Larsen, CEO of PDM Technology. It was important for the group to evaluate with Jørgen, as he and PDM Technology were project stakeholders and helped during the project. Jørgen was previously interviewed about the ideal solution in section 7.2.

## 13.1 Goal of Expert Evaluation

The goal with evaluating with Jørgen was to follow-up on the previous interview and to get feedback in regards to if the prototype had met his expectations for the project. Additionally, discussing future uses of the technology and how it could be used by PDM Technology.

## 13.2 Setup and Equipment

The following is a list of equipment used to conduct the expert evaluation:

- iPad with the prototype installed
- 3D printed real life amplifier outfitted with markers along with screws and a screwdriver
- Interview script
- Computer for note-taking

The evaluation was carried out by two group members, one as interviewer and one as note-taker.

## 13.3 Methods and Procedure

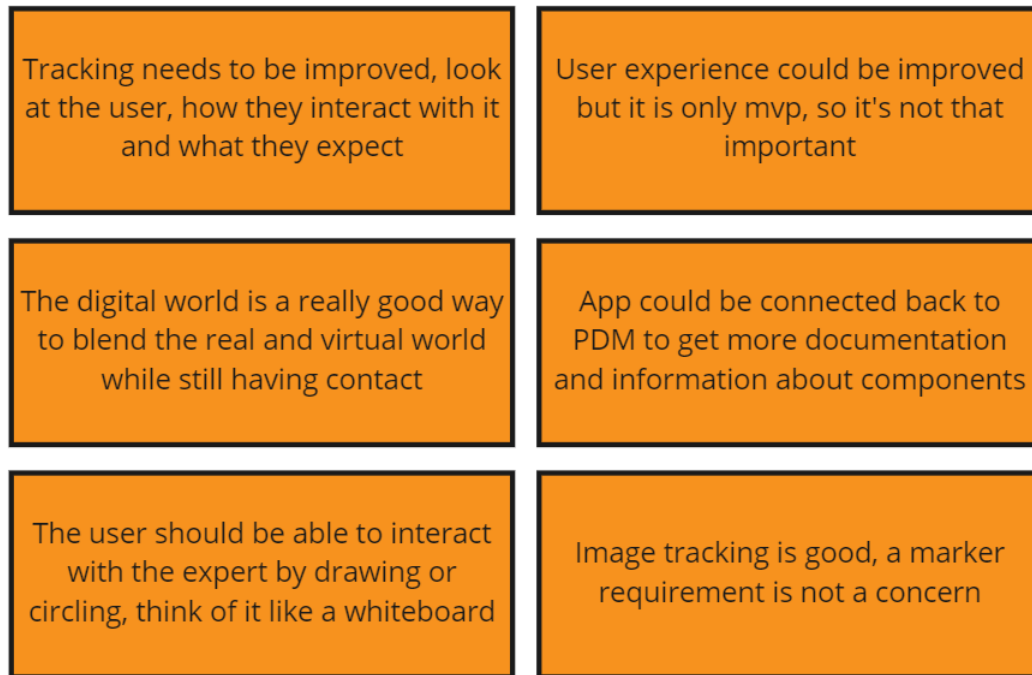
The expert evaluation followed a similar method as the ideal solution expert interview (see section 7.2). The group started out with an introduction, where they describe the prototype and its limitations. Following that, Jørgen was shown the prototype and went through the same tasks as the participants in the user evaluation while using the think-aloud method (see chapter 12). The expert interview ended with a semi-structured interview, where Jørgen was asked the following questions:

- What were your needs/requirements for the application?
  - Does the application fulfill those needs/requirements? (Why/why not)
- Does the alignment of worlds seem realistic and fulfill the requirements?

- What part of the application would be the most useful to focus on going forward?
  - Digital world, Expert collaboration, Finding Object i.e.?
- Does the application provide enough feedback during assembly / disassembly processes?
  - Why/ Why not?
- Does the virtual object resemble the physical object?
  - How much does it resemble?
- How is the interaction options within the digital world?
  - Rotate, move scale i.e.
  - Anything missing?
- How is the contact expert collaboration feature within the app?
  - Call function, expert interaction?
  - Anything missing?
- Does the image tracking work as intended?
  - Time, and position to find an object?
  - How do you feel about using the marker?

## 13.4 Expert Evaluation Results

Figure 13.1 shows an affinity diagram with a subset of the most important statements from Jørgen during the interview. After trying out the prototype, Jørgen expressed he was satisfied with the prototype and felt it lived up to his expectations for the project, which was pushing the borders of technology and exploring what could be done with it. He remarked that the tracking does need some improvements, and it could be improved by looking at how user interacts with it and asking them what they expect. In terms of how close the digital and real world aligned, Jørgen felt it was very close and that image tracking was a good method to use, as he did not mind the tracker, but felt it was an okay requirement to use the system. Jørgen expressed that the user experience was not perfect, and images could use different icons or explaining texts, but also that it was a prototype containing the least viable product and functionality. Jørgen liked how the different features were integrated, how the app supported both assembly and disassembly and how the digital world could be used to get a better understanding of the object before beginning to assemble or disassemble. For the expert collaboration, Jørgen would have liked there to be interaction the other way, so that the user could interact with the expert via pointing, drawing or circling components. In terms of future work, Jørgen would put the emphasis on improving the tracking and making it more stable and easy to use for the user. Jørgen saw potential for connecting the technology with Bluestar and PDM Technology, so the user could for example get more information about a component or documentation, or opening the model directly on Bluestar through the application.



**Figure 13.1:** Affinity diagram showing the experts answers.

## 13.5 Summary

This chapter described how the prototype was evaluated with Jørgen, CEO of PDM Technology. In the evaluation, Jørgen tried out the prototype by going through the same tasks as the users in the user evaluation, followed by a more substantial semi-structured interview. The results of the interview showed that Jørgen was satisfied with the prototype, and felt it had accomplished in pushing the borders of technology and exploring what AR and DT could be used for. Developing the prototype further, Jørgen would focus on improving the tracking functionality and making it a better user experience, while potentially connecting it to PDM Technologies Bluestar.

## 14 | System Improvements

This chapter describes a series of potential improvements to the application based on the results of the user and expert evaluations.

### 14.1 Usability Improvements

These improvements aim to enhance the users experience of the app. The improvements are in a prioritised list based on ease of fix to perceived UX reward:

1. **Fix tracking across different assembly steps:** This fix is crucial in order for the app to be use-able in its intended purpose.
2. **Provide feedback on chosen tracking method and explain how it works:** Making this change is key in order to make the user understand how to use the tracking in the app.
3. **Change icons across the app:** Using more descriptive icons will allow the user to much easier understand what the different buttons in the app does. Icons to be changed include: image tracking, anchor, lock, digital world, rotate, toggle tracking.
4. **Ensure consistency in on/off colors:** Participants were very confused about which colors signified an option was on or off.
5. **Increase the time the help pop-up stays before fading out:** Participants liked the help pop-up a lot but found it disappeared too quickly.
6. **Make buttons at the top of assembly screen look like buttons:** Very few participants discovered it was buttons at the top of the assembly screen.
7. **Inform the user about tracking health and give hints as to how to improve it:** Giving the user more information about the tracking could benefit them and help them use the feature more efficiently.

### 14.2 Summary

The chapter suggests a series of potential improvements based on feedback from the users and expert, that could be implemented into the application and improve the user experience.



