INSTITUTO SUPERIOR DE ENGENHARIA DO PORTO
MESTRADO EM ENGENHARIA INFORMÁTICA




Augmented Reality for the Mobile Police Force

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Junho de 2022

POLITÉCNICO
DO PORTO

Instituto Superior de Engenharia do Porto

Augmented Reality for the Mobile Police Force

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A dissertation submitted in partial fulfillment of the requirements for the degree of Master of Science, Specialisation Area of Sistemas Gráficos e Multimédia

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Porto, June 26, 2022

Dedicatory

To all my family members, friends and supervisor who supported me through all this journey. And finally, to myself, who persevered through the arduous stages and managed to accomplish this research.

Abstract

Portuguese law enforcement organizations currently face a significant technology gap. Research has shown that some law organizations, such as *Polícia Judiciária (PJ)* and *Polícia de Segurança Pública (PSP)*, often criticize the lack of technology to support the Police work in all kinds of fields, from criminality prevention to minor infractions.

This study aims to determine how augmented reality (AR) technology can be used to ease/improve the day-to-day tasks of the law enforcement forces and how do the end-users perceive this new type of information. Based on a review of the literature and implementations on AR technologies to aid law enforcement organizations, a proof-of-concept smartphone application was developed in order to aid the police infraction ticket issuing process.

The developed solution was analysed to infer its usability. As such, various users tests were conducted with a total of thirty users including police personnel and non-associated users. The users were then asked to answer a questionnaire contemplating the System Usability Scale (SUS) questions. The responses were analysed and then combined with the Quantitative Evaluation Framework (QEF) in order to extrapolate the proof-of-concept's final value.

The results suggest that the ticket issuing process was fully integrated in the proof-of-concept and was well received amongst the users. The system contemplates the possibility to scale to other devices other than the smartphone, for example surveillance cameras or wearables, as well as including new features to perform different tasks such as recognizing vehicles through AR and Depth.

Keywords: Augmented Reality, Law Enforcement Applications, Infraction Tickets, Smartphone

Resumo

A introdução da tecnologia na sociedade alterou o paradigma de como as tarefas são realizadas. Uma grande parte dos setores económicos decidiu apostar na automatização e mecanização de processos, reduzindo assim os encargos em recursos humanos, bem como o número de erros humanos.

Apesar do uso de tecnologias ser recorrente em várias áreas e serviços, as forças policiais continuam a ter o seu uso negligenciado. Muitas das tarefas policiais, como a passagem de infrações ou contra-ordenações, são feitas através da introdução manual de dados num sistema generalizado implantado num computador de bordo ou através da passagem de uma contra-ordenação por escrito que é posteriormente introduzida no sistema aquando a chegada do agente à esquadra do seu destacamento. O processo em questão acaba por ser bastante moroso, como também propenso à realização de erros humanos. O descontentamento das Forças policiais como a Polícia Judiciária (PJ) ou a Polícia de Segurança Pública (PSP) é visível nas contestações feitas relacionadas com a falta de suporte tecnológico em variadas operações policiais.

Este estudo tem como objetivo determinar como as tecnologias de *Augmented Reality* (AR) podem ser utilizadas de modo a otimizar as tarefas policiais e como a introdução da mesma é percecionada pelos utilizadores nas tarefas em questão. A investigação foca-se no desenvolvimento de uma aplicação de AR para smartphone como uma prova de conceito com o intuito de assistir as forças policiais na passagem de infrações e contra-ordenações. Consequentemente, foi realizada uma investigação sobre a tecnologia de AR e as suas categorias. Após serem detalhadas as nuances da AR, foi efetuada uma investigação na literatura e implementações de trabalhos relacionados contendo sistemas que implementam AR com o objetivo primário de assistir as forças policiais em variadas tarefas. Desta forma, foi possível detalhar algumas das possíveis tecnologias que acabaram por ser utilizadas para o desenvolvimento da aplicação supramencionada.

Aquando da finalização do estudo dos trabalhos relacionados, foi analisado o contexto de negócio da prova de conceito a desenvolver, validando a necessidade e o contexto onde o sistema desenvolvido viria ser inserido.

A aplicação foi desenvolvida em Unity com recurso à framework ARFoundation, que possibilitou o incorporamento e sobreposição de dados virtuais sobre a vista real observada pelo utilizador. O sistema foi desenhado de forma a realizar a deteção automática de matrículas expondo a informação detetada na forma de componentes AR no ecrã do utilizador, possibilitando a posterior submissão de uma infração se a matrícula selecionada pelo utilizador estiver contida na base de dados.

