Augmented Reality in Historical Museum

A Case Study at Fjell Fortress

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Abstract

Over the years, there has been development in using the technologies in historical museums for various reasons. The recent development of smartphones and Computer Graphics (CG) has enabled us to provide a new way of interaction between the artifacts and visitors. Augmented Reality (AR) provides a platform to add a third dimension to displays bringing the scene to life. It is gaining popularity among the users because of its beneficial features to engage the users.

Therefore this thesis aims to investigate the use of AR in Fjell Fortress to assist the visitors. A comparative study of different AR frameworks is done, and ARCore is chosen to develop a mobile application. A detailed study with the features of ARCore is performed to get an understanding of the framework. The features to reconstruct the past, an indoor and outdoor guide to the Fortress, are developed. Finally, the personal experience is used to discuss the challenges and limitations of the technology in developing the application, and an online survey is used to evaluate the applicability and usability of the application.

Keywords: Augmented Reality (AR), Historical sites, Museums, Cultural Heritage, ARCore, Fjell Fortress

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Acronyms

2D Two Dimensional. 11, 12, 18, 25, 27, 44

3D Three Dimensional. 2, 9, 11, 24, 25, 36, 37, 44

ALU Arbela Layers Uncovered. 11

AR Augmented Reality. i, ii, iii, iv, vi, 1, 5, 6, 8, 9, 10, 11, 12, 13, 14, 15, 16, 17, 18, 19, 20, 21, 22, 23, 24, 25, 28, 30, 34, 35, 36, 37, 39, 42, 43, 44, 45, 46, 47

ARCHEOGUIDE Augmented Reality-based Cultural Heritage On-site GUIDE. 11, 12

ARS Augmented Reality System. iii, vi, 15

ATLAS Association for Leisure and Tourism Education. 5

CAVE Cave Automatic virtual Environment. 9, 10

CG Computer Graphics. i, x

COM concurrent odometry and mapping. 28

GPS Global Positioning System. 13, 17, 18, 22

HMD Head Mounted Display. 9, 10, 16

IDE Integrated Development Environment. 25

IMU inertial measurement unit. x

MARS Mobile Augmented Reality Systems. 11

NDK Native Development Kit. 25

OST Optical-see-through. 16

POI Point Of Interest. 10, 11, 43

PSVR PlayStation VR. 9

SDK Software Development Kit. 18, 20, 21, 25, 31, 37, 40

SIGGRAPH Special Interest Group on Computer GRAPHics and Interactive Techniques. x

UNESCO United Nations Educational, Scientific and Cultural Organization. 4

VR Virtual Reality. iii, vi, 2, 8, 9, 10, 12, 25, 43, 44

VST Video-see-through. 16

WW2 World War II. 1, 2, 3

Glossary

controlled environment Controlled environment is the environment where the parameters affecting the environment can be controlled to the needs.. 42, 43

IMU IMU is an electronic device that measures and reports a body's specific force, angular rate, and sometimes the orientation of the body, using a combination of accelerometers, gyroscopes, and sometimes magnetometers.. 22, 28

prefab It is an asset type in Unity that allows to store a collection of GameObjects with all its related components and basically acts as a template which can be reused creating new instances of it. 31, 39, 40

scene The scene is like a container in Unity which stores all the asset that is used in a given moment.. 25, 37

SIGGRAPH SIGGRAPH is an annual conference on CG organized by the ACM SIGGRAPH, starting in 1974. 9

Chapter 1

Introduction

Augmented Reality (AR) is a technology that is gaining popularity over the past few years. This technology allows extending the virtual media out in the real world by augmenting the surrounding environment with the virtual entities. Advancements in software and hardware technologies have accelerated the use of AR to a broader range. By mixing computer-generated entities to real scenes, AR technology provides a unique experience in navigating the space [6].

Looking at the current usage of AR, Centre for New Media wanted to experiment AR with a historical museum, Fjell Fortress. Fjell Fortress is one of the biggest German fortress in Norway during World War II (WW2). During the thesis work, I had several meetings with the Centre for New Media to discuss the possibilities of using AR in the fortress. In this thesis, I have investigated the use of AR framework for developing a mobile application.

1.1 | A word about Centre for New Media

Centre for New Media is a department within HVL which works with digital productions such as graphics design, web design, digital photography, development of applications for mobile phones and tablets. It also has offered online distance learning courses in media and communication topics. The centre works in collaboration with researchers, educators, and motivates students for developing and researching new technological aspects at HVL

[7].

In 2017 Centre for New Media in collaboration with Bachelor groups performed the scanning of the Fjell fortress and have created virtual Three Dimensional (3D) models of tunnels and monuments that exist in Fjell Fortress. They have also created a VR supported Unity scene of the fortress.

1.2 | Fjell Fortress

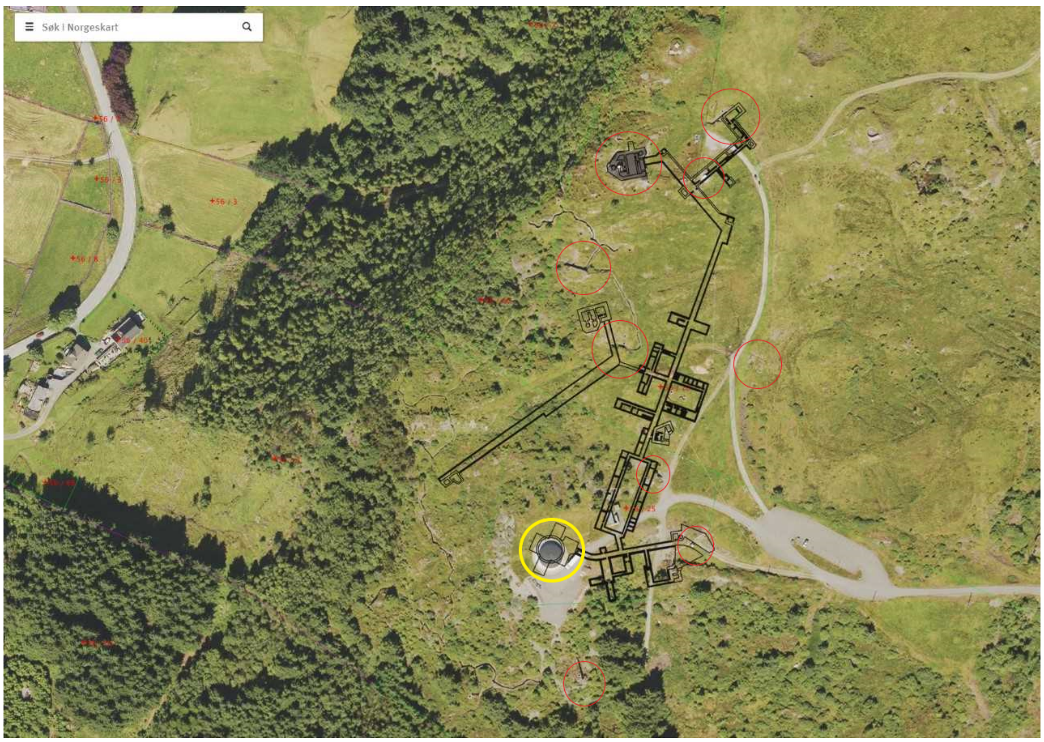


Figure (1.1) Top View of Fjell Fortress

Norway is home to many cultural heritages, one of them is fjell fortress. It has a great historical background from WW2. It is located on the top of Fjedalfjellet mountain, in Fjell municipality. Germans built it during the second world war to defend the sea entrance to Bergen. It has an impressive underground military base with dormitories, kitchens, washing facility, heating facility, saunas, showers, and a network of command bunkers.

It also has railways, military equipment, ventilation systems, and advanced electrical installations. The fortress has several bunkers with exciting stories and plays a vital role to understand the fortress shown in figure 1.1

During WW2, Germans used a ship *Gneisenau* for the invasion of Norway. The British force later damaged the ship in February 1942 [8]. The ship had two cannons, one of them was set up at Fjell Fortress. After the war was over, the fortress was taken over by the Norwegian military, and the guns and cannons were scrapped in 1968. The fortress was a restricted area and used as a coastal radar station until 2003. Now the area is made public as a museum and is preserved as a military heritage by The Central Office of Historic Monuments [9]. There are still many types of equipment and structures which are in the original state untouched, but some are rebuilt for safety and preservation purpose.

1.2.1 Defining the Problem

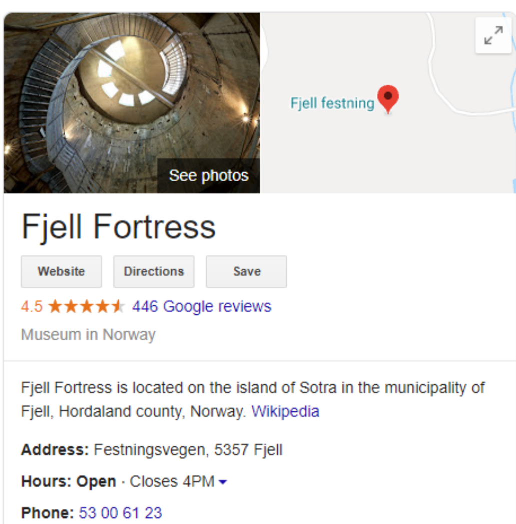


Figure (1.2) Review in Google [1]

Fjell Fortress takes about 30 minutes to drive from the city centre. The public transport is available till the foot of the fortress, and the way to the top of the fortress involves adventurous mountain trek with beautiful scenery along with the stories from WW2. Although the private vehicles can be taken to the top but trekking through the mountain is preferred. The site has a positive response rated with 4.5 stars out of 5 based on 446 reviews in google [1] shown in figure 1.2. Most of the visitors suggest it an excellent place to visit. The site provides a guided tour facility with a price included only on Sunday.

From figure 1.1, top view of the fortress, it is evident that the fortress is spread over the large area. The particular problems during the visit are described.

The circled areas on the map are different infrastructures on the ground, which are associated with the history of the fortress. These infrastructures have a story to tell about history. Without a guide, it is not easy to visit the whole area and understand the description of the overall structure.

The yellow circle on the map is the location of the cannon, which is the main attraction of the fortress. The cannon has been removed now, and a cafeteria is built shown in figure 1.3. Not only the cannon, but several other types of equipment from the past are also removed from the site. The bunkers are also degrading over time.

The next difficulty during the visit is to understand and connect with the underground tunnels. The cafeteria is now the main entrance, which leads to deep under the ground. The tunnels have a complex structure and are connected to different infrastructures on the ground at different locations.

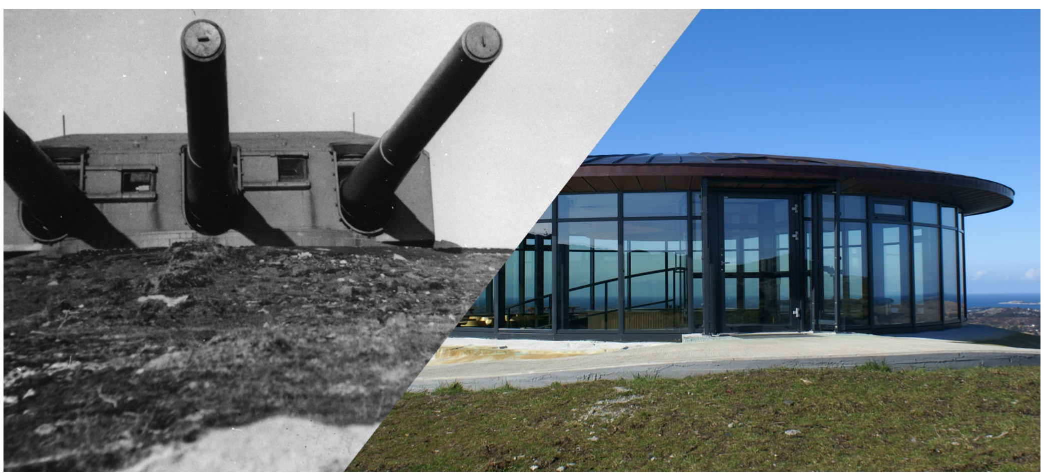


Figure (1.3) Cafe Build in place of Cannon

1.3 | Motivation

Cultural tourism is one of the largest and fastest-growing global tourism markets, claimed by United Nations Educational, Scientific and Cultural Organization (UNESCO) [10]. A study in the cultural exploration habits of Europeans indicated that people visited cultural heritages frequently [11]. Cultural tourism is viewed as an essential resource that not only supports economic development but also develops the cultural harmony [12]. Many countries and regions are promoting cultural tourism as an economic development tool because every place has a culture to present. The definition of cultural tourism provided by Association for Leisure and Tourism Education (ATLAS) is: "The movement of persons to cultural attractions away from their normal place of residence, with the intention to gather new information and experiences to satisfy their cultural needs" [13]. The cultural tourism attractions are classified as attractions and events by Muners (1996) as reviewed in [12]. According to Muners, attractions are monuments, museums, routes, theme parks, and events are cultural-historic events, art events, events, and attractions. The definition states that visitors' satisfaction and experience has a significant role in cultural tourism.