# **Part V**

## **Reflection**

# 15 | Discussion

In this chapter the results of the evaluations and the validity and reliability of the tests are discussed. The group reflects on the development of the application, general approach to the project and finally potential future work on the prototype. The overall evaluation of this project is based on the final problem statement in chapter 6 as well as the core requirements established in 7.4. The overall goal of the project was to develop an application which combined Augmented Reality and Digital Twin technology. Furthermore it was desired that the application would align the virtual and digital worlds and use that to assist the user in how to assemble and disassemble machines. User tests were conducted to both establish if the developed application worked as intended, provided a good user experience and aligned the words in a way that was helpful for assembly/disassembly processes. An expert interview was conducted to determine if the application met the requirements set by PDM Technology.

## 15.1 Validity of Evaluation

The group set out to use two different methods to align the virtual and real world: object tracking and image tracking. However object tracking never worked at an acceptable rate, and thus was not tested by the participants. The object tracking button and functionality were still available in the prototype, which unnecessarily confused some participants, and could have lead to a lower SUS score. Testing the two tracking methods against each other and asking participants which method aligned worlds the best and helped them with assembly/disassembly could have been an interesting angle for the project to take and could potentially have revealed some insight about how users interact differently with different forms of tracking. While participants generally liked how the image tracking system worked, the group was aware of the major bug with tracking not working across different assembly steps. Using the poorly understood locking feature as a temporary solution in the test was not the groups intention, and surely gave participants a less than stellar impression of how the tracking system in the prototype would work on a real system. The group proceeded with the user evaluation even with knowledge of this problem due to time constraints of the project. If the group were to repeat user tests, the prototype would contain a working object detection system as well as improved image detection that works across assembly steps.

In addition to the tracking system not being representative of a final product, the group felt using the 3D printed amplifier as testing machine did not provide a very realistic scenario for how the prototype would be used with a real machine. The group had started to work on implementing a second, more realistic machine into the prototype, but ran into trouble finding/creating a 3D model to look exactly like it within the time constraints of the project. In a future user testing, a more complex real life machine would be used.

While expert collaboration features were not the focus of the project, participants were still asked to use the feature during the user evaluation. This was mostly to show the participant that the feature was there, was could be done with it and gauge interest in the feature. Testing the expert collaboration features properly could involve participants being left on their own to assemble a complex machine using the app. The expert would be sitting in the next room, ready to be contacted and help trough the features in the app. Researched would observe the test trough a camera setup. This test could reveal if the tools available to the expert and user were appropriate and helpful, if a feature was missing and if the expert collaboration feature was necessary for the user to complete assembly at all. Potential key metrics for the test could be assembly time, assembly steps made in error or frustration level of the participant. An A-B test could be made, comparing these metrics to a participant assembling the same machine by using YouTube videos or an instructions manual.

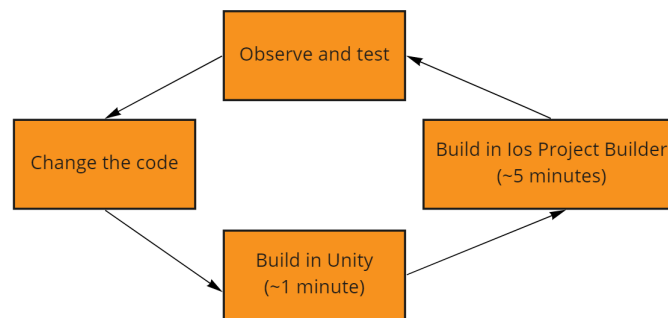
The users evaluation was conducted with 10 participants, which is double of what is needed to discover most user experience problems. All the participants were employees at PDM Technology, but had different positions within the company. Six participants were in software engineering roles, while two were in marketing and two were project managers. Two participants give the prototype 97.5 SUS score, which is very close to the highest attainable score. Both of these participants were in software engineering related roles. It can clearly be seen that the software engineering participants generally rated the prototype higher in terms of SUS score, which might be due to their familiarly with technology. However one outlier in this category also gave the prototype the lowest SUS score of 45. This participant could have been critical of the prototype due to their background or experience. The participant had a an opposite viewpoint of most other participants, stating they would not use the app to assemble/disassemble complex machines but would use for more simple machines instead.

The results of the user evaluation showed the prototype had an SUS score of 70.75 out of 100 points. Converting the score to percentile through normalisation with other tests SUS scores results in 58% and the grade C. This is considered above the average SUS score of 68 points or 50%. The score is on the border of being considered marginally acceptable to acceptable. [38]. The score shows participants had significant issues using the prototype and understanding how to navigate it. Nevertheless, the majority of test participants seemed enthusiastic about the prototype and its features. It was especially the digital world participants were very interested in and used throughout the test. Some participants also liked the expert communication tools a lot. However the participants in the evaluation were likely to be biased towards giving the group members positive results, due to existing relationships and connections between researches and group members. These connections were formed during the project while the group were working out of PDM Technologies' office. An evaluation with unknown participants would likely produce a lower SUS score.

Expert evaluation with Jørgen showed he felt the group had met the expectations and had produced a prototype that explored the edge of technology and used AR well, but also had some significant issues in the form of tracking not working well and the user experience being sub-par. While it was important to evaluate with Jørgen as a stakeholder of the project, it is important to note the potential of a significant bias, as Jørgen has been a part of the project and provided feedback and guidance along the way. As such, it could have benefited the validity of the findings to evaluate with more external experts, such as PhD's or professors from Aalborg University.

## 15.2 Application Development

The application was developed in a project group of 2 people, which meant there was a limit on how many ideas could be generated during design and implementation. In general tasks were split between the two group members, so work could be done on different aspects of the system at the same time. Using Unity Engine to create the prototype was beneficial, as Unity had many tools and features that supported fast and iterative development. A normal Unity workflow consists of changing some code, pressing the play button in the editor and then instantly being able to test out the code and observe changes. The process is then repeated. Once a system works, Unity can take some time to build and deploy the solutions on a targeted device for real testing.



**Figure 15.1:** Workflow when building the prototype.

The workflow of the project was significantly slower than the normal Unity workflow. The steps involved can be seen in figure 15.1. Due to the nature of AR Foundation, most changes could not be observed in the Unity editor itself, but had to be built on a device in order to work and test it properly, because they required a camera, sensors, etc. and would not function without. This meant taking valuable time after every change to build on a device, observe and test the changes, before repeating. Another component in the process was building for iOS devices, which was easier with iOS Project Builder for Windows, but still took additional time.

The group spent a long time trying to implement object tracking, before changing direction and focusing on image tracking. The reason for choosing object tracking was due to a desire to make the system as easy and convenient to use as possible. The prevailing thought was, that having to deal with a marker on the machine to be assembled would not be convenient and could be a barrier that prevented the user from easily pulling out and using the system on their phone at any time. A potential compromise that could make image tracking more convenient to use would be to re-purpose a marker that already exists on a machine, such as a bar-code or other identifying sticker. A bigger stationary machine could work well with approach, as there would be no need to continuously track a stationary machine and keep the marker in view.

During development the group generally struggled a lot with bugs and crashes. It was a difficult process to identify where the bugs came from, as the application needed to run on a device, where Unity's tools for debugging could not be used. When possible, features were isolated and tested in another test scene or project, allowing access to Unity's debugging tools. When this was not possible, such as with AR Foundation errors, Log Viewer[15] was a useful tool. The

problems grew larger after the group decided to use Angora for expert collaboration. The fragile setup required to screen-share AR elements with Angora meant errors from AR Foundation and Angora would combine in unexpected ways and often result in a black screen application with no errors logged, frustrating group members significantly and resulting in time spent investigating and bug fixing.