A prova de conceito é composta por seis conceitos de negócio, sendo estes: a interface gráfica para o utilizador; o módulo de *Optical Character Recognition* (OCR), responsável pela deteção e comparação de carateres alfanuméricos pre-registados no sistema: o Plate Recognition Training, responsável pelo aprendizagem dos contornos e localizações das matrículas; a câmara, responsável pela obtenção do vídeo em tempo real para deteção; o integration system, responsável por integrar todos os módulos supramencionados; e por último, o resources/fileSystem, responsável por armazenar todos os dados necessários para o funcionamento da aplicação.

Após a implementação do sistema, o mesmo foi submetido a vários testes de utilizador com recurso a um conjunto predefinido de ações, de modo a aferir a integração e usabilidade da aplicação. Foram feitos testes com trinta utilizadores, incluindo alguns agentes policiais. Posteriormente, os utilizadores supracitados foram convidados à realização de um questionário. As respostas foram analisadas de forma a apurar o valor de usabilidade final referente à prova de conceito.

Os resultados obtidos confirmam que o processo de submissão de infrações foi totalmente integrado na prova de conceito e que o sistema foi positivamente avaliado pelos utilizadores. O sistema contempla a possibilidade de ser integrado em diferentes dispositivos em adição ao smartphone, como por exemplo câmaras de videovigilância ou wearables. O sistema está ainda preparado para ser escalado e incluir novas funcionalidades para realizar diferentes tarefas policiais, como a de reconhecer veículos através de AR e Profundidade, sendo que este conceito foi brevemente explorado nesta tese.

Acknowledgement

Firstly, I would like to show my appreciation to the thesis' supervisor, Professor Filipe de Faria Pacheco, who accompanied me through all the research steps and for the availability and engagement when discussing the research path.

Secondly, I would like to extend my appreciation to all my family and friends who kindly supported me in the research both technically and emotionally.

Finally, I would like to express my gratitude to all the users that undertook the user test experience that allowed me to achieve the research results.

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List of Acronyms

AHP	Analytic Hierarchy Process.
AR	Augmented Reality.
DEI	*Departamento de Engenharia Informática*.
DSRM	Design Science Research Methodology.
E2E	End-to-End.
FFE	Fuzzy Front End.
GPS	USA Global Positioning System.
ISEP	*Instituto Superior de Engenharia do Porto*.
LPR	License Plate Recognition.
MEI	*Mestrado em Engenharia Informática*.
NASA	USA National Aeronautics and Space Administration.
NPD	New Product Development.
OCR	Optical Character Recognition.
ONNX	Open Neural Network Exchange.
PBR	Product Backlog Refinement.
QEF	Quantitative Evaluation Framework.

SUS System Usability Scale.
SWOT Strengths Weaknesses Opportunities Threats.

TMDEI *Tese / Dissertação / Estágio Mestrado de Engenharia Informática*.

VR Virtual Reality.

YOLO You Only Look Once.

Chapter 1

Introduction

Within the scope of the Curricular Unit TMDEI (*Tese / Dissertação / Estágio Mestrado de Engenharia Informática*), this research intends to consolidate the attained knowledge throughout the Master's Degree and apply it to a real situation. All the research carried out, as well as all the necessary steps that led to the achievement's completion, are covered in this Thesis.

The introductory chapter will be responsible for covering the details of this thesis' context coupled with the problem interpretation. Secondly, the objectives are detailed in order to find a solution to the aforementioned problem. Following these objectives, there is the necessity to implement a list of expected results that will be attained following a specific approach.

Lastly, this introductory chapter will also include a succinct layout of this document's structure.

1.1 Context

This Thesis' research theme emerged as a potential solution to improve the workflow of Police Officers when issuing infraction tickets. This proposal will strive to deliver a proof-of-concept application that compiles the infraction ticket issuing using Augmented Reality as its main feature. As such, this research will also consider the various possibilities for Augmented Reality (AR) development and integration as well as the criteria behind the alternatives made throughout the investigation.

Augmented Reality usage has been exponentially multiplied throughout various applications that populate the current technology market. Therefore, this reason was a major influence when determining the thesis' direction and workflow.

1.2 Problem Interpretation

The introduction of technology in our society's lifestyle has brought a huge improvement in productivity, enhanced entertainment, boosted leadership, assisted medicine, etc. As such, most economic sectors and lines of work have some kind of interaction with said technologies, thus increasing the access to information and communication.