In recent years, the studies in the behavior of cultural tourism are directly linked with the use of technological applications [14]. Technological tools and new social trends influence the needs and expectations of cultural consumers [14]. In order to attract more visitors, cultural heritages are adopting new technologies. Recently AR is gaining popularity among the cultural heritage sites. AR is the leading technology outlined in many research works and projects to engage the users in an enhanced perception of surrounding [15]. As AR and its supporting technology is continuing to flourish, it makes an ideal platform for enriching historic architecture and remains of cultural heritages [16]. Moreover, another recent development shows that nowadays, almost all the museum visitors carry smartphones, which can be utilized to enhance museum experiences [17].

This research is motivated in the use of AR technology with mobile devices to assist during the visit. Although the thesis is focused on Fjell Fortress, this study can be used as a base for the development of the application for other historical museums.

1.4 | Thesis Goal

The main goal of this thesis is to develop a mobile application that utilizes the AR functionality to enhance the visit at Fjell Fortress.

To follow the goal I will be doing the following tasks:

- Review different AR frameworks.
- Study the features of the ARCore framework.
- Develop a mobile application.
- Test the application for evaluating the visitors' experience.

1.5 | Report Structure

This section gives a sketch of the chapters in this thesis work by briefly mentioning the contents.

Chapter 1 (Introduction) sets the nature of this thesis work by discussing the motivation and goals of the research. It also describes the problems which form the base for the work.

Chapter 2 (Background) presents the technological background of the museum, along with the related works.

Chapter 3 (ARCore Overview) provides the general information and technologies to support AR. The comparison within the different frameworks is also discussed.

Chapter 3 (ARCore Overview) sheds light on ARCore and different studies done with ARCore.

Chapter 4 (Application Development) discusses the development of the features of an application.

Chapter 5 (Discussion) presents the discussion while developing the application and the challenges with the technology. It also presents the user study conducted to evaluate the application.

Chapter 6 (Epilogue) concludes the thesis with a conclusion and future work.

Chapter 2

Background

Museums are essential institutions that care for the collection of artistic, cultural, historical, or scientific importance artifacts. They hold the cultural wealth of the nation and helps the future generations to understand and appreciate their history and culture and take pride in the achievements of those before them. Museums are concrete evidence from the past. Visits to the museum should be developed and encouraged as they educate and inspire people. Museums also play a vital role in providing economic benefits, creating many employment opportunities by attracting national and international visitors.

2.1 | Museums and Technology

Traditionally, museums used to offer a static experience to the visitors. The museums were just the collection of artifacts exhibited behind the glass. However, the museums' digitization movement started at the beginning of the 21st century introduced the use of digital technologies in the museums [18]. The technology can be used for various purposes, such as documentation of the artifacts, digital preservation, engagement of the visitors [4]. The advancement of digital technology has provided a new way of interaction between the artifacts and visitors due to which more and more museums are exploring to enhance the users' experience. The study conducted in history and science collections-based museums proved that the interactive experiences in the museums supported visitors' learning [19]. Museums have used several approaches, such as location-aware guides, mobile applications, games, interactive touch displays, VR, and AR applications [4]. Some of the interactive technologies used by museums to enhance the experience of the visit are discussed as:

2.1.1 Other technologies

Online Museum: Museums have created a database which is made digitally available over the internet. The museums' websites provide various supportive information to the visitor. Nowadays, museum websites are providing tools to download the maps of the museum and take a virtual tour and explore the artifacts sitting in the room. A study in Louvre's digital presence over the internet has proved the growth of audiences [20]. Another example of amplifying the virtual artwork experience is Google Art Project. It is a free online database that provides information about the artworks from all over the world [21].

Interactive Multi-touch Surfaces: The multi-touch screens provide the information to a large number of audiences since multi-touch supports to identify two or more simultaneous touches providing several people to interact with the application at the same time. Besides this, the dimension of the touch area and big screen attracts the visitors to use the devices [22]. An example of this interface can be found in Gallery One at the Cleveland Museum of Art, located in the United States. The museum has a 40-foot Collection Wall installation, which displays over 3500 objects from the most important museums in the world [23]. When the image on the screen is touched, the screen provides detail information about the collection. This device can be used by several visitors simultaneously. The visitors can personalize and share their tours.

Interactive projections: With the increase in the engagement of the visitors, some of the museums have provided immersive interactive projection exhibits [22]. The system has big projection displays and motion detection hardware. Visitors can see things from a completely different perspective and can even use their body gestures to interact. The immersive interaction projection installation at the Wu Kingdom Helv Relics Museum is one of the examples. It provides unique visual storytelling with interactive floors and walls [24].

2.1.2 VR

VR places the user inside a virtually simulated environment with an ability to interact with 3D world. VR is spreading in museums, and cultural heritages for enhancing the visitors' experience providing a new means of experience which is impossible in the real world [25]. It simulates different senses such as hearing, vision, touch, even smell. The sounds and immersive displays are commonly used technologies. There are different display technologies used for an immersive experience in VR.

Head Mounted Display (HMD): HMDs are one of the standard immersive displays used in VR technology. HMDs are attached to the head and presents visual direct to the eyes. These will also have an option to use headphones. Sony's PlayStation VR (PSVR), Facebook's Oculus Rift, and HTC Vive are the major players currently in the market.

Cave Automatic virtual Environment (CAVE): The CAVE systems are one of the virtual reality devices available for portraying the virtual environment [26]. It allows a user to enter a cube wearing stereoscopic glasses and can experience the presence in the virtual environment. The walls, floors, and celling of the cube act as displays. The CAVE achieved the international recognition after it was displayed at the 1992 SIGGRAPH conference as reviewed in [26].

2.1.3 AR

AR is a mixture of virtual objects in the real environment. Unlike VR, which is immersing the user totally in the virtual environment, AR superimposes the virtual objects and information with reality. It bridges the gap between the virtual world and the real environment. AR technology started to enter the museum's environment in the early 2000s [4]. Using AR, museums can add a layer of extra information on top of existing exhibits. The study on the visitor experience shows the potential of AR is museums [19]. A detailed

(a) HMD [27] (b) CAVE [28]

Figure (2.1) Virtual Reality (VR)

discussion about AR technology is done in chapter 3. This section describes some points why museums are using AR technology [29].

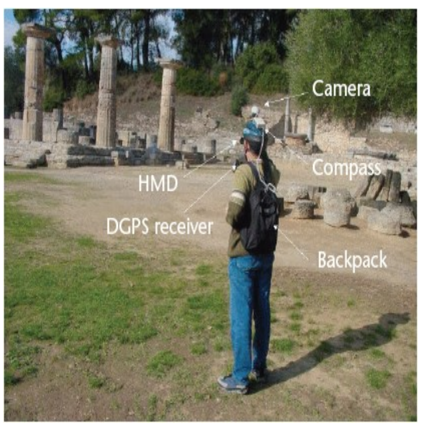
- **AR is engaging:** AR is used to add an extra layer of information that can be reached out to more audiences. It is more flexible in adding any information which can be made personalized so that the users get more connected in learning. Visitors get an opportunity to look at an artifact from an entirely new angle.
- **AR brings artifacts to life:** By adding a digital layer of augments over the Point Of Interest (POI), museums can provide detailed information about the artifacts. With the features of AR, museums can provide not only textual, audio, and video presentations but also use animated characters that act as a virtual storyteller. The whole story can be explained using different virtual characters in the real world.
- **AR is fun and interactive:** Many museums have integrated AR with little fun into the artifacts to attract families and young visitors. AR gaming has made a way in new generations where the players can make use of real-world and virtual world to play the games. Museums can integrate different activities such as treasure hunting in the museums, which helps the visitor to learn with fun.

- **AR is easily accessible:** AR can run on most of the existing smart devices, and they do not need extra hardware to integrate or an expert in using it. Most of the sensors needed for AR are packed in the device itself, which makes it popular among the users. The usage of AR is as simple as using mobile phone applications.
- **AR gives visitors a reason to visit - and revisit:** The AR application makes use of a virtual environment, so it is easy to make any changes or refresh the outdated information with the new information. Museums can always provide something new from time to time to provide a different experience in every visit to the visitors, such as changing the theme of the museum, changing the interaction activity, and many more. It provides a reason for visitors to revisit the museum.

2.2 | Related Works

Although AR has a history back to 60's but the adaption of AR in historical museums began as early as 1999 with the MARS project [30]. Augmented Reality-based Cultural Heritage On-site GUIDE (ARCHEOGUIDE) in 2002 provided personalized AR tour in order to help visitors enjoy the past glory of the site [31]. It used AR to reconstruct the ruins from the past. The supporting components for AR were not portable in the past, which can be seen in figure 2.2a. The development of smartphones in recent years has enabled us to use AR within handheld devices. The hardware and sensors required are packed into a single hand device, and different SDKs provide an easy software solution in building the applications. The technology started with Two Dimensional (2D) representations and 2D target objects and now the technology has improved to 3D visualization and interactions [32].

Arbela Layers Uncovered (ALU) was developed as a proof of concept of an AR application to explore the ruined archaeological sites [33]. The study also addressed the design of a mobile interface. A mobile AR application "The Historical Tour Guide" was developed in 2012 to provide additional information about the historical street in Trondheim [34]. The application is a location-aware mobile information system that provides an augmented reality view where POI are shown as floating icons overlaying the camera feed shown in figure 2.2b. A proposal of an adaptive mixed reality system known as "MixAR Mobile Prototype" aiming to provide the visualization of virtual buildings properly aligned with real-world structures was made in 2015 [35]. Another application of AR in 2015 is used to provide information about the engravings on the walls of the temple. AR, combined with audio commentary, helped visitors to locate the different graffiti easily and learn facts and motives about the engravings [36]. ArtLens 2.0 is an AR application that uses image-recognization technology to recognize the 2D pieces of artwork. It is provided by the Cleveland Museum of Art and was launched in summer 2016 [37]. A recent example is Chicago 00 Project experimenting with location-based AR. The project is a partnership between Chicago History Museum and filmmaker Geoffrey Alan Rhodes which provides AR and VR experiences [38] of the museum. "Chicago 00 The Eastland Disaster" is an on-site AR tour using over 70 historical photographs and newsreel films to describe the disaster.



(a) ARCHEOGUIDE [31]

(b) The Historical Tour Guide [34]

Figure (2.2) Related Works

Chapter 3

Augmented Reality: An Overview

This chapter provides a general introduction and the history of AR. It describes the technology and working of AR. Finally, the AR frameworks for creating an application are discussed, and a comparison is made.

3.1 | What is AR?

Augmented Reality (AR), in a general term, is to blend the virtual world with the real world. In AR, users interact digitally with the information in the real world. As it is not a new idea, but with the advancement of smartphones and tablets, it has now extended its possibilities in many ways; Augmented Reality applications have been developed to run on them. AR applications use the device sensors (camera, Global Positioning System (GPS), compass) and fuse useful information on top of the image from the camera viewed on the device's screen.

The figure 3.1 describes the concept of Paul Milgram; the continuous scale ranging complete real and complete virtual [39]. On the left lies a real-world, and, on the right lies the virtual world. Everything in between is a mixed reality where physical and digital objects interact together.