### 15.3 General Discussion

While the group intended to use an agile approach for the whole project, where the focus would be on fast iterations and quickly producing new solutions based on the feedback gathered, the actual process could better be described as a waterfall approach. In a waterfall approach a prototype solution is created based on a set of requirements. It is then evaluated by conducting user tests. In order to make the process more agile, more iterations of the design, implementation and evaluation would be needed. A review process should be put in place after each cycle, to determine if further iterations are needed. The group applied the agile methodology during implementation, where extreme programming was used for great benefit, as it resulted in several needed changes to the design along the way. The group also used the Google Design Sprint method during design, which can be said to be an agile method. However it was difficult to use the method, as the group only consisted of two members, and thus were limited in generating different ideas.

### 15.4 Future Work

Potential avenues of future work includes implementing the proposed system improvements (see chapter 14) and improve the prototype to a significant degree, before testing it with users and likely doing more iterations, where the user feedback would be analysed and resulting changes implemented. These changes include an overhaul of the UI, implementing object tracking and making tracking more consistent and working across assembly steps. In the expert evaluation, Jørgen expressed future work should aim to improve the tracking first. This improved prototype could be used to pitch the solution to business and potentially build a company out of the project (see appendix B). Following that, the full proposed solution (see chapter 7) could be implemented and tested with users.

The main features of the system could be expanded in a variety of ways. Tracking and digital twin could become a lot more complex and automatic. The system could for example be expanded to recognise a machine when a user has completed a step using computer vision. To achieve this, the system could make use of object tracking to track a target component in each step, however it could prove troublesome to implement for smaller components, such as screws. This change could lead to a more autonomous system, that could monitor an assembly/disassembly processes in factories instead of directly supporting and guiding users.

Updating the digital twin with various parameters related to the status of the real life object, such as temperature, pressure or error messages, could enable the twin to function as an error diagnostic tool. This could be done by the user measuring the object and inputting data, or an IoT module on the machine directly sending data to the app. The app would process the data and inform the user about which areas the fault could be in and help them assemble/disassemble the machine to reach that area. Potentially the data could be compared to data about

the machine from Bluestar to identify the fault. This feature could work well to expand the digital world.

Assembly/disassembly could be expanded to include other types of objects than machines, such as furniture, Lego or other electronics. In theory, the app could already do this now, as it is just the object that needs to be changed. To make the process easier, a workflow of adding new objects should exist that does not require making changes to the app in the Unity Editor, but instead is generic and integrated into the application. This could be achieved by creating a supporting ".xml" file, that provides the app with all the information it needs about the object, such as origin of marker, assembly steps, object name and hints to each step. This file along with a 3D file of the object would then be selected in a file-browser and loaded into the application at the touch of a button.

The expert collaboration could be expanded upon with more interaction between the user and the expert. A focus could be allowing the user to interact with the expert more, such as drawing or pointing in their real world. The information available to the expert could also be massively increased. The expert could get more information about the machine, such as the information presented when pressing the machines name in the app, more information about the user, such as location, identity or professional expertise. The information could enable the expert to have an easier time helping, but it is important to consider GDPR in that process. Additionally the app could be turned into a data platform, that teaches companies about how users interact with their machines. The app could show companies which assembly/disassembly steps a user struggles with, which steps have to be repeated and which steps a user skips. A potential pitfall in the process is licensing and insurance, as companies might not want users to disassemble their machines unsupervised, or give information about how a machine works.

## 16 | Conclusion

The project was aiming to develop an application that would help users in assembling/disassembling machines using Augmented Reality and Digital Twin. The goal was to find an answer to the following problem statement:

*How can the Digital Twin and Augmented Reality technologies be used to develop an iOS application that can assist users in assembly/disassembly processes?*

A problem analysis was conducted, which investigated key questions surrounding Augmented Reality, Digital Twin along with platforms and current assembly/disassembly solutions that use these technologies. Different types of Digital Twin were identified, such as the digital shadow, where information from the physical object influences the digital object. Augmented reality was explored, along with different solutions of aligning the real and digital worlds, such as using markers or object tracking. Current solutions that use augmented reality or digital twin for assembly or disassembly were described and compared to each other in terms of features.

Based on the findings from the problem analysis an ideal solution for the problem was created. This solution incorporated different kind of features from the current solutions, along with expanding on them and using both Augmented Reality and Digital Twin. Following the ideal solution, Jørgen, CEO of PDM Technology was interviewed, in order to get his input on where the focus of the project should be. This interview formed the basis of a set of delimitations of the ideal solution, in order to limit the scope of the project. The final scope would focus on how to align the digital and real world in a way that would benefit the user in assembly and disassembly purposes.

Based on the delimitations, a set of core requirements were created in order to serve as guidelines for design and implementation of the prototype. Design was conducted using a Google design sprint, and creating different iterations of sketches, before creating a mock-up of the prototype in Adobe XD. This design could be imported into Unity, and an application using AR foundation for iOS devices could be developed.

Following implementation, the prototype was tested with 10 employees of PDM Technology along with an expert, in order to determine if the prototype had a good user experience, if the world alignment and tracking worked well and if the prototype lived up to the core requirements set in the project and by PDM Technology. The prototype received an SUS score of 70.75, which is bordering on acceptable and in general is not considered good, but participants were exited about it and felt the world were aligned well. The expert felt the application lived up the requirements and provided feedback about what future work should focus on. Based on all the feedback, a set of system improvements were defined, which if implemented could improve the user experience of the system significantly.

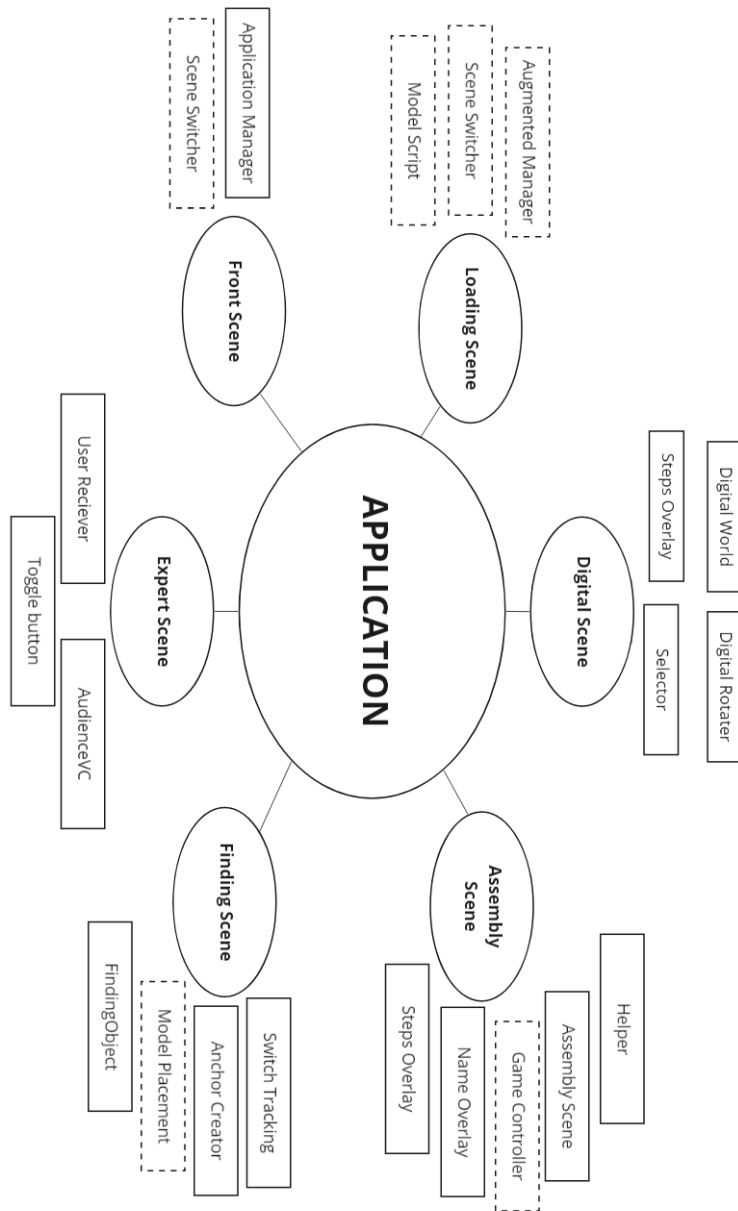
In general it can be concluded that Digital Twin and Augmented Reality technologies proved beneficial to supporting users in assembly or disassembly of machines within the context of this study.