Police officers still miss the help from said technologies in their field work, despite all the examples in Investigation TV Series and Movies where AR is used as a catalyst to speed up the Police work. For instance, a Police officer that wants to identify a certain car in a Stop Operation to issue an infraction ticket, needs to perform a set of actions, like inputting the data (plate, colour, brand, model) about the vehicle in the system (computer, tablet, etc) and that process might take too much time, therefore slowing down the efficiency of the Stop Operation itself.

Currently, all the work related to infraction ticket issuing relies on manual operations, as such, a Police Officer must manually input all the data related to the occurrence in the portable or handwritten System in order to issue said ticket. This is an error-prone process that requires time and ultimately slows down the operational work. Additionally, the *Polícia de Segurança Pública (PSP)* and *Polícia Judiciária (PJ)* often criticize the lack of technology to support the Police work in all kinds of fields, from criminality prevention to minor infractions (Augusto 2018 & Delgado 2021).

1.3 Objectives

The objective of this study lies in the investigation of various AR engines and software, with the goal of building a demonstration AR system to improve police operations and reduce delays when completing routine activities. Due to the extensive breadth of the AR subject and Police duties, this dissertation will focus on the development of a proof-of-concept application to enable faster data collection in order to ease and streamline the infraction ticket issuance procedure as a contributory example to the development of this technology inside the law enforcement department. It is then possible to develop a solution that, with the usage of AR, is able to display, in a portable device, relevant information to a police officer and help gathering the needed information quickly and accurately (e.g. identify the make and model of the vehicle, automatic recognition of license plate, etc). Various Image recognition solutions will be analysed to choose the best fitted for this specific case.

The aforementioned system will be able to answer some requirements that a normal image processing application is not capable of. The user will be able to overlay processed information in real-time on the smartphone display. Additionally, with the existence of a provided Database that contains various preregistered information, it would be possible to cross-reference data in real-time, for example, a given plate with the corresponding make and model of the vehicle. Although the system will be thought for smartphones, this research also aims to provide a new alternative that can be scaled to specific hardware such as the Google Glass, which contains an overall better interface for an AR situation.

There will be three key considerations: whether the solution is practical, feasible, and complies with the following restrictions:

- Hardware restrictions: since the available hardware might compromise possible solutions architecture;
- Software restrictions: since the focus will be mainly on freeware solutions;
- Time restrictions: since there will be a limited time to investigate, it is possible that there will be additional work in the future;
- Information restriction: since there will be a need to ask for help and indications to the Police force in order to attest the usability of the application.

1.4 Research Questions

The investigation required a starting point, so the following research questions were established with the cooperation of this thesis' supervisor in order to carry out this research:

- How can AR technology be used to ease/improve the day-to-day tasks of the Law Enforcement forces?
- How do end-users perceive the deployment of AR-assisted functions in police force applications, such as the information presented by the system mixed with the real-world camera feed?

The first research question means that the investigation should begin by identifying some of the current technologies in the field of augmented reality applications with a scope similar to that of this thesis. As a result, the investigation's State of the Art will emphasize on identifying possible technologies and systems that could be used to build the proof of concept that this thesis requires. It also considers the dimensioning and fulfilment of the needs acquired. Finally, the last question allows the research to establish the system's usability, i.e., whether the system is reliable, easy to use, and offers information in a way that even non-technical people can understand. This research questions will be further analysed in the Evaluation and Experimentation chapter (chapter 6).

1.5 Preferred Approach

This dissertation focuses on the investigation and subsequent development of a proof-of-concept to improve the field work of police officers, highlighting the need for a method that ensures the research's reliability and accomplishment. As such, the Design Science Research Methodology (DSRM) applied to information systems was deemed to be the most fit for the development of this dissertation.

DSRM is a framework that discloses the necessary guidelines to successfully evaluate the present Design Science Research (DSR) in the information systems, incorporating principles, practices, and procedures required to carry out the research. This methodology is divided in six steps: problem identification and motivation, definition of the objectives for a solution, design and development, demonstration, evaluation, and communication (Peffers et al. 2007).