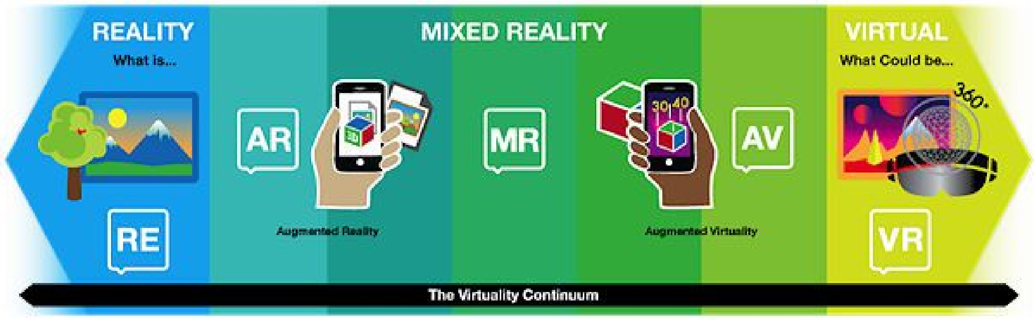


Figure (3.1) Reality-Virtuality Continuum (Paul Milgram 1994)

3.2 | History of AR

Although AR seems a new technology the story begins in 1968, a head-mounted display developed by Ivan Sutherland [40] but the term "Augmented Reality" was first used by Boeing researcher Tom Caudell in 1992 [41] while helping workers to assemble the wires and cable for aircraft. In 1994 Paul Milgram presented a continuum diagram that spans from the real environment to the virtual environment [39]. Ronald Azuma in 1997 provides a most used academic definition for AR identified by three characteristics: it combines real and virtual, it is interactive in real-time, it is registered in 3D [42]. In 1998 the broadcast company "Sportvision" used AR to cast a virtual yellow first-down marker in a live NFL game and NASA to provide virtual-navigation during test flights. A year later, Hirokazu Kato and Mark Billinghurst introduced a template-based approach for recognition using square fiducials: ARToolKit, available as open-source under the GPL license [42]. Bruce Thomas developed the first outdoor mobile AR game ARQuake in 2000 [43] and in the following years, more and more AR applications were developed such as Wikitude AR travel guide launched in 2008 [44]. Google brought "Google Glass" to the market in 2012, which used AR to show real-time information on the glass. Although it was not a commercial success product, some companies found it useful, such as medical and automobiles. After the massive success of an AR mobile game application Pokémon Go in 2016, lots of other applications started exploring. Snapchat, Facebook, Instagram added entertaining AR face filters, which was a new experience to the users. The announcement of ARKit and ARCore in 2017 made it more popular among the mobile phone application developers and users. With the growing attraction of AR, companies are spending millions of dollars to harness its potential, so it is fascinating to see every new release of this technology.

(a) Ivan (b) Google Glass (c) Pokémon Go

Figure (3.2) History

3.3 | Augmented Reality System (ARS)

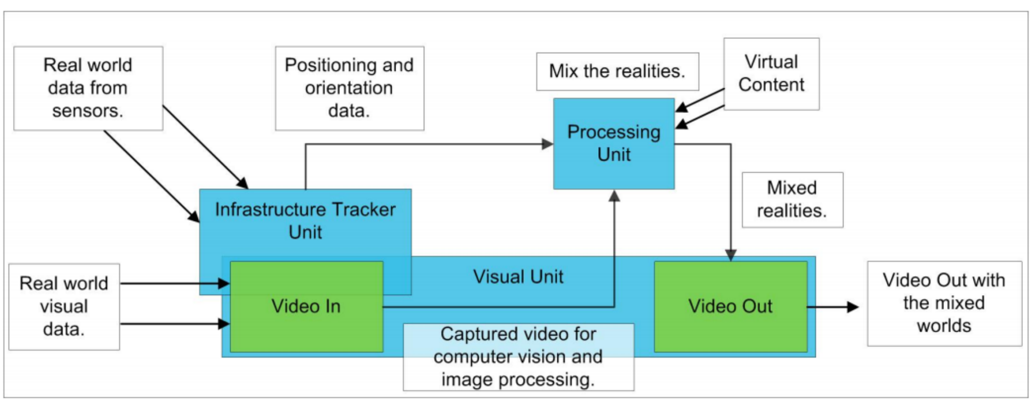


Figure (3.3) Augmented Reality System (ARS) standard design [2]

The standard ARS design consists of tracker unit, processing unit and visual unit as illustrated in figure 3.3 [2]. The tracker unit collects the data from the sensors and provides it to the processing unit. The tracker unit tracks the position and orientation data. The visual unit takes the video from the real world and sends the data to the processing unit. The processing unit takes the real-world data from the tracker and visual unit and mixes it with virtual content. These mixed data are then sent to the visual unit for output video.

3.4 | Enabling Technologies

The technology for AR is developing rapidly. Hardware is getting cheaper and smaller, and the software is becoming more faster. The essential components for AR are display, tracking, registration, calibration technology [45].

3.4.1 Display

Displays are the essential equipment of the AR system. It is used to view the final output of AR. There are three major types of displays used for AR: Head Mounted Display (HMD), handheld displays, and spatial displays [44].

HMD is a display worn over the head like a helmet, and a pair of displays are adjusted over the eyes. It has cameras attached to take the images, and then the virtual graphics are fused then is displayed on the screen. HMD are categorized as Video-see-through (VST) and Optical-see-through (OST) [46]. VST displays are those where the users see the video of the real-world with graphics overlaid on it. VST has more control over the view. Various image processing techniques can be used to get a consistent result. OST displays use a half-silvered mirror or similar technology to let the user see the real world through it overlaying the graphics onto the user's view. In OST, the real world cannot be delayed, so a small delay in overlaying the virtual objects are noticeable. It is difficult to obtain than VST.

Handheld displays are the ones that are easy to hold in the hands, and smartphones are the most popular. These displays are good alternative to HMD for AR applications. All the components needed for the technology are packed into the device, which makes it more portable and socially acceptable [46].

Projection based displays makes use of digital projectors to display graphical information onto the physical world. It separates most of the technology from the user and integrates it into the environment [44].

3.4.2 Tracking

Tracking is one of the enabling technology for AR. Accurate position and orientation tracking are needed to align virtual objects in the real world. The tracking process involves reconstructing the correct position between the real world and virtual objects when the position of the device is changed. There are three types of tracking and registration methods:

Sensor-Based tracking uses sensors to track the motion of the user and continuously update the user location in the virtual world. The different hardware that helps in motion tracking are accelerometer, gyroscope, and camera. The accelerometer measures the change in velocity. The gyroscope measures the orientation and angular velocity. The camera provides live images of the surrounding, which is used in understanding the real world. The hardware that enables location-based AR is Magnetometer and GPS. Magnetometer lets the device know the earth's magnetic field, and the global navigation satellite system provides geolocation and time information to the GPS receiver [45].

Vision-Based tracking uses complex image processing algorithms to determine the feature points in the environment. The images are feed through the camera of the device. The algorithm compares vital points with the stored points to determine the orientation and position of the device. The advantage of this method is fast and applies to smaller areas but needs high power for processing complex algorithms [45].

Hybrid method is promising for indoor and outdoor AR environments. It uses both the hardware-based and vision-based technology for the tracking and registration process [45].

3.4.3 Registration

In AR, registration is the alignment of virtual objects to the real world. Registration methods are divided into two types: sensor-based registration and computer-vision-based registration [47]. In sensor-based registration, special sensors are used in determining the relationship between the device and the real world. For example, magnetic field detectors, radio frequency, audio signals are used to get the position of the objects in the surrounding. This method is not portable because it involves extra hardware and equipment attached to the device.

The computer-vision-based method provides the solution without the need for additional sensors. It computes the position of the objects in the surroundings using images. This approach is complex to achieve.

3.4.4 Calibration

The configuration of all the necessary parameters for accurate registration of the virtual object in the real world is called calibration. The geometric relationship among the physical objects, virtual objects, and the camera is established to get the correct view of the model object [48]. For example, transferring the pose information from one coordinate system into another coordinate system to render the object from the right perspective [49]. The computer uses a virtual camera to see the objects in the virtual world. This virtual world is then overlaid in the real world, adjusting different parameters. If these parameters do not fit properly, then the virtual world may have a different size than the real one.

3.5 | Types of AR

Generally there are two types of AR: Marker-based and Markerless [3].

Marker-Based AR depends on the fiducial markers to calculate the orientation and position of the device. The markers can be QR/2D codes or the images which have lots of details that can be easily recognizable [50]. Marker-based AR is almost handled through mobile devices. There are several Software Development Kit (SDK)s available to provide this feature. After the software detects the markers, the virtual objects are linked with the marker.

Markerless AR is categorized as location-based AR or Vision-based AR. Location-based AR is based on the hardware like GPS, accelerometer, digital compass, and a velocity meter. These sensors provide the location and direction information of the device, which can be used to get the orientation and position of the device. Vision-based AR uses image processing algorithms to determine the unique feature points from the environment, and these points are used to determine the pose of the device. This technology is getting more popularization because of the availability of smartphones, which are packed with all the needed sensors are capable of running complicated calculations [50].

Comparison Aspects		**Marker-based AR**	**Markerless AR**
Methods	Relative position/angle	Depends on markers	Depends on localization technology and gyroscope
	AR Software Development Kit (SDK)	Commonly used	Rarely used
Position accuracy	High/low	Relatively higher	Relatively lower
	Influence factors	Brightness	Localization technology
Stability	High/low	Relatively lower	Relatively higher
	Influence factors	Markers and SDKs	Localization technology and gyroscopes
Hardware support	Desktop	Supported	Usually not supported
	Mobile	supported	Supported

Figure (3.4) Comparision between marker-based AR and markerless AR [3]

Comparision: Different studies have been done to compare marker-based and markerless technology. For developing an application, it is essential to differentiate the technologies in terms of technology, which is provided by [3]. This comparison takes location-based technology as a markerless AR. The study concluded that the markerless technology is more complicated to develop than marker-based, whereas marker-based is more accurate in positioning the object than markerless. Markerless is more stable but supports only in mobile devices. On the other hand, marker-based is supported by both desktop and mobile devices but is less stable than markerless.

3.6 | AR frameworks

AR is gaining popularity in multiple areas such as tourism, entertainment, education, art, and many more. The report prepared by Tractica shows that the users for mobile AR will reach 2 billion by 2022, and with the advancement of the affordable software development kit (SDKs), more applications tend to include AR [51]. Several frameworks provide a solution in building practical AR applications. Some of the popular frameworks are listed below with their features described briefly.

ARKit: In June 2017, Apple announced the ARKit framework at the World Wide Developers Conference (WWDC). This framework supplies numerous and powerful features to build Augmented Reality applications and games for iOS devices. ARKit uses technologies such as Metal, SceneKit, SpriteKit, Unity, Unreal Engine to handle the processing of the 3D models in the scene. ARKit can be used in the devices that have minimum A-9 processor hardware and iOS 11 operating software [52].

ARKit can track different surfaces, images, and 3D objects. It also provides a feature to react in different lighting conditions. In June 2018, ARKit was updated with version 2, which provides a feature that can communicate with other devices to create a multiuser application or game. In the recent update, it is loaded with the feature to persist between different sessions [52].

ARKit API is free to download and use, but an annual Developer Program account is needed for store distribution, which is priced US$99.

ARCore: Google started the journey of AR with Project Tango from 2014. ARCore is the new software development kit announced in 2017 for developing AR applications and games. ARCore works on different devices with android 7.0 and higher in android devices and iOS 11 or higher in apple devices. ARCore satisfies most of the developers by providing SDK for Android, Android NDK, Unity for iOS and Android, iOS, Unreal Engine. ARCore uses Sceneform SDK, which is a 3D framework for developing applications without the knowledge of OpenGL for android development.

ARCore can detect 2D images and planar surfaces. With cloud anchors, it lets users have the same AR experiences simultaneously in different devices iOS or Android[53]. With recent updates in handling Augmented images and movement of light, ARCore is getting more impressive.

ARcore is free to download, use, and distribute.

Vuforia: Vuforia is the popular SDK for mobile devices that enable in creating Augmented Reality applications for Android, iOS, and UWP. The applications can be built with Unity, Android Studio, Xcode, and Visual Studio.

It uses computer vision technology to recognize and track image targets in real-time. It implements different functionalities such as recognition of different types of visual objects, text, environment, VuMark. Also, the object targets can be created using Vuforia Object Scanner [54].

All plugins and functionalities of the platform are free to use, but it includes a Vuforia watermark. There are different pricing plans with different features and removal of the watermark.

Mapbox: Mapbox is a platform that provides live location data founded in 2010. Mapbox Studio is the function that helps in customizing the maps. It provides a Maps SDK for iOS and Android for publishing the maps in native applications. Mapbox Maps SDK for Unity provides the tools required to build Unity application using the map data. Recently in 2018, Mapbox released its Mapbox AR. The platform uses the low-level features of ARCore and ARKit along with digital mapping technology [55, 56].