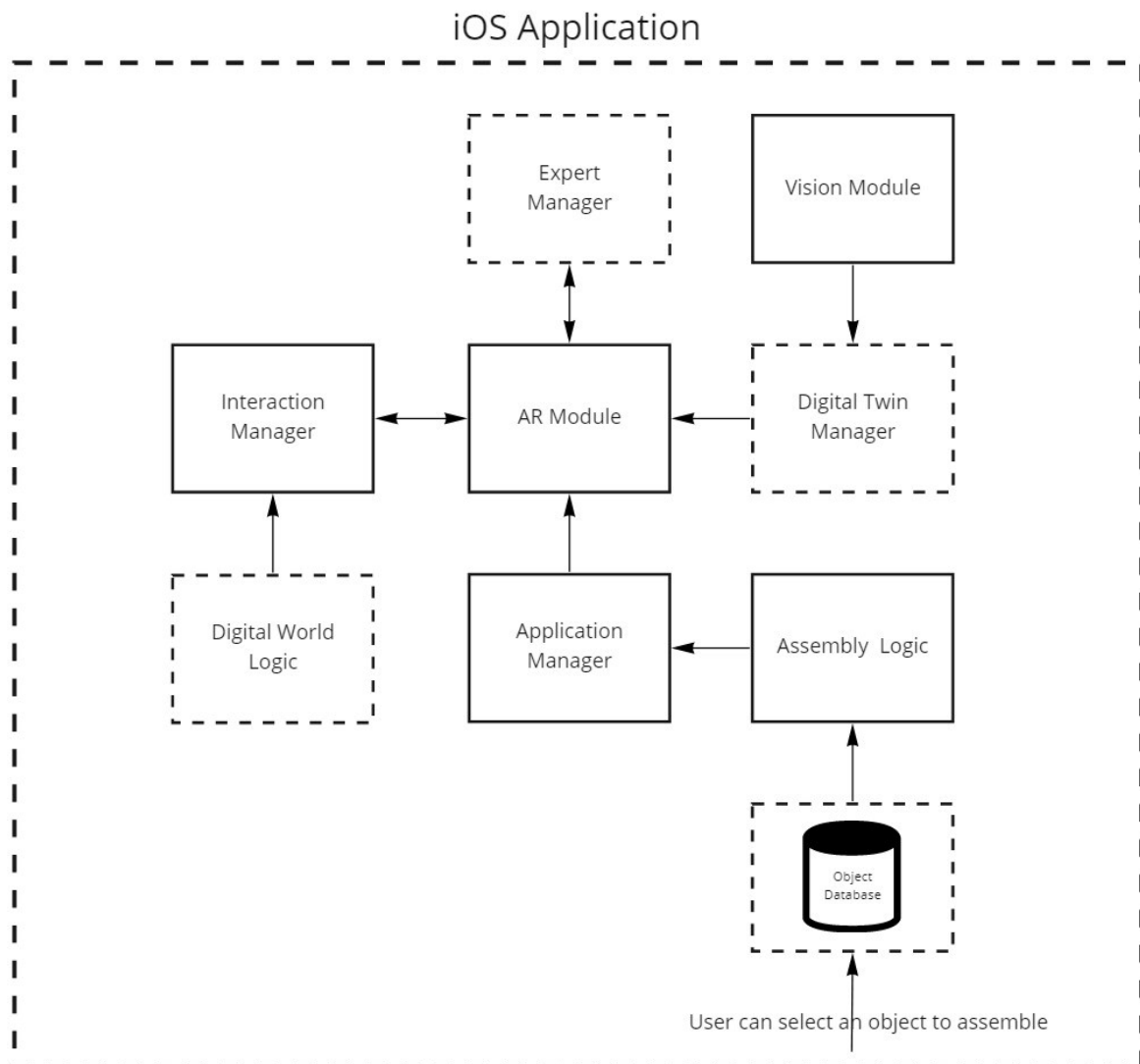
# A | Supplementary Material

## A.1 Additional Figures

Figure A.1 shows how the different classes belong to different screens. Classes are identified as square boxes, while circles are scenes. Dotted outline boxes are singleton classes, that persist into the following scenes.



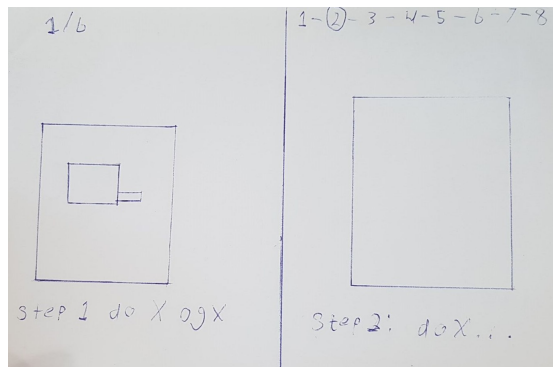
**Figure A.1:** Figure showing how the system works.



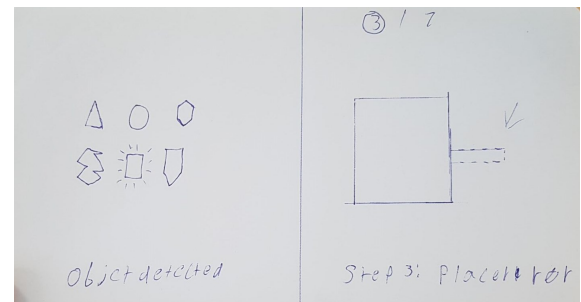
**Figure A.2:** Initial proposed architecture of the system.

### A.1.1 Design Sketches

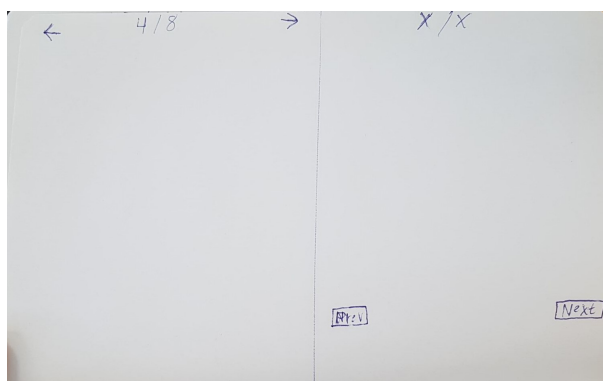
The following sketches were created during the design sprint.