- Problem identification and motivation: dwells on the definition of the Problem at hand as well as the justification for the value of a solution applied to this research context. This document encompasses the problem interpretation in the Chapter 1.2 and the subsequent value of the prospective solution in Chapter 3;
- Objectives for a solution: consists on stipulating the objectives regarding the problem at hand and its respective constraints. It is a prerequisite to assess the most available approaches in order to properly gauge the drawbacks when delineating the objectives, which can be quantitative (where a desirable solution surpasses the value of the current ones) or qualitative (how a certain artifact

supports the solution to a given limitation). The objectives are detailed in the Chapter 1.3;

- Design and development: Design and Implementation of the chosen solution. The design emerges from the analysis of the State of the Art which contains the frameworks, patterns, techniques and technologies in order to produce a proof of concept application that represents the chosen solution and delivers the aforementioned objectives. This topic will be detailed throughout the Chapters 4 and 5 ;
- Demonstration: Resides in determining and exhibiting the effectiveness of the implementation regarding the chosen solution and the know problem. As such, in Chapter 6 will be unveiled the experimentation and evidences of how the implemented solution tackles the existing problem.
- Evaluation: Detect and measure the efficacy of the implementation regarding the chosen solution when analysing metrics and assessing results. As such, in the Chapter 6 will be the comparison between the achieved results displayed in the demonstration versus the initial objectives as well as the outputted value.
- Communication: The conciseness of the communication when delivering the problem and its importance, the projected solution, its utility and effectiveness, is a critical part that must be conveyed throughout this document. Consequently, Chapter 7 will encapsulate and communicate the conclusions reached through this research.

1.6 Work Planning

In order to succeed while performing the research for this dissertation, it is crucial to delineate a work plan. The chosen work plan for this research is similar to the SCRUM framework in the Agile Methodologies. Even though SCRUM was a framework meant to be mainly used by teams with multiple elements, the plan will contemplate the work structure of this framework while only having an active contributor to the increments made to this thesis. As a result, the planning will neither take into account the SCRUM framework's formal meetings, nor will it adhere to the framework's standards. However, there will be regular meetings with the thesis' supervisor to discuss the sprints, which will last two weeks. The sessions will function as a sprint review, a Product Backlog Refinement (PBR) and a Sprint Planning session, with all stakeholders involved aligning on what was accomplished and what has to be accomplished in the following sprint, as well as what to prioritize.

Thus, the work will be divided into smaller increments, taking form of user stories that will be actively done throughout each sprint. This plan will guarantee the possibility to smoothly document all the research progress as well as to keep notion of an incremental development. Also, the milestones and objectives measurements will be more straightforward when accompanied by the respective acceptance and completion criteria.

The first milestone is represented by the research of the State of the Art, which contemplates the presentation and understanding of the thesis purpose as well as the research and comparison on the potential technologies, architectures and techniques that can be used to achieve the desired results. This milestone will be developed between mid November 2021 until start of March 2022.

Secondly, the value analysis will be developed between mid November 2021 and mid February 2022. The focus of the value analysis relies on the assessment of how to increase the value of the product while encompassing the lowest possible costs, not neglecting the quality.

Afterwards, follows the analysis and design of the solution, that presents the problem domain and the architecture, with the subsequent creation of the Functional and Non-Functional Requirements that the solution may imply. Also, this milestone will include the Design decisions, which will be developed between early January 2022 until late March 2022.

Subsequently, the analysis and design of the solution will culminate in the development of a prototype following the aforementioned requirements. This milestone will be developed between late February 2022 until early June 2022.

Lastly, lies the evaluation and experimentation of all the produced results, hence being compared with the previously projected objectives in order to infer their completion. This milestone will be developed between mid April 2022 until late June 2022.

The Milestones can be found displayed in the *Gantt* Diagram in the Figure 1.1.