Comparision: Many online portals [57, 58] describe the differences between the popular ones and provide their opinions. Each of the engines has its pros and cons, along with its distinct features, so it is difficult to choose a SDK engine.

In my study, I have considered the comparison done by [4]. This study was made online in December 2018, so this was the latest comparison while I was working with the thesis. The figure 3.5 features the comparison based on the characteristics that each framework points out the most. The study has discarded the frameworks which have not been updated after 2016. Among the different platforms listed in the table, I have only looked at the popular

Framework	Last version found	Markers		Sensors		SLAM	Dynamic occlusion	Implementation
		2D tracking	3D object tracking	GPS	IMU			SDK package
Apple ARKit		✓	✓	✓	✓	Not found	✗	iOS
AR Core	8 May 2018	✓	✗	✓	✓	✓	✗	Unity Unreal
ArUco	17 May 2018	✓	✗	✗	✗	✗	✓	✗
Augmented Pixels	26 Apr 2017 (protype)	✗	✗	✓	✓	✓	✗	✗
Catchoom CraftAR	28 Mar 2017	✓	✗	✗	✗	✗	✗	Unity
EasyAR SDK Basic	6 Mar 2018	✓	✗	✗	✗	✗	✗	Unity
EasyAR SDK Pro			✓			✓		
Kudan	23 Mar 2018	✓	✓	✓	✓	✓	✗	Unity
MAXST AR	19 Mar 2018	✓	✓	✗	✗	✓	✗	Unity
NyARToolkit	24 May 2016	✓	✗	✗	✗	✗	✗	Unity
Tango	1 Mar 2018	✓	✗	✓	✓	✓	✓	Unity
Vuforia	1 Mar 2018	✓	✓	✗	✓	✓	✗	Unity
Wikitude	21 Feb 2018	✓	✓	✓	✓	✓	✗	Unity

Figure (3.5) Comparative study of the SDKs available to implement AR in mobile systems [4].

and freely available platforms ARKit, ARCore, and Vuforia.

ARKit and Vuforia provide 3D object tracking, but ARCore only provides 2D image tracking. Both ARCore and ARKit uses GPS and IMU for localization of the device but Vuforia does not use GPS sensors, it uses only IMU to provide AR experience. None of the three platforms provide dynamic occlusion feature. In the whole list, only ArUco and Tango provides occlusion. ARCore and Vuforia use SLAM for mapping, whereas the mapping technology for ARKit is not specified. ARCore and ARKit are SDKs from the biggest tech giants available free of charge. ARCore and ARKit platforms have their strengths and weakness, and it is difficult to differentiate which of them is better. Both the platforms are well suited to provide a good AR experience [59].

Chapter 4

ARCore: An Overview

This chapter will discuss the overview of ARCore describing the development environments, fundamental concepts, and a detailed study of features.

Before ARCore, Project Tango was an effort from Google to bring augmented reality to phones. Project Tango was introduced in 2014, and a couple of consumer devices were launched. These devices were optimized with extra hardware, a barometer for elevation, a dedicated motion-tracking camera, a dedicated infrared depth-sensing camera, a high megapixel camera to view the objects. In 2017 Google released ARCore a software-only AR solution that can work on many Android supported devices. ARCore only requires a color camera and does not need any extra hardware, which made Google shut down Tango in 2018 officially.

Tango uses its refined hardware to generate a 3D map of the designated area, which makes it more accurate in providing an AR experience. While ARCore works good in flat surfaces, Tango wins the race in mapping larger and irregular surfaces with a complicated environment. Even though Tango is better than ARCore, ARCore will be able to bring AR to millions of devices without the need for extra hardware. ARCore is designed to work on the android phones running Android 7.0 (Nougat) and later. The list of supported devices is listed in [60].

4.1 | Development Environments

ARCore provides SDK for popular development environments. These SDKs are capable of providing the basic features of ARCore. Some of them are listed below:

- **Android Studio:** Android Studio is the official Integrated Development Environment (IDE) for developing Android applications. ARCore was initially released with OpenGL, which was difficult for someone with basic graphics. Later Sceneform SDK was introduced to work with 3D scenes. With Sceneform, ARCore applications can be written as normal android applications in Java (or Kotlin) without having much knowledge in 3D graphics programming. Android Studio also offers the Native Development Kit (NDK) that allows using C, C++ with the studio.

- **Unreal Engine:** Unreal Engine is a game engine, supports for 2D and fully 3D rendered games. It provides full features for creating high-quality games across PC, mobile, VR, and AR. It uses Blueprint Visual Scripting technology, which allows creating games using the Blueprint only. The coding language is C++.

- **Unity:** Unity is also a game engine that gives the ability to create 2D and 3D games. The primary scripting language is c#, but it also supports UnityScript (javascript for Unity). It has easy to use tools and workflows with tons of optimizations features. It provides one-click deployment to different platforms. Unity works basically on scene that can be thought of as a level in the game, and each of the scenes can be designed with its environment, obstacles, and decorations.

Comparision: Unreal offers high-fidelity visuals than any other game engines, but it demands high processing power. Unity, on the other hand, enables to create complex projects on lower-powered devices [61]. Unity has better performance in developing 2D/3D games, whereas Unreal is suitable in developing highly graphical and photorealistic games [62]. Unity is more matured and provides lots of pro features like custom shaders. It is famous among graphics developers because of its simplicity and reusability.

Sceneform is relatively new and immature.

4.2 | Fundamental concepts

The fundamental concepts used in ARCore are discussed below. Together with these fundamental concepts, ARCore can provide an Augmented Reality experience. It is crucial to understand these concepts before using ARCore for building the applications.

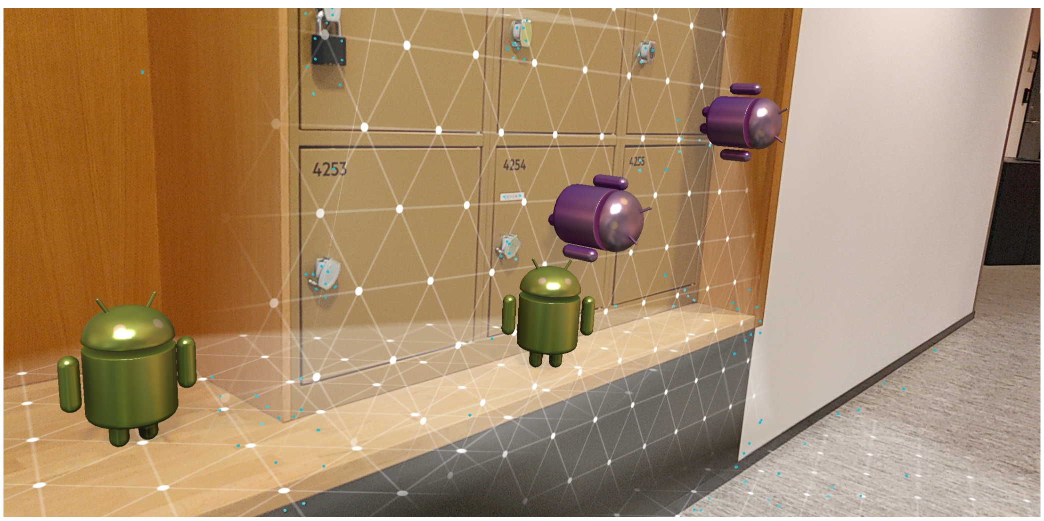


Figure (4.1) Figure represents the fundamental concepts of ARCore. The blue dots represent the feature points, white triangles represent the vertical and horizontal detected planes, green andy stand on the horizontal plane and purple andy stand on the vertical plane.

- **Pose:** Pose in ARCore describes the transformation from the object's local coordinate space to the world coordinate space. The transformation is defined using a quaternion rotation about the origin, followed by a translation [63].
- **Feature Points:** Feature points are the visually distinct features in images- for example, corners, edges. Every feature point has a unique fingerprint. These feature points are used in combination with the

device sensors to find out the device location in the space and estimate the pose [5].

- **Plane:** ARCore takes the images from the camera and detects the planar surface using image processing algorithms. These detected planar surfaces called planes could be used to anchor the virtual objects to the scene [64].

- **Hit Result:** It is the intersection between a ray and estimated real-world geometry [65]. ARCore runs a hit test from the (x,y) coordinate of the screen and returns planes or feature points intersected by this ray along with the pose of the intersection. This result is used to create anchors and attach virtual objects to the real world.

- **User Interaction:** ARCore uses hit testing to get the planes and feature points to the area user tapped on the mobile screen. It allows the user to select or interact with virtual objects in the environment [5].

- **Anchors and Trackable:** The anchor is the fixed location and orientation in the real world. The virtual objects are anchored to a fixed location in the real world, and this point is updated accordingly with the change in the pose of the device [5].

  Trackables are something that ARCore can keep track. Anchors are attached to trackable to ensure the relationship between the virtual objects and real objects remains stable [5].

  Anchors can be added to the scene, either using a trackable or the ARCore Session. Using trackable maintains the position of the virtual object to the trackable, and the same rotational effect is applied as trackable. Anchor added with ARCore Session lets the object to stay at the same pose in world space throughout the session [66].

- **Augmented Images:** Augmented Images in ARCore are the set of 2D images, which can form an image database. An augmented image is trackable. Each dataset can contain 1000 augmented images. The images in the database are distinguished using the feature points. ARCore can track up to 20 images simultaneously but cannot track moving images. Image dataset is present within the application, so an internet connection is not required for tracking the image. ARCore session has the instance of the database [67].

There are certain tips from the developers of ARCore to be followed for a good reference image. PNG, JPG, and JPEG image formats are supported. The image's resolution should be at least 300*300 pixels, and the image should have more details rather than images having repetitive patterns. Every image in the dataset has a score that determines the quality of the reference image. The score above 75 is recommended. The physical image should cover at least 25% of the device screen. [67]

ARCore uses three capabilities to understand the real world and provide AR experiences based on the information. The capabilities are discussed below:

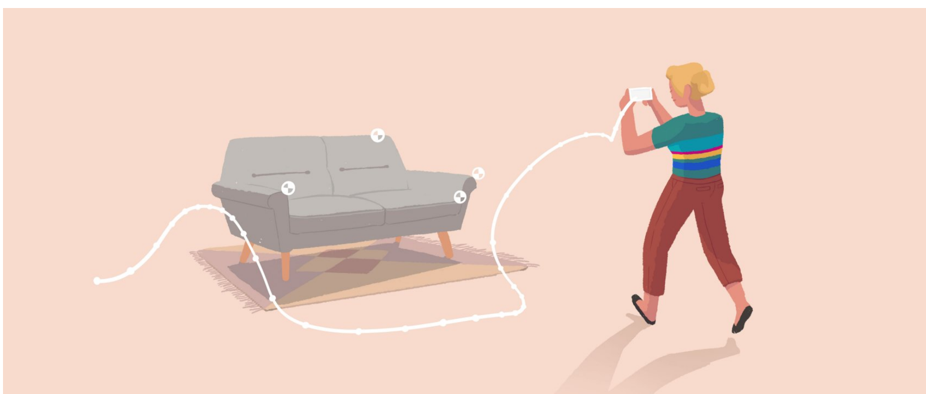


Figure (4.2) Motion Tracking in ARCore [5]

Motion tracking: ARCore uses a process called concurrent odometry and mapping (COM) to understand the position of the device in the real world. ARCore makes use of computer vision to get distinct feature points from the environment to understand and uses these points to compute its change in location. The visual information is combined with IMU from the device to estimate the pose of the device. The pose of the virtual camera is aligned with the pose of the device's camera provided by ARCore to render the virtual content [5]. This feature in ARCore helps in the calculation of position and size of the virtual object relative to the real world so that virtual objects seem a part of the real world.

Environmental understanding: ARCore is continually looking for clusters of feature points to improve its understanding of the real-world environment. Feature points play a vital role in understanding the environment. Flat surfaces without texture, such as a white wall are not detected correctly [5]. ARCore application uses this feature to place the virtual object onto the real-world surfaces.