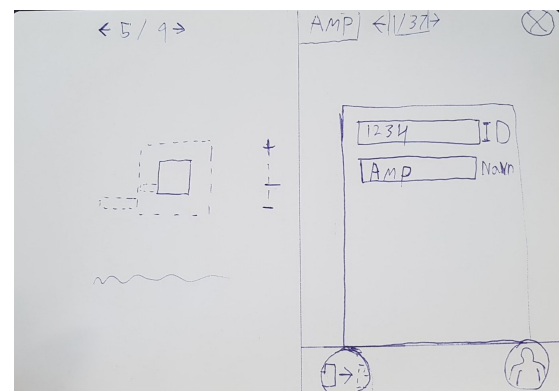
**Figure A.3:** Assembly process.



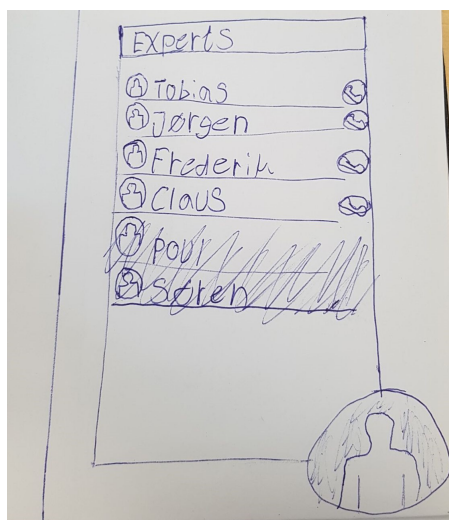
**Figure A.4:** Object detection.



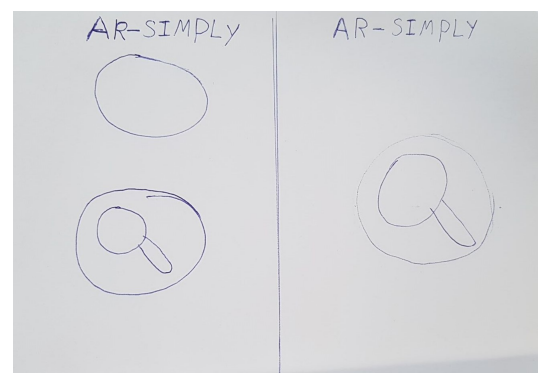
**Figure A.5:** Progressing to next step.



**Figure A.6:** Digital world.

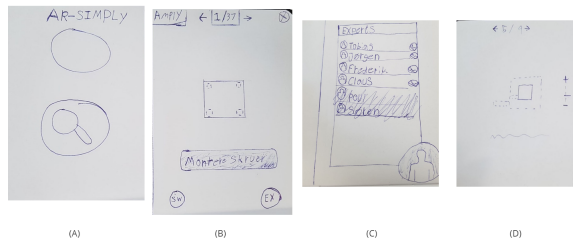


**Figure A.7:** Expert collaboration.

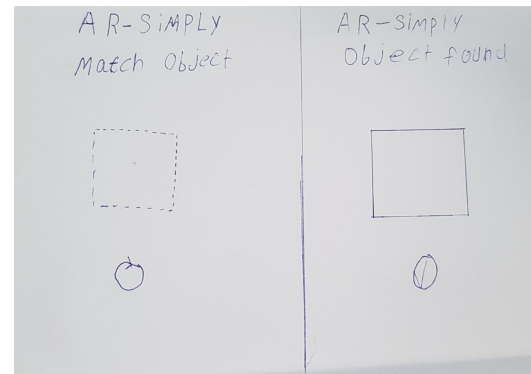


**Figure A.8:** Front page.

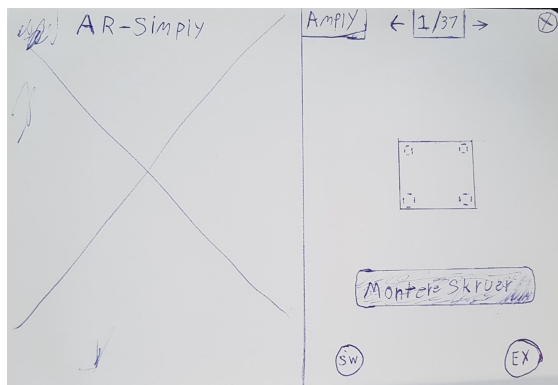
## APPENDIX A. SUPPLEMENTARY MATERIAL



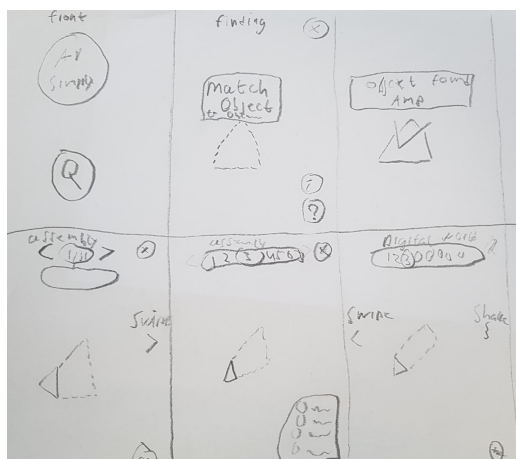
**Figure A.9:** Collection of sketches



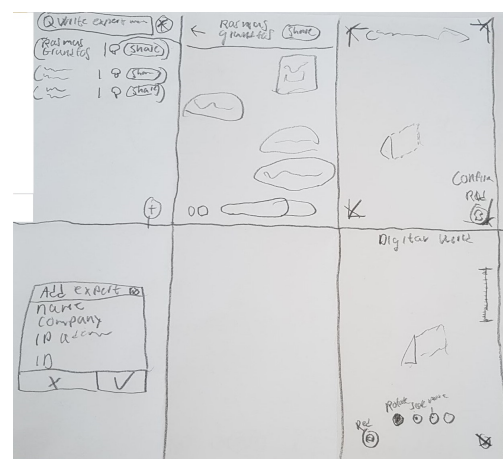
**Figure A.10:** Object detection.



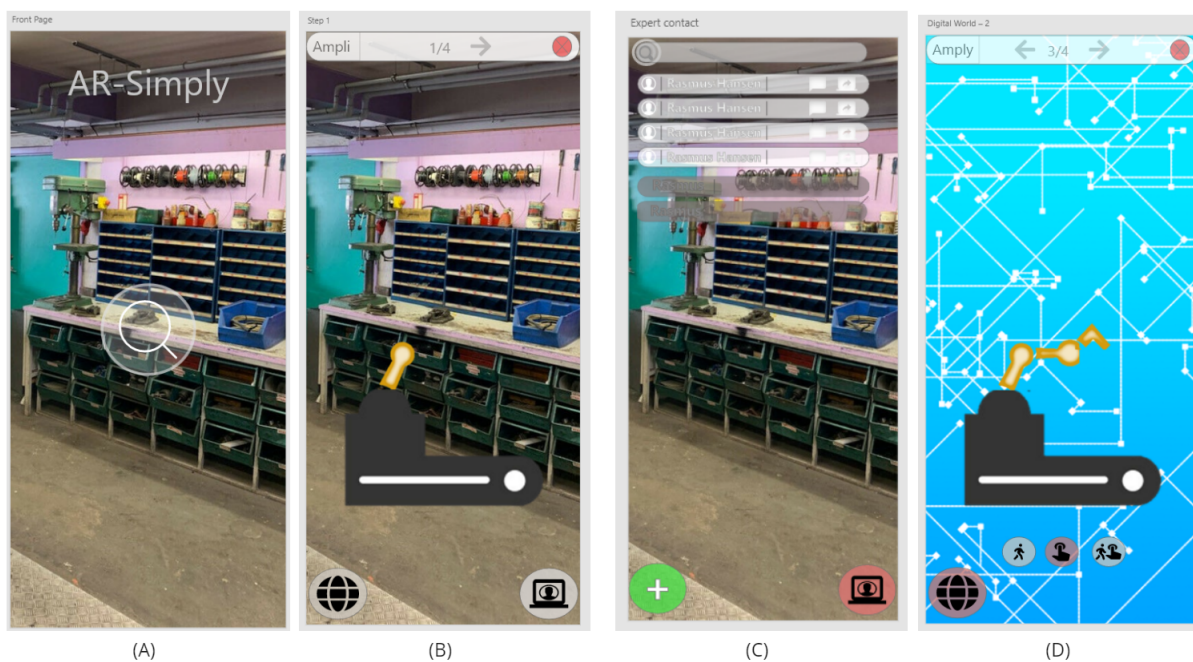
**Figure A.11:** Assembly screen.