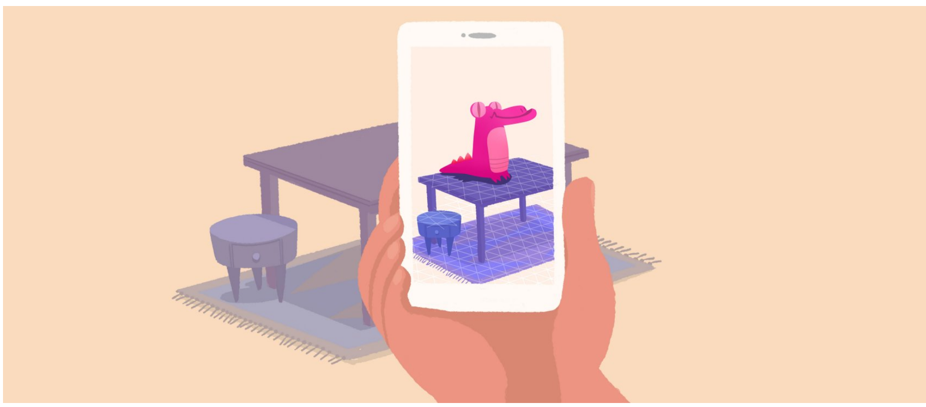


Figure (4.3) Environmental Understanding in ARCore [5]

Light estimation: ARCore can estimate the lighting conditions around the environment. This information allows adjusting the colors of the virtual objects under the same environment around them, increasing the sense of realism [5].

Figure (4.4) Light Estimation in ARCore [5]

4.3 | Studying the Features of ARCore

In this section, a detailed study with the functionalities of ARCore is done. An application is developed that is taking advantage of the described features in section 4.2. This application will be used to test the capabilities of the framework.

4.3.1 Visualizing Planes and Placing Objects

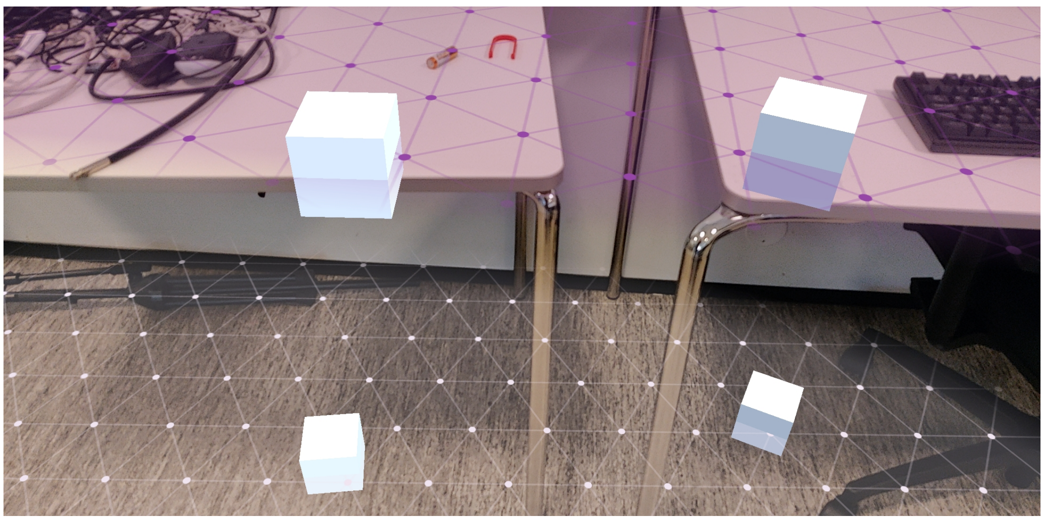


Figure (4.5) Figure represents the visualizing planes and placing objects.

It is a common feature used in AR applications such as Google camera playground, IKEA furniture. The application detects the planar surface around the environment, and the anchor is created with the detected trackable. The anchor is then used to hold the virtual object.

The *Frame.GetNewPlanes()* method provided by ARCore returns the list of reference to all newly detected planes from the current frame. The detected planes grow as ARCore understands the environment, and later, these planes are merged.

The sample application generates planes with different colors to differentiate between the planes making them more visible as shown in figure 4.5. An object is placed on the plane when the user taps on the screen. The application registers the touch event generated by the user, and a raycast is performed on the plane from the touch position. This action is performed by *Session.Raycat()* method of ARCore SDK. As a hit with the plane is detected, the method returns *true* and stores the information about the hit point. This information is used to create an anchor. The virtual object is glued with the anchor, which ensures the object retains its physical location in the real world.

The speed of detection is incredible when the plane has many detailed structures. It was difficult to detect the planes when they had fewer details. The planes are sometimes more extensive than the real plane and at a different height. The height of the planes was incorrectly determined most of the time. Placing an object in the real world is also good enough. The tracking of the object was impressive.

The major limitation of this approach is that the planes cannot be detected at a far distance. During the experiment, the planes were detected at a distance of 4 to 5 meters. It allows creating an anchor within the short-range, which limits to place an object at far distant. This procedure is suitable for the situation where the virtual objects are near to the device camera or user.

4.3.2 Light Estimation

ARcore SDK provides a prefab for environmental light. In general, the prefab reads the estimated light from the environment and saves it called as *GlobalColorCorrection*. The value can be used by the shaders to adjust the color of the object's surface.

In the sample application, *Environmental Light* prefab is included in the scene which contains *EnvironmentLight.cs* script, responsible for reading the light estimate from the frame. *DiffuseWithLightEstimation* shader provided by ARCore use the value from the *GlobalColorCorrection* and assigns the intensity of light to shade the virtual object.

The light estimation feature in ARCore helps to make the overall impression of the scene more realistic. Only one *GlobalColorCorrection* is provided for the entire scene. The object shader can be adjusted in a whole scene, not to the specific position of the virtual object in the scene. The figure is shown in 4.4 is the official picture of light estimation from Google, but in reality, it is not possible to have two different shaders for two different objects in the same scene.

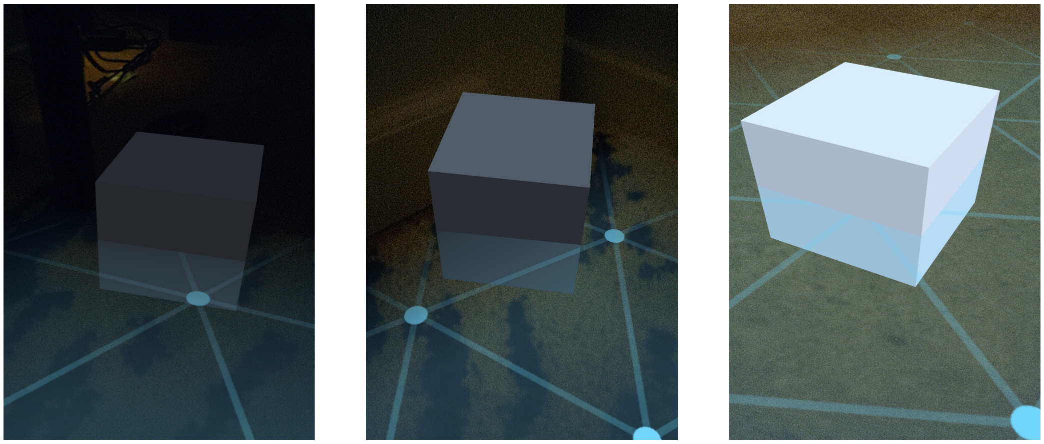


Figure (4.6) A cube at different lightning environment.

4.3.3 Using Augmented Image

Fiducial marker is known as Augmented image in ARCore described in Figure 4.2. ARcore provides the location of these images in the real world, which can be used to track any object associated with the images. Mostly the virtual objects are placed on top of the images, but in some cases, the virtual objects can be kept apart from the images. It is important to test both cases to get a clear idea.

Object on top of the image: To test the first case, an application was designed to appear a virtual object on top of the image when the image was detected.

The image was placed both on the vertical and horizontal planes. The distance between the camera and image depends upon the size of the image. The image should cover at least 25% of the screen in normal environments. The experiment was conducted in a good lightning room. The size of the image used was 10*10cm, and the distance between the camera and image was 40cm.

The image detection was fast, and tracking of the object was impressive. The object did not respond to the movement of the image when the object was fixed to a position. The image was rescanned to move the object to the new position by changing the position of the image to the desired position. The object was tracked even the image was not visible on the screen. The coverage of the tracking was good in the room of 10*10m dimension. Sometimes the tracking was lost in short distance, and the reason was unknown. ARCore was able to track 5-6 pictures at the same time when placed close to each other.

Object away from the image: In the second case, the object was put at a distance apart from the augmented image. There can be two cases while creating the anchor after the image is detected. The anchor can be created at the position of the image or the position of the virtual object. There was no difference in the result with both the cases, so both of the methods are suitable.

To measure the accuracy, a cube with the size of the box was made and kept at a distance of 4m to the left side of the image and 2m behind the image and 20cm below the image on the table. The goal was to cover the entire box with the virtual cube. From the far distance, the object seemed to cover the box, but when the object was rendered from the near distance, there was a difference in the position of the real-world box and the virtual cube. The position of the virtual cube had some displacement in the random direction in every experiment, which was not predictable. Apart from that, the tracking was excellent even in the broad area.

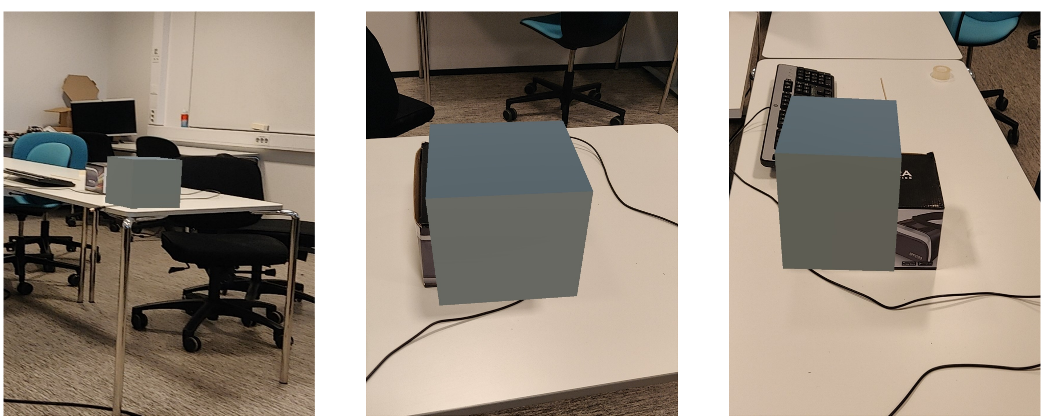


Figure (4.7) Viewing the cube from different angles, placed at a distance from the augmented image.

The object can also be placed at a distance independent of the image. The image was only used to trigger the event to make the virtual object appear. The anchor was created at a certain distance without attaching to the image. In this case, the position of the device acts as the origin, and the object depends on the position of the device rather than the position of the image. The object is stable in this approach, but the difficulty is that the device should always be at the same distance from the image with the same rotation value to get the object in the same position in every scan of the image. The device is used by the user where the precision cannot be expected due to human error.

Using Multiple Augmented Images: When the object has to be placed at a very far distance from the augmented image, it involves tracking over the vast area. There is a chance of losing the position or tracking of the virtual object while moving towards the object. Therefore multiple augmented images can be placed at different positions between the first image and the virtual object so that the user does not have to return to the image to re-scan and get the object back into the position. The images in different positions provide the location information of the virtual object from the image so that the object can be placed in the original location.

To test this method, an object was placed 200 meters away on the right side of the first image. Every 50 meters, a new image was placed, which provided a position of the object relative to itself, i.e., the second image placed the object 150 meters away on the right side. While the object was far from the device position, there was a displacement of position when moving towards the object. The new image was introduced to put the object back to the original position. The experiment was successful as intended.

This approach is suitable to use when the objects have to be placed at a very far distance from the image.

4.4 | Summary

ARCore is suitable for getting most of the basic AR experiences. Since ARCore is relatively new, there are many areas where improvements can be made. The platform is actively updated fixing the issues and adding new functionalities in every release, so the impression of the unfinished product will pass away soon [59].

ARCore is focused on providing the services cross-platform and make shared AR experience more easy and reliable. Google's Cloud Anchors API lets the user share the experience among each other across Android and iOS. Previously it was limited to 24 hours time period, but in the recent announcement, it is working to provide a *AR save button*, which can save the experience indefinitely. The ARCore is also rolling out new features such as *Augmented Faces* [68].

Chapter 5

Application Development

After the study of AR and investigation of ARCore features, this chapter will discuss the steps involved in the development of an application utilizing AR functionality for Fjell fortress.

The problems in Fjell Fortress are described in subsection 1.2.1. The application will provide the features as the solutions to these problems. The features of the application are discussed as:

- **Reconstruct the Past:** This feature is designed to reconstruct the past by supplementing reality with virtual models. In the application, the 3D objects from the past are superimposed in the real world that has been removed or changed at present. This feature will recreate the past and allow visitors to see what is impossible to view now.
- **Outdoor Guide:** The second feature in the application is to provide a guide to the visitor and meet a character at the spot. There are lots of spots to visit on the site. This feature will describe the spots so that the visitor gets to know the story. It will also put an animated character on the spot to tell a story.
- **Indoor Guide:** This feature provides indoor guidance to a visitor while inside the tunnels. The underground tunnels have a complex structure and are spread over a large area. Due to which the visitor is confused and gets disconnected from the overall story of the fortress.

The development of the features mentioned above is described in the upcoming sections in detail.

5.1 | Reconstruct the Past

To reconstruct the past, the virtual objects from the past are placed in the real environment in the exact location where the artifact was present in the past, or the incident had happened. To place the 3D virtual object in the desired position the possible options are to use *HitResult*, marker-based AR and location-based AR.

When the user clicks the screen, ARCore returns the *HitResult*. A *HitResult* is either a plane or a feature point, and this information is used to create an anchor. It allows the user to place the object anywhere in the environment after the planes are detected. However, in the application the object has to be present in the specified location without relying on the user, which makes it not suitable.

As described in section 3.5, marker-based AR has the advantage of accurately overlaying the object in the environment. However, location-based AR is more scalable and does not rely on markers. To superimpose the real object with the virtual object, accurate positioning is an essential factor. So the markers are used in the application to supplement reality and reconstruct the past. The markers are called Augmented Image in ARCore described in Figure 4.2.

The 3D models to be used in the fortress are big, which makes it challenging to place the objects on top of the markers. For example, the cafeteria has to be replaced by the giant cannon from the past. Placing a marker on the cafeteria and scanning the marker and getting the view of the cannon is not possible. To get the complete view of the cannon, the marker has to be placed a few meters away from the cafeteria. Then the 3D structure of the cannon in the exact position can be observed from a distance. After the cannon appears in the real world, the user can go near and render the cannon from outside and inside. The positioning of the object away from the image using ARCore is described in subsection 4.3.3.

A scene was created in unity. ARCore SDK for unity provides *ARCore*

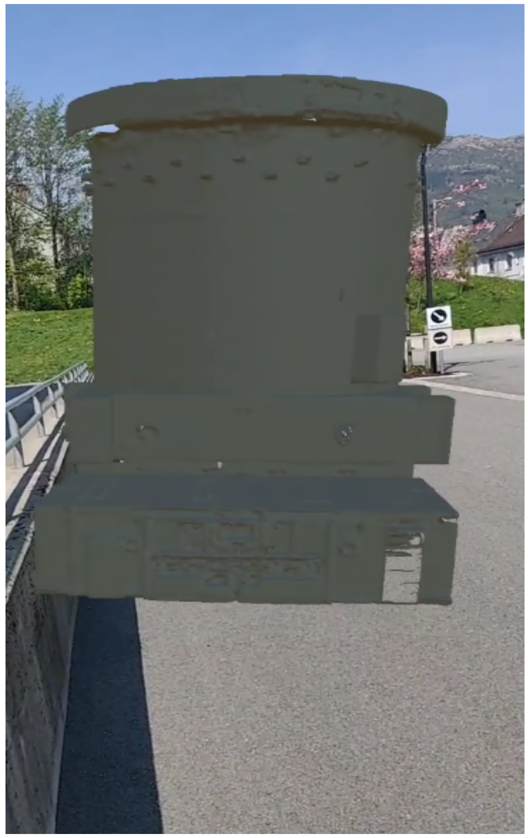


Figure (5.1) A model from the Fortress positioned in the real world.

Device and *Environmental Light* for building the AR applications. *ARCore Device* creates and initializes an *ARCore session*. It provides a background renderer to the unity camera. It is also responsible for requesting the user to grant permission for using camera in the application. *ARCore Device* has two sub-components *ARCore Session* and *First person camera*.

ARCore Session is responsible for handling AR system state and session lifecycles. The session is assigned with the image database to keep track of the images. *ARCoreSessionConfig* holds the settings that are used to configure the session.

First person camera is the window to the real world augmented with virtual objects. The attached *ARCoreBackgroundRenderer* uses the camera of the device to get images of the real world and provides a background to the AR scene. The attached *TrackedPoseDriver* updates the first-person camera's position and rotation to match the real camera pose.

Environmental Light prefab is used to adjust the lighting of the virtual object in the AR scene concerning the real environment.

A C# script *SceneController keeps* track of images and checks the state in each frame. The script is responsible for performing the actions in the scene. After ARCore detects an image in the scene, an anchor is created. The anchors keep track of the attached object.

5.2 | Outdoor Guide

The museum is spread over a large area, and there are lots of areas that carry a part of the story of the past. It is essential to visit all the spots and get the information to understand the story of the Fjell Fortress. The outdoor environment is large, and the use of marker-based technology is not feasible. Although marker-based technology is accurate in positioning the objects, it is not scalable to a large area. Location-based AR will be used to superimpose the supplement information in the real world. A challenge with location-based AR is to position the object precisely.

Figure (5.2) Screenshot of an animated character.

This feature, therefore, is used to provide the general information of the area where accuracy is not a crucial factor. The icons on the screen in the respective direction of the spot guides the user to the desired spot. After the user is in a spot, the location information is used to place a virtual animated character in the area as shown in figure 5.2. This gives an exciting and engaging factor to the user to learn about history.

A scene was created and the prefabs from the Mapbox SDK for unity is used. Mapbox is used to get real-world map data and convert the GPS positions into unity coordinate space. *Abstract Map* is an abstract base class provided by mapbox which controls the visualization of map data. It encapsulates the image, terrain, and vector sources and provides a centralized interface for controlling the visualization of the map. Mapbox uses a *SimpleAutomaticSynchronizationContext* to align the map with the position of the AR camera. *SimpleAutomaticSynchronizationContectBehaviour* is a wrapper around the context which allows specifying settings in the inspector. It is responsible for listening location updates from location provider and adding synchronization nodes to the context. *DeviceLocationProvider* object provides the location reading of the device. SPawnOnMap script takes the world coordinates and maps to unity coordinates to place a virtual object in the specified location.

5.3 | Indoor Guide

Location-based AR uses GPS positions, but the unavailability of good GPS signals inside the tunnels [69] results in need to find a good solution for indoor navigations. Several applications have been developed and proposed using different sensors and radio signals such as WiFi signals, Bluetooth beacons, NFC, RFID. The problems with these techniques are the need for more sensors to be deployed, the need for regular maintenance and difficulty in using for users.

ARCore is enabled with motion tracking capability, which can be used to track the position of the device. Motion tracking explained in 4.2 provides the pose of the device. The change in the pose value can be used to illustrate the position of the device on the map graphically.

An image of the floor plan was used as a map to navigate. The relationship between any distance between two points on the map and the correspondent distance in the real-world should be 1 to 1. The map was scaled to the real-world scale. It guarantees that the distance covered in the physical world is the same on the map. A 3D sphere was placed at the starting point. The device should be in the same position before the tracking starts. This point can be manually set on the map, or markers can be used to initialize the starting point. The markers will tell the application where the device is on the map, and this point can be used as the starting point.

A c# script was written to get the pose in every frame update. The delta position was calculated in every frame, and this translation was used to move the sphere on the map. The translation was only applied to X and Z-axes because the tracking was done on the XZ plane, and any changes to Y-axis would make the pointer move below the plane.

To test the usability of this feature, a model of the floor is made and used as a test location shown in figure 5.3.

Figure (5.3) Screenshot of indoor guide.

Chapter 6

Discussion

This chapter will discuss the overall experience in developing the features of the application. It will describe the challenges faced while using AR technology. A user study at the end of the chapter will provide the effectiveness of the application.

6.1 | Development of the Application

Before developing the application, the features of AR framework was studied. The study helped to get in-depth knowledge of the functionalities to use while developing the features. Three features were developed for the application, each dedicated to solving a problem of the Fortress. This section provides the discussion of each feature developed.

Reconstruct the past: To reconstruct the past, markers were used to place an object in the intended position. Although the positioning of the object was accurate, the markers were vulnerable to different lighting conditions, and tracking speed was dependent on the type of image used. The change in position of the image leads to the change in the position of the virtual object.

The markers are best suitable for indoor and controlled environment. They are accurate in positioning the objects in the small and fixed space where the objects are small and can be placed on top of the marker itself.

Outdoor Guide: The outdoor environment is large and has lots of uncontrolled factors. Location-based AR was chosen because of its advantage in scalability. It does not require any manual work, which makes it user-friendly and easy to use. However, it needs an internet connection to get location information. The disadvantage of using this technology is that the accuracy depends on the sensors of the device. Getting the accurate orientation value using the earth's magnetic field is problematic in the mobile device since its electronics are interfering [69].

In the application, this feature was used to give the direction and the location information of the POI. The visitor also meets a character when reaching the spot. The character can be a soldier or a local to tell the story.

Indoor Guide: The tracking was impressive in the environment with good lighting and lots of details. The tracking was lost when the camera was covered and low lightning. It did not work good in the environment with repetitive patterns like walking in the corridor. The overall experience with this feature was good but in a small and controlled environment. This feature will not serve useful in the tunnels of the museum because of the low lightning conditions and lack of details. However, this feature can be used for other purposes in controlled environment.

6.2 | Challenges

AR has opened a wide range of opportunities to build interactive applications. The task of combining the real and virtual is more critical than the VR system, where the user is immersed in the virtual environment. With the increase of the AR market, lots of vendors are providing their solutions through the development of SDK. Due to the competition in marketing, they present the videos and descriptions to impress the users. This leads the users to get the misconception of the technology, which, in reality, is not possible to develop using the frameworks. The full potential of AR still faces many technical challenges. Some of the challenges experienced while developing the application are discussed below.

Estimation of Light Lightning is a difficult phenomenon to study in the real world. It is challenging to estimate the source light and light direction in the real world due to limited available resources. The detailed study is described in subsection 4.3.2.

Accuracy The accuracy of pose estimation is an essential factor for registering the virtual object in the real world. A small error in the registration of the object breaks the sense of realism. The error in registration makes the virtual objects look floating around the real objects. More accurate registration is needed in AR than VR because it is easily detectable when there is any inaccuracy in aligning virtual objects with the physical world. The marker-based approach can provide some accuracy, but it is not scalable in large scenarios.

Occlusion Occlusion is the ability to hide virtual objects by real objects. If the geometry of the virtual object is not hidden behind the real-world objects when it should be, the illusion of reality is broken. The device should be able to sense 3D information from camera (2D) images. Considering this as a hard problem, many researchers are working to solve it [70].

6.3 | User Survey

Although the application was not completed and evaluated among the visitor but to get the impression of the features developed, a small online survey was conducted. The online document with some questions was created and shared in the social media group, where the users within the group were able to read and provide feedback. The members of the group were mostly the students and researchers doing an online survey.

The content in the online document starts with the purpose of the survey, followed by some questions. Then the problems of the Fortress were described along with the short introduction. A definition of AR was also provided for those who were unaware of the technology. After the features of the application were discussed, some questions were provided for the reader to provide feedback. In the end, two comment boxes for a suggestion of any other feature and comments were provided. The online document provided to the readers is in Appendix C.

Sixteen people participated in the survey aged between 22 and 35. The people who participated visited a museum at least once a year. All the sixteen participants had a smartphone and were comfortable to use it while visiting the museum. However, only ten people reported to have a smartphone supporting AR, and five people did not know about it. Twelve people in the survey were aware of the AR technology.

The feedback was dependent upon the description of the application; therefore, it was essential to know the clarity of it. Most of the readers rated with 4 and 5 stars out of 5 for the description. Even though all the participants were positive with 5, 4, and 3 stars out of 5 rated by 8, 7, and 1 number of people respectively, that the application would enhance the visit to the museum, but one participant denied to use the application while visiting. Finally, some comments and suggestions to include other features in the application were also provided by the readers.