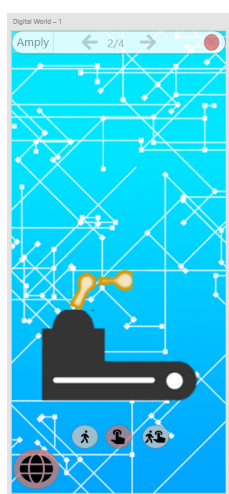
**Figure A.12:** Various sketches.



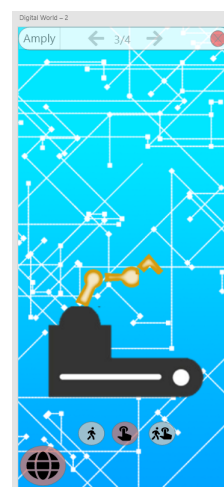
**Figure A.13:** Various sketches.



**Figure A.14:** Mock up of selected screens.



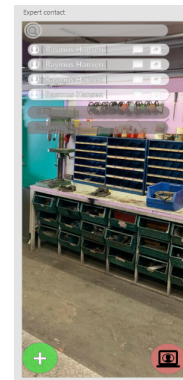
**Figure A.15:** Using the digital world to see future steps.



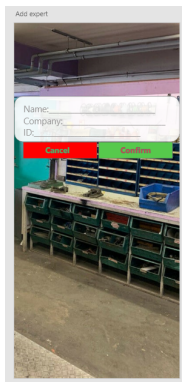
**Figure A.16:** Using the digital world to see future steps.



**Figure A.17:** Using the digital world to see future steps.



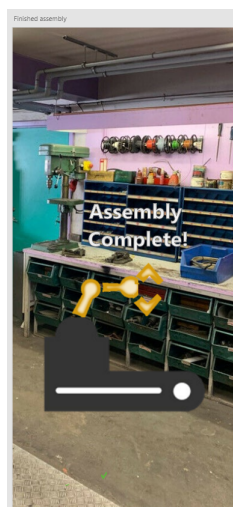
**Figure A.18:** Expert overlay for available experts to contact.



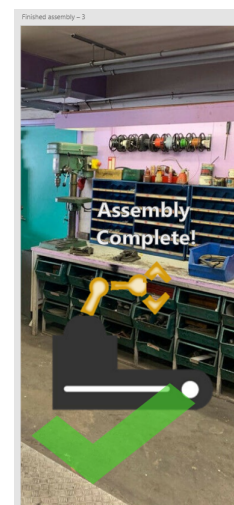
**Figure A.19:** Input information for new expert to contact.



**Figure A.20:** New expert information has been added.



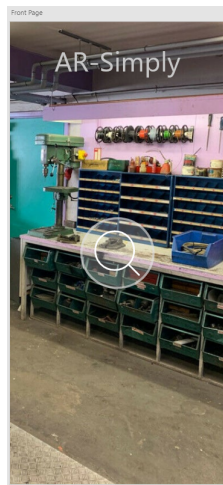
**Figure A.21:** Assembly of machine has been completed.



**Figure A.22:** The system gives feedback about the process being complete.



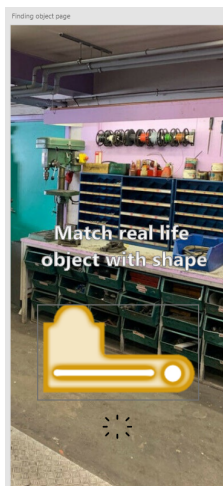
## APPENDIX A. SUPPLEMENTARY MATERIAL



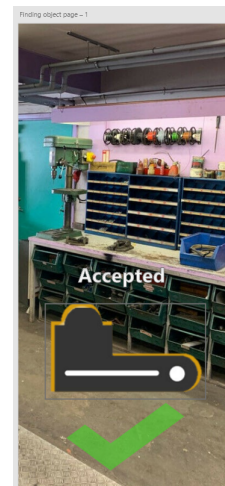
**Figure A.23:** Front page for the application.



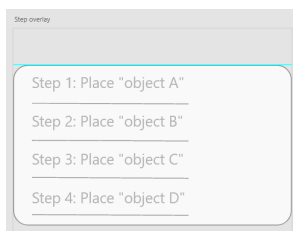
**Figure A.24:** Information overlay about the machine.



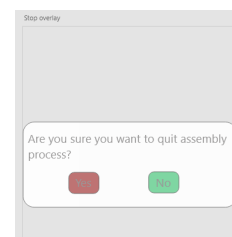
**Figure A.25:** Object tracking screen for alignment of real and digital world.



**Figure A.26:** Object has been recognised and tracked.



**Figure A.27:** Short-cut pop-up to switch between steps.



**Figure A.28:** Pop-up asking the user to confirm quitting assembly.



## A.2 Additional Sections

### A.2.1 Implementing a marker-based system

The following list describes a series of steps that could be taken to implement a typical marker-based system:

1. **Acquire the image**
2. **Pre-process the image:** Perform low-level image processing such as grey-scaling, find lines, edges and the corners of the marker.
3. **Detect potential markers and reject obvious non-markers:** Cleans up the data and focus on potential markers. Accomplished by acceptance/rejection testing.
4. **Identify and decode markers:** Can use methods such as template matching.
5. **Calculate an estimation of marker pose:** Estimating the cameras location and orientation in world coordinates, expressed with translations and rotation angles around each coordinate axes.

These steps can then be repeated each frame for continuous tracking, and the system can be improved by taking prior history into account.

## A.3 Interview Scripts

### A.3.1 Proposed Solution Expert Interview

#### Goals for the interview

Find ud af hvad jørgen tænker om vores system ide baseret på ideal solution

#### Introduction Part 1

Vi starter ud med nogle nemme spørgsmål til at varme op. Derefter vil vi fortælle dig om vores system ide og vise dig et diagram der forklarer hvordan delene hænger sammen. Efter det stiller vi dig nogle spørgsmål om dine tanker. Vi vil gerne optage interviewet

#### Introduction Part 2

Her ser du vores ide for det ideelle system, hvor vi ikke har tænkt så meget over begrænser eller tids-prioriteter endnu. Systemet består af en AR app til iOS og et desktop program. Appen bliver brugt af en bruger ude i felten og desktop programmet bliver brugt af en ekspert, som er ansat af jeres kunde. Ideen er altså at programmet bliver customised og solgt til en PDM Technology kunde, på samme måde som i sælger Bluestar, og at eksperten så er ansat ved kunden.