Suggested features are:

- *Higher resolution graphics would make it more interesting.*
- *Push notifications informing fascinating facts about the Fortress once the user reahes areas in the Fortress. (Push notifications mapped with geolocation perhaps?)*
- *How about sharing option in social media*

Comments for the applications are:

- *I would like to use this application on my phone to get AR exprience.*
- *Loved the concept and may be I will use it when i visit.*
- *Its a good project and it may help to get more easier in measum.*
- *Sounds like a very interesting way to navigate through a fortress with a history.*

Chapter 7

Epilogue

7.1 | Conclusion

This thesis work aimed to develop a mobile application investigating the use of AR at Fjell Fortress. From the background study, the need for AR in historical museums was highlighted. The in-depth study of the AR framework provided knowledge about the capabilities of the technology, which helped in the development of the features of the application. During the work of the thesis, three different features to reconstruct the past, outdoor guide, and indoor guide using AR is developed. Although the development of the application was not completed, an online survey based on the description of the features developed was conducted.

In summary, the study conducted shows that AR technology has the potential to be further used in historical sites. It is because of the advantages and beneficial use of AR to engage visitors and enhance their visit. These good responses are important because they indicate the willingness of visitors to use the application during the visit.

Despite the growing popularity of AR and the advancement of technology, there are several challenges and limitations currently in using the technology, which is discussed in section 6.2. When the potential of AR technology is fully explored, the beneficial functions of AR can be used widely in providing even better solutions.

7.2 | Future Work

With the exponential spread of AR devices and research work carried out for the development of computer vision and other technologies, the future of virtuality and integration with the physical world is promising. The work presented here is a small step to make use of AR in visiting the historical museum. Based on the result of the study, the application has a good impression among the readers and greater usability in historical sites. It motivates further research and development of the application.

Firstly, future work is required to complete the development of the application that can be used at Fjell Fortress. Research can be done in making the application more adaptable to the environment. Additionally, the research can be carried out on the different features of the application. Further evaluations would need to be performed after the application is sufficiently developed to gather more insight into the users' opinions.

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Appendix A

Application Setup

A.1 | Requirements

A.1.1 Hardware

- An Arcore supported phone.
- A USB cable to connect the phone to the device.

A.1.2 Software

- Unity 2017.4.15f1 or later with Android build support during installation.
- Android SDK 7.0 or later.
- ARCore SDK 1.6.0 or later.

The features of PC that is used in developing the application. It is not mandatory to have the following requirements.

- OS : windows 10 Home 64-bit
- Processor : Intel(R) Core(TM)i7-7700k CPU @ 4.20GHz

- RAM : 32867 MB
- Graphics : NVIDIA GeForce GTX 1080 Ti
- Graphics memory : 27441 MB

A.2 | Setting up the Unity project for ARCore

A 3D project is created in Unity and the path for the Android SDK is set **Unity>Preferences>External Tools**. ARCore SDK is also imported **Assets>Import Package>Custom Package**, provides some sample applications to test how the technology works.

Load the scenes in the project and select the scene to install in the device and switch the platform to android **File>Build Settings**. Use "Player Settings" to change the options:

- Other Settings > Multithreaded Rendering : **off**
- Other Settings > Package name : **a unique app ID**.
- Other Settings > Minimum required API level : **7.0**
- Other Settings > Target API level : **7.0** or **highest installed**
- XR Settings > ARCore Supported.

Appendix B

Pictures of fortress

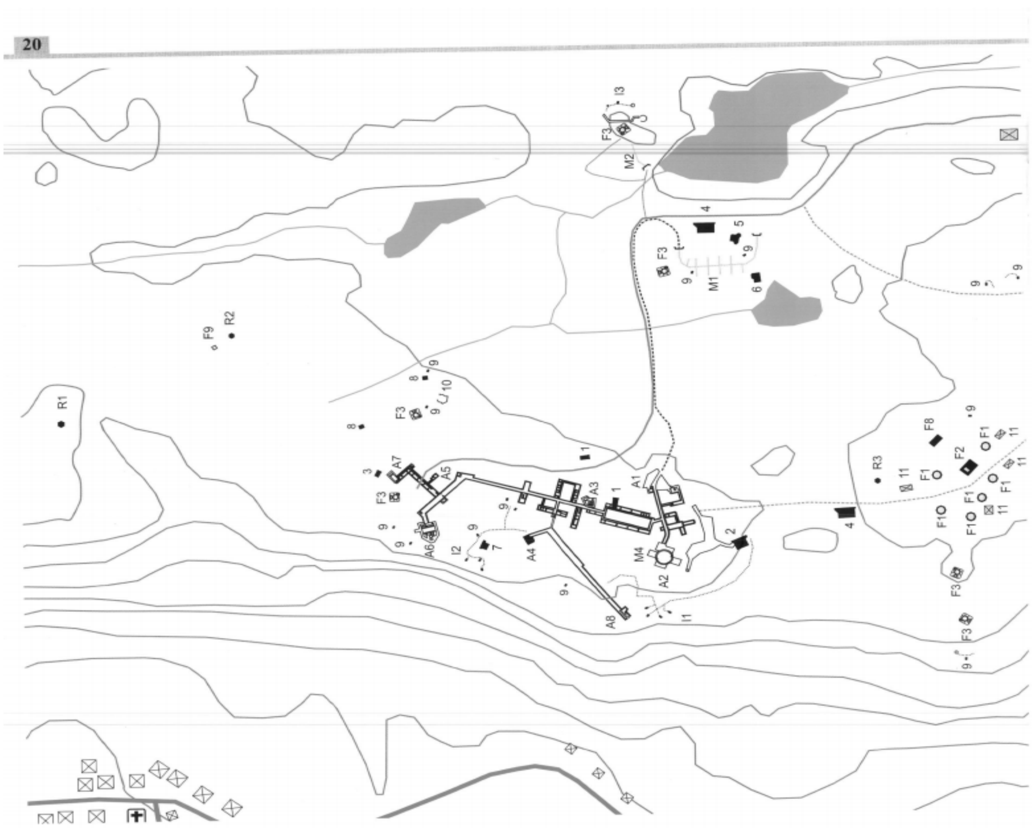

Figure (B.1) Detailed map of the fortress

HOVEDTUNNEL
A1 - Hovedinngang
A2 - 3 x 28 cm kanontårn
A3 - MG SK maskingeværbunker
A4 - R 633, tilknyttet hovedtunnelen
A5 - 35P8 kuppel for to MG, tilknyttet hovedtunnelen
A6 - S 446, tilknyttet hovedtunnelen
A7 - SK Inngang nord
A8 - SK Inngang vest
BATTERISIKRING
01 - 2 x R 672 Pakgarasjer
02 - R 629SK tilknyttet tunnel og observasjonskuppel
03 - Bunker
04 - 2 x R 638 sanitetsbunkere
05 - R 632 for MG
06 - 2 x R 633
07 - R 621
08 - 2 x R 668
09 - Rs 58
10 - Byggegrop
11 - Brakkefundamenter/grunnmur
AMMUNISJON
M1 - Ammolager med to inn-/utganger og nærforsvar
M2 - Ammolager
M3 - Ammolager, U-formet
LUFTVERN
F1 - 6 x Stillinger for 10,5 cm Flak
F2 - Avstandsmåler
F3 - 6 x Fl 242
F4 - 2 x stillinger for lyskaster eller lett luftvern
F5 - R 622 med stilling på taket
F6 - Feltmessig forsterket ammolager
F7 - Garasje
F8 - Strømforsyning/aggregat
F9 - luftvernstilling (nord)
RADARSTILLINGER
R1 - Würzburg Riese / FuMo 214
R2 - Freya Freiburg, med "Radattel" peiler / FuMO 303
R3 - Würzburg Dora / FuMO 213
INFANTERISIKRING
I1 - Løpegraver med 2 x Rs 58 + 2 x Rs 61
I2 - Løpegraver med 5 x Rs 58 + 1 x Rs 61
I3 - Liten tunnel, kanonstilling og løpegraver
med 2 x MG-stillinger + Rs 58
I4 - Løpegraver med 4 x Rs 58 + 2 x Rs 61 + MG-stilling
I5 - Løpegraver med 3 x Rs 58 + 1 x Rs 61 + 1 x mannskapsbunker

MAIN TUNNEL SYSTEM
A1 - main entrance
A2 - triple gun turret
A3 - MG bunker with steel plate
A4 - R 633 with emergency exit
A5 - 35P8 steel turret for two MG
A6 - S 446 fire control bunker
A7 - Exit north
A8 - Exit west
MAIN BATTERY DEFENCE
01 - 2 x R 672
02 - R 629 connected via a tunnel to an observation cupola
03 - 2 x Fl 242 light AA gun bunkers
04 - 2 x R 638 first aid bunker
05 - R 632 bunker for one machine gun in a steel turret
06 - R 633 for grenade launcher M19
07 - R 621 crew shelter
08 - 2 x R 668 crew shelter
09 - Rs 58
10 - Building area
11 - Barrack foundations
AMMUNITION DEPOT
M1 - U-shaped underground system with two entrances
M2 - ammunition
M3 - U-shaped underground system
HEAVY AA BATTERIY
F1 - 6 open emplacements for 10.5 cm SKC/32 guns
F2 - Fire control post
F3 - 2 x Fl 242 light AA gun bunkers
F4 - 2 x searchlight position
F5 - R 622 with emplacement on the rooftop
F6 - Vf ammunition bunker
F7 - Garage
F8 - Power generator
F9 - AA emplacement north
RADAR
R1 - Würzburg Riese / FuMo 214
R2 - Freya Freiburg, with "Radattel" detector / FuMO 303
R3 - Würzburg Dora / FuMO 213
INFANTRY DEFENCE
I1 - Trench system with 2 x Rs 58 and 2 x Rs 61
I2 - Trench system with 5 x Rs 58 and 1 x Rs 61
I3 - small underground system, emplacement for anti tank gun,
trench system 1 x Rs 58 and 2 x MG position
I4 - trench system with 4 x Rs 58 and 2 x Rs 61and 1 x MG position
I5 - trench system with 3 x Rs 58, 1 x Rs 61 and a small crew shelter

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Figure (B.2) Data about the map from B.1

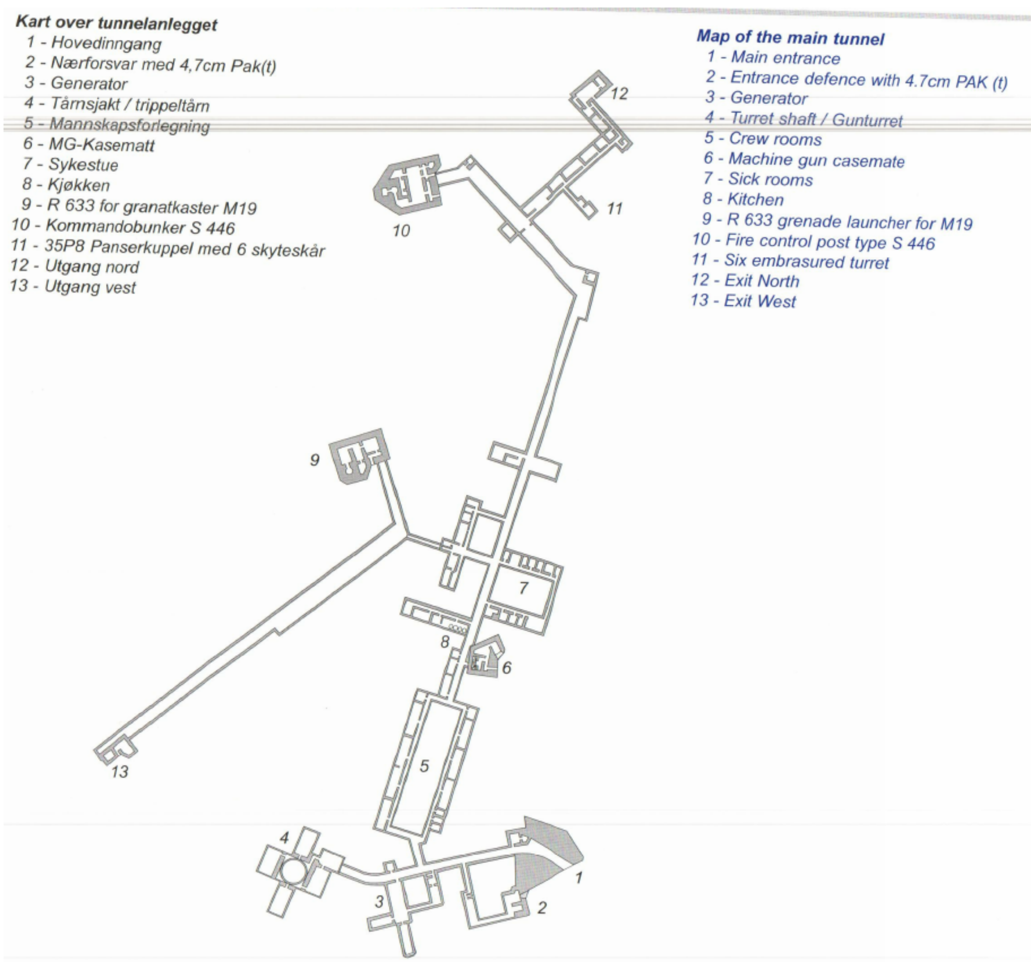

Figure (B.3) Map of tunnel

Appendix C

Online survey

C.1 | Online document

Review of a mobile Application

Hello Reader,
I am sending this document to you to get some feedback on a mobile phone application that I am building as a part of my master's thesis. The application will help to enhance the visitors' experience during the visit to the museum. This document will describe the features the app will have.