Vi starter med appen. I appen kan brugeren vælge en model de vil samle/skille ad igennem en database. Når brugeren har valgt en model, informerer appen brugeren om hvad for et komponent der er det første i assembly processen. Brugeren placerer komponentet hvor de vil assemble, og viser det til appen. Appen genkender at det er det første komponent, og bruger efterfølgende det som en marker til at aligne verdnerne. Appen laver en digital twin og placerer den ovenpå den rigtige model, og laver en outline til at fortælle brugeren om det næste skridt.

## APPENDIX A. SUPPLEMENTARY MATERIAL

Brugeren placerer det komponent og viser det til appen and so on indtil modellen er komplet, og appen genkender det.

Brugeren har hele tiden mulighed for at skifte mellem AR viewet og et rent digital view. I det digitale view har brugeren mulighed for at interagere med modellen. Brugeren kan gå skridt frem og tilbage, fjerne komponenter eller få mere information om komponenter ved at trykke på dem. Når brugeren går tilbage til AR view bliver modellen reset så den svarer til den fysiske model igen.

Brugeren har mulighed for at tage kontakt til en ekspert i appen. Eksperten sidder ved en computer og kan tage imod opkaldet. Eksperten kan se både brugerens AR view og det digitale view på hans skærm. Eksperten kan høre og kommunikere med brugeren via stemme og chat. Eksperten kan trykke på et specifikt komponent og markere det for brugeren for at guide dem.

### Warm up session

- Hvad er din rolle i PDM Technology?
- Hvad er din vision for projektet?
- Hvorfor synes du det er “unik”?

### Main session

- Hvad tænker du om den løsning vi har beskrevet for dig?
- Er der nogle features du synes der mangler?
- Er der nogle features du synes er unødvendige?
- Hvad for nogle features synes du vi skal prioritere mest; AR og DT, Assembly/disassembly eller expert collaboration?
- Hvordan passer løsningen ind i det PDM technology laver?
- Hvordan kunne appen passe mere ind?
- Hvad tænker du om den måde eksperten er inkluderet på; ansat af jeres kunde og sidder med computer?
- Har du andre forslag til hvordan brugeren og eksperten kan kommunikere?
- Hvad tænker om den måde appen hjælper brugeren med assembly og disassembly?
- Hvordan forestiller du dig at interaktion mellem brugeren og eksperten skal foregå? Lyd, video, tekst?
- Hvad for en interaktion skal appen tilbyde?

### Cool down session

- Har PDM Technology guidelines til hvordan UI, ikoner eller sådan skal se ud?
- Har du nogle sidste kommentarer eller spørgsmål om appen eller projektet?

# B | Business Plan

This chapter aims to investigate the application from a business point of view. The goal is to determine how a potential startup based on the project could be sustainable and bring value to customers. The chapter is presented as a business plan formed by the group members, based on their skills acquired by participating in the AAU Startup Program and Scandinavian Growth Creators during the semester. Additionally the business plan is summed up in a lean canvas in section B.6.

## B.1 Resume

We are two master students from Aalborg University and we are making a new innovative app for both iOS and Android, that combines the emerging technologies of augmented reality and digital twin. We want to help companies support their users in how to assemble and disassemble their machines, which can result in saving both money and time.

### B.1.1 Elevator Pitch

Triforce Energy Production from Skagen (Fictive company) bought some of their critical machine infrastructure from Copenhagen Machinery (Fictive company) on Sjælland. Every time one of the machines has problems, a technician has to drive to Skagen in order to perform diagnostics on the machines. This is both time consuming and costly. With our AR app the technician can get a live feed of the machine and perform virtual diagnostics, while interacting with the user and guiding them using AR. This saves Copenhagen Machinery both time and money and results in the cost of repairs for Triforce Energy Production being lowered.

### B.1.2 Potential Customers

Potential customers are other businesses that have elements of assembly and disassembly of machines either to users or employees as core components of their business.

### B.1.3 Pricing Structure

Initial ideas are an upfront cost for buying our custom software solution followed by a subscription service for maintenance, costs related to upkeep and continual development of the solution.

### B.1.4 Owners

The company is to be founded by Tobias Adamsen and Frederik Jensen upon finishing their master studies in 2022. Both with technical backgrounds from Aalborg University combined

with knowledge of entrepreneurship in practice from AAU Startup Programme, Scandinavian Growth Creators and Dania Business Academy, Frederik and Tobias have the necessary skills and the drive to implement this business concept into reality.

## B.2 Idea Foundation

### B.2.1 Problem

It's difficult to assemble/disassemble machines. Many things can go wrong in the process: fragile pieces can break, screws can be put in the wrong place or machines could be assembled/disassembled in the wrong order. The time-loss related to error-prone assembly/disassembly processes can cost a lot of money for companies, as they might have to pause production and push deadlines, angering customers. Customers of machines could also benefit from a smarter and customise-able solution to assembly/disassembly processes. Everyone has had problems with a machine in their life and tried to look up YouTube videos of how to take it apart. But the YouTube videos have problems too: they could be of low quality, could skip steps or be too slow/fast to follow along with. All these problems are what our app addresses.

### B.2.2 Proposed Solution

A combination of Augmented Reality and Digital Twin technology could potentially solve the problem. Augmented Reality is an enhanced version of the real physical world, where digital elements appear and exist in the real world through head-mounted displays, phones or 3D display rooms. A digital twin is a virtual representation of a real object and thus goes well on top of augmented reality. The idea is to make the twin appear as closely as possible to the real version, and have them exist in the same space through a phone app. Users would then be able to see exactly where to put components in the assembly/disassembly process. Additionally the app includes a feature to contact an expert, and share the screen and the digital twin with them in real time, in order to receive advice on how to proceed. The expert would also be able to interact with the digital twin and make changes appear on the user's side.

### B.2.3 Value Proposition

The objective of the app is to help support other companies in guiding their employees or customers towards easier, faster and less error-prone assembly/disassembly processes. Additionally the app has value as a data platform, where companies can obtain information about how users approach the assembly/disassembly process; which steps they have problems with, how long time it takes and how many problems they face along the way.

### B.2.4 Competitive Advantage / Standout Features

- Ability to see Digital Twin of a real object overlaid on top of a real object in Augmented Reality
- Ability to be guided towards assembly or disassembly of an object
- Ability to contact an expert in the app
- Ability for the user and expert to share screens and interact with augmented reality objects

## **B.3 Product and Market**

### **B.3.1 Income**

The primary source of income in the company would be other companies buying our custom software solution. It would consist of an upfront cost followed by a subscription service for us to maintain the software, related framework and continually improve the service. The subscription could have different tiers depending on level of service, amount of machines to include or amount of users.

### **B.3.2 Distribution channels**

Ideally the app would be for both iOS and Android, and would be distributed to customers through their preferred app store or other means.

### **B.3.3 Customers**

Customers include businesses such as mechanics and repair shops and a variety of other businesses such as factories, car manufacturers, etc., that all could benefit from the solution.

### **B.3.4 Competition**

From market research we have concluded that there currently are no applications which connect digital twins and Augmented reality. This shows that currently no existing competitors exist; this is further supported by consulting with experts from PDM Technology at Novi, whom also stated that currently there are no applications like ours. This gap in the market is what we intend to fill.

While research showed no current competitors, the research also showed that the idea of an augmented reality assembly app is not new, and there are several design concepts out there for assembling things such as furniture. Our app distinguishes itself from these concepts by including digital twin technology and intends to make the assembly process much smarter for the user.