This survey will provide me the data in evaluating my thesis work.

There are some questions before the description and some questions after the description.

Please provide the answer to the questions.

Age *

How often do you visit museum? *

- Never
- Once a Year
- Once in six months
- Once in quarter year
- Once in two months
- Once in a month
- More than once a month

Do you know about Augmented Reality (AR)? *

- Yes
- No

Do you own a smart phone? *

- Yes
- No

Does it support Augmented Reality (AR)? *

- Yes
- No
- Don't Know

Are you comfortable to use your device while visit to museum? *

Yes

No

Definition of Augmented Reality (AR):

In general terms, AR is viewing the real world on the mobile screen through the camera device with additional virtual information.

Description of the site:

The site is Fjell fortress. It is on top of Fjedlafjedlet Mountain, in Fjell municipality (Norway). It is an impressive underground military base. It has an underground network connecting kitchens, medical centers, workshop, washing facilities, and communication centers. The front wing contains the railway tracks, military equipment ventilation systems, and advanced electrical installations.

- It is an old site, so most of the things are changed or removed from the original place. For example, there was a big cannon in the fortress which was used to defend Bergen from the west sea, and now it is replaced by a cafeteria. The cannon is the vital part of the story of the fortress.
- The site is spread over a large area. There are different bunkers and monuments with a different story to tell in the site. It is impossible to visit all these spots and learn the story without a proper guide.
- The main exhibition is underground. It has an underground complex spread over the area. The underground network has different connections to outside. Without proper guidance, it is difficult for a visitor to understand the structure of the whole fortress.

The features are developed to address the problems faced while the visit to the site.

The features the application provides are:

- The application uses AR to replace the object from the real world with the virtual object. For example, the cannon from the fortress was removed, and a cafeteria is built, this feature will help to see a cannon from the past on top of the cafeteria on the mobile screen. This will also let the user go around the cannon and get the feeling of how enormous the cannon was and many more things. The user has to open the application and point the camera to an image. After the successful scanning of the image, the user can start looking around to see different virtual objects on top of the real world.
- With the other feature available, it will help the visitor to visit and learn the story of all the spots in the area without the help of a guide. The mobile phone will act as a personal guide. The user has to open the application and see around through the screen, based on the location the spots are shown on the mobile phone screen in the respective direction. This allows the user to navigate to the place he/she wants to go. The feature is used to provide the location and general information of the spot.
- The last feature the application provides is indoor navigation. It uses the map from the fortress and locates the visitor on the map. When the visitor is inside the tunnels GPS signal fails to provide the navigation where this feature comes into action. With this feature, the user can connect him/her self to the fortress and have an overall understanding of the fort.

How would you rate the description I have provided about the application? *

1 2 3 4 5

How much would you rate for the application with these features? *

1 2 3 4 5

Not Clear Clear

Worst Best

Do you think an application with these features would enhance your visit to the museum? *

Yes

No

Would you use this application while visit to museum? *

Yes

No

What other feature in the application would make it interesting?

Final Comments

C.2 | Feedback

Review of a mobile Application for a historic site

Age	29
How often do you visit museum?	Once in quarter year
Do you know about Augmented Reality (AR)?	Yes
Do you own a smart phone?	Yes
Does it support Augmented Reality (AR)?	Yes
Are you comfortable to use your device while visit to museum?	Yes
How would you rate the description I have provided about the application?	5/5
How much would you rate for the application with these features?	5/5
Do you think an application with these features would enhance your visit to the museum?	Yes
Would you use this application while visit to museum?	Yes
What other feature in the application would make it interesting?	Higher resolution graphics would make it more interesting.
Final Comments	I would like to use this application on my phone to get AR exprience.

Review of a mobile Application for a historic site

Age	35
How often do you visit museum?	Once in quarter year
Do you know about Augmented Reality (AR)?	Yes
Do you own a smart phone?	Yes
Does it support Augmented Reality (AR)?	Yes
Are you comfortable to use your device while visit to museum?	Yes
How would you rate the description I have provided about the application?	5/5
How much would you rate for the application with these features?	5/5
Do you think an application with these features would enhance your visit to the museum?	Yes
Would you use this application while visit to museum?	Yes

Review of a mobile Application for a historic site

Age	25
How often do you visit museum?	Once in two months
Do you know about Augmented Reality (AR)?	No
Do you own a smart phone?	Yes
Does it support Augmented Reality (AR)?	Don't Know
Are you comfortable to use your device while visit to museum?	Yes
How would you rate the description I have provided about the application?	4/5
How much would you rate for the application with these features?	4/5
Do you think an application with these features would enhance your visit to the museum?	Yes
Would you use this application while visit to museum?	Yes
Final Comments	Loved the concept and may be I will use it when i visit.

Review of a mobile Application for a historic site

Age	30
How often do you visit museum?	More than once a month
Do you know about Augmented Reality (AR)?	Yes
Do you own a smart phone?	Yes
Does it support Augmented Reality (AR)?	Yes
Are you comfortable to use your device while visit to museum?	Yes
How would you rate the description I have provided about the application?	4/5
How much would you rate for the application with these features?	4/5
Do you think an application with these features would enhance your visit to the museum?	Yes
Would you use this application while visit to museum?	Yes
Final Comments	Its a good project and it may help to get more easier in measum.

Review of a mobile Application for a historic site

Age	27
How often do you visit museum?	Never
Do you know about Augmented Reality (AR)?	Yes
Do you own a smart phone?	Yes
Does it support Augmented Reality (AR)?	Yes
Are you comfortable to use your device while visit to museum?	Yes
How would you rate the description I have provided about the application?	3/5
How much would you rate for the application with these features?	4/5
Do you think an application with these features would enhance your visit to the museum?	Yes
Would you use this application while visit to museum?	Yes
What other feature in the application would make it interesting?	Push notifications informing fascinating facts about the fortress once the user reahes areas in the fortress. (Push notifications mapped with geolocation perhaps?)
Final Comments	Sounds like a very interesting way to navigate through a fortress with a history.

Review of a mobile Application for a historic site

Age	25
How often do you visit museum?	Once a Year
Do you know about Augmented Reality (AR)?	Yes
Do you own a smart phone?	Yes
Does it support Augmented Reality (AR)?	Yes
Are you comfortable to use your device while visit to museum?	Yes
How would you rate the description I have provided about the application?	3/5
How much would you rate for the application with these features?	3/5
Do you think an application with these features would enhance your visit to the museum?	Yes
Would you use this application while visit to museum?	Yes

Review of a mobile Application for a historic site

Age	25
How often do you visit museum?	Once in six months
Do you know about Augmented Reality (AR)?	No
Do you own a smart phone?	Yes
Does it support Augmented Reality (AR)?	Don't Know
Are you comfortable to use your device while visit to museum?	Yes
How would you rate the description I have provided about the application?	4/5
How much would you rate for the application with these features?	4/5
Do you think an application with these features would enhance your visit to the museum?	Yes
Would you use this application while visit to museum?	Yes
What other feature in the application would make it interesting?	How about sharing option in social media 😍

Review of a mobile Application for a historic site

Age	28
How often do you visit museum?	Once a Year
Do you know about Augmented Reality (AR)?	Yes
Do you own a smart phone?	Yes
Does it support Augmented Reality (AR)?	Yes
Are you comfortable to use your device while visit to museum?	Yes
How would you rate the description I have provided about the application?	4/5
How much would you rate for the application with these features?	4/5
Do you think an application with these features would enhance your visit to the museum?	Yes
Would you use this application while visit to museum?	Yes

Review of a mobile Application for a historic site

Age	30
How often do you visit museum?	Never
Do you know about Augmented Reality (AR)?	Yes
Do you own a smart phone?	Yes
Does it support Augmented Reality (AR)?	No
Are you comfortable to use your device while visit to museum?	Yes
How would you rate the description I have provided about the application?	5/5
How much would you rate for the application with these features?	5/5
Do you think an application with these features would enhance your visit to the museum?	Yes
Would you use this application while visit to museum?	Yes

Review of a mobile Application for a historic site

Age	35
How often do you visit museum?	Once a Year
Do you know about Augmented Reality (AR)?	No
Do you own a smart phone?	Yes
Does it support Augmented Reality (AR)?	Don't Know
Are you comfortable to use your device while visit to museum?	Yes
How would you rate the description I have provided about the application?	5/5
How much would you rate for the application with these features?	5/5
Do you think an application with these features would enhance your visit to the museum?	Yes
Would you use this application while visit to museum?	Yes

Review of a mobile Application for a historic site

Age	29
How often do you visit museum?	Once a Year
Do you know about Augmented Reality (AR)?	Yes
Do you own a smart phone?	Yes
Does it support Augmented Reality (AR)?	Don't Know
Are you comfortable to use your device while visit to museum?	Yes
How would you rate the description I have provided about the application?	4/5
How much would you rate for the application with these features?	4/5
Do you think an application with these features would enhance your visit to the museum?	Yes
Would you use this application while visit to museum?	No

Review of a mobile Application for a historic site

Age	22
How often do you visit museum?	Once in six months
Do you know about Augmented Reality (AR)?	Yes
Do you own a smart phone?	Yes
Does it support Augmented Reality (AR)?	Yes
Are you comfortable to use your device while visit to museum?	Yes
How would you rate the description I have provided about the application?	5/5
How much would you rate for the application with these features?	5/5
Do you think an application with these features would enhance your visit to the museum?	Yes
Would you use this application while visit to museum?	Yes
Final Comments	Would love something like this in museums!

Review of a mobile Application for a historic site

Age	32
How often do you visit museum?	Once a Year
Do you know about Augmented Reality (AR)?	No
Do you own a smart phone?	Yes
Does it support Augmented Reality (AR)?	Don't Know
Are you comfortable to use your device while visit to museum?	Yes
How would you rate the description I have provided about the application?	5/5
How much would you rate for the application with these features?	5/5
Do you think an application with these features would enhance your visit to the museum?	Yes
Would you use this application while visit to museum?	Yes

Review of a mobile Application for a historic site

Age	25
How often do you visit museum?	Once in quarter year
Do you know about Augmented Reality (AR)?	Yes
Do you own a smart phone?	Yes
Does it support Augmented Reality (AR)?	Yes
Are you comfortable to use your device while visit to museum?	Yes
How would you rate the description I have provided about the application?	4/5
How much would you rate for the application with these features?	4/5
Do you think an application with these features would enhance your visit to the museum?	Yes
Would you use this application while visit to museum?	Yes

Review of a mobile Application for a historic site

Age	30
How often do you visit museum?	Once a Year
Do you know about Augmented Reality (AR)?	Yes
Do you own a smart phone?	Yes
Does it support Augmented Reality (AR)?	Yes
Are you comfortable to use your device while visit to museum?	Yes
How would you rate the description I have provided about the application?	5/5
How much would you rate for the application with these features?	5/5
Do you think an application with these features would enhance your visit to the museum?	Yes
Would you use this application while visit to museum?	Yes

Review of a mobile Application for a historic site

Age	31
How often do you visit museum?	Once a Year
Do you know about Augmented Reality (AR)?	Yes
Do you own a smart phone?	Yes
Does it support Augmented Reality (AR)?	Yes
Are you comfortable to use your device while visit to museum?	Yes
How would you rate the description I have provided about the application?	4/5
How much would you rate for the application with these features?	5/5
Do you think an application with these features would enhance your visit to the museum?	Yes
Would you use this application while visit to museum?	Yes