### **B.3.5 Potential Threats**

As the technologies of Augmented Reality and Digital Twin matures it is possible competitors could also get the idea of combining and creating applications to compete against ours. In order to keep ahead of future competition it is important that we keep an eye on the market at all times and that we keep being innovative and developing new features for our app, such as 3D scanning.

## **B.4 Personal Goals and Resources**

### **B.4.1 About Us**

Frederik is an enthusiast and user-focused developer, who has mainly worked with projects concerning integration of users into development as well as creating digital platforms and solutions based on user needs. For this business, Frederik brings a lot of user focused knowledge and development scenarios as well as being heavily interested in the entrepreneur part of the business.

Charismatic and outgoing, Frederik would have the role CEO of the company.

Tobias is a dedicated and solution-oriented engineer, who pays attention to all the small details and makes sure everyone on the team are heard when considering the next step in the process. For this business, Tobias brings a lot of technical knowledge in particular about Augmented Reality and software testing to the table. Tobias is very passionate about technology and especially using it to help people and improve the world. In the company Tobias would have the role of CTO.

### **B.4.2 Knowledge of the Product / Service**

As we have a combined 10 years of technical experience and have created apps and worked with Augmented Reality previously, we are confident in our ability to create a worthwhile product. Once we have a prototype, we will draw on our knowledge of user experience and test the product with real users in order to get feedback and improve the product. We also have some knowledge of methods and business theory that we will strive to make use of and expand with this project.

### **B.4.3 Weak Points in Regards to Business**

Coming straight out of academia, we have extremely limited knowledge of how business and the real world functions. The only real world experience we have consists of internships in software companies and collaborations with companies during our time at university. This is a big point of weakness that we are very aware of and will work to remedy.

### **B.4.4 Personal Resources**

While we intend to work on the project full time while studying, the financial contribution we can make to the project during this period is limited. We are determined to work hard and put all the hours required into making the project a successful venture for both ourselves, potential investors and customers. It is important for us to learn and develop as individuals together with the business evolving and in the end create a product that improves the world.

## **B.5 Business Development**

### **B.5.1 Initial Business Concept**

It is important to note the business concept in this document is at a very early stage and is subject to change as the app gets developed and tested. The goal is to keep developing the business concept and expand the feature set of the app. One potential way forward is to expand to other types of assembly and disassembly in the future. This could include things such as furniture, consumer electronics and other products that require assembly.

The first year the business would survive by business grants and potential investors. Initial investments would be used to hire new employees such as marketing associates, who would help us become visible to the customers.

As the business grows and the app gets adopted by more companies, we intend to scale up and hire people to suit the business needs, so that we can keep servicing our customers the most efficient way possible.

### **B.5.2 Evolving Business**

Within 6 months of running the business we will have a proof of concept application that can be tested with users and improved based on feedback, before being pitched to potential customers. Within 1 year we see ourselves as having a stable and scale-able application that is ready to or has entered the market.

Within 2 years we will have sold our solution to various companies and integrated a large selection of machinery into the solution. The market for different types of assembly could also be captured, however beforehand a market analysis would need to be conducted to look for any competitors and an in-depth look into how our solution could be scaled into other types of assembly/disassembly.

Along the way we see ourselves branching out and exploring other possible use-cases for AR and Digital Twin technology, in order to expand the number of services our company can provide.

## **B.6 Lean Canvas**

Figure B.1 shows the lean canvas of the proposed business idea. The canvas is an efficient way to communicate several key components of the business idea to stakeholders. The canvas answers such questions as who are customers, how will money be made and what are the metrics to consider the business a success.

## APPENDIX B. BUSINESS PLAN



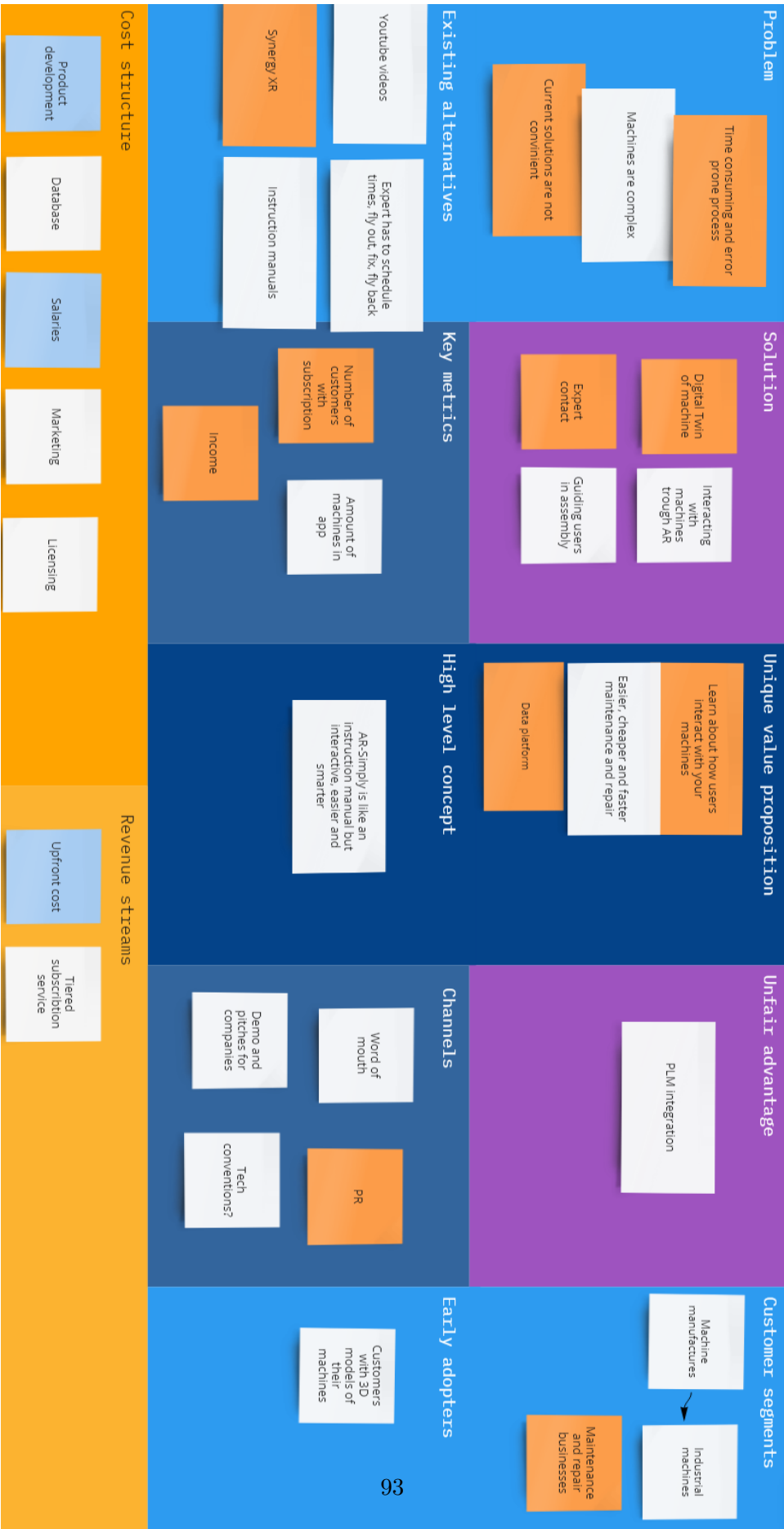


Figure B.1: Lean canvas of the business proposal.

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