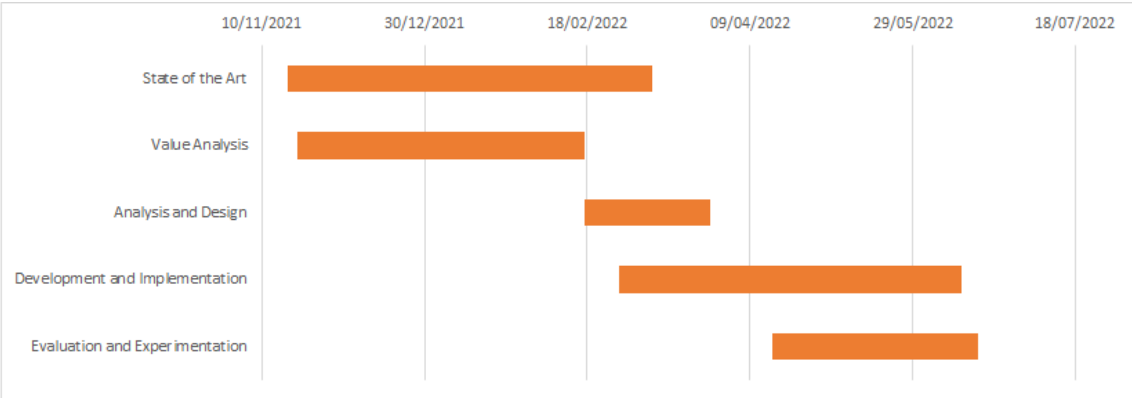

Figure 1.1: Gantt Diagram with the Milestones

1.7 Document Structure

There are seven chapters in this document. To better arrange and present the studied information to the reader, each chapter has its subsequent sections. As a result, the structure is divided into the following sections: Introduction, State of the Art, Value Analysis, Analysis and Design, Implementation, Evaluation and Experimentation and the Conclusions.

The project is contextualized in the introduction, which is followed by a brief discussion of the problem that motivated this dissertation, the definition of the objectives, the preferred approach, and finally the work planning.

The State of the Art captures Augmented Reality's contextualization in order to better frame the technology and its potential applications. Second, some related projects are described, demonstrating how technology may assist law enforcement agencies. Finally, Augmented Reality software for system development is analyzed in order to determine which is the best to use in this project.

The project's Value Analysis is represented in the next chapter. As a result, it starts with a description of the Innovation Process, as well as the characterization of its theoretical constituents and implementation in this thesis. Second, the Analytic Hierarchy Process (AHP) is utilized to choose the optimal Augmented Reality alternative to use throughout this study. Finally, the Value Proposition, Customer Value, and Canvas Business Model in this thesis are structured to help the reader better comprehend the value that will be delivered to the clients.

The analysis and design of the proof-of-concept system are the main topics of the following chapter after the best AR alternative and the value of the delivered solution have been defined in the Value Analysis chapter. As a result, it will reveal the problem domain and associated business concepts that are necessary to grasp the system that has to be implemented. The Functional and Non-Functional Requirements will be defined in order to completely understand the scope and characteristics of the solution. Finally, a summary of the design choices that took into account the aforementioned requirements will be provided.

The following chapter, titled Implementation, will depict how the previously stated requirements have been implemented. The development of the Unity Scenes, which act as the user's interface with the system, as well as the implementation of the augmented reality (AR) and license plate recognition (LPR) systems will thus be detailed in this chapter.

The study of the research questions and the creation of hypotheses will be covered in the chapter Evaluation and Experimentation. As a result, it will outline the evaluation procedures used to determine whether the presented hypothesis are accurate and to evaluate the overall effectiveness of the solution that was provided.

The final chapter, which is represented by the Conclusions, will address the objectives that were achieved regarding the research, implementations and milestones present in this thesis. Second, it will outline the constraints encountered when conducting research and designing the solution. Following the constraints and limitations, there is a depiction of the future work that may be done to further enhance the worth of this thesis' object of study. The final considerations in this chapter will summarize the significance of the research and the proposed solution to the author.

Chapter 2

State of the Art

The following chapter is mainly divided through four sections. Firstly, there is contextualization in what Augmented Reality consists, as wells as the existing differences between it and Virtual Reality on the Mixed Reality realm. Also, the history behind the various AR creations will be summarized. Since there must be a procedural interpretation of the License Plates size, format, text and numbers, there will be some contextualization on Optical Character Recognition (OCR) and Machine Learning.

Secondly, some related researches will be analysed revealing various technologies and processes that are applied amidst similar conditions. Subsequently, resulting from the previous analysis, will emerge the existent technologies that can be used to further develop this research. Finally, this chapter will include a comparison between all the researched technologies in order select the best ones applicable to the proof-of-concept application.

2.1 Introduction to Augmented Reality

With the recurrent appearance of Augmented Reality (AR) in games and applications that are easily accessible to end-users through common means, such as Smartphones or tablets, the use case of this technology was heightened. AR emerged as a possible solution to real world situations that benefited from the overlay of additional information onto the real world, enhancing the perception of the user's world. Hence the need to properly contextualize this technology and its relationship in the larger class of technologies which we refer to as Mixed Reality (MR).

While the term Augmented Reality has begun to incorporate literature with increasing frequency, its definition is mostly mixed along with the rest of the MR technologies, not being clearly separated. Paul Migram, Haruo Takemura, Akira Utsumi and Fumio Kishino throughout their research brought to light two questions in order to obtain a possible answer that properly identified and distinguished AR:

- What is the relationship between Augmented Reality (AR) and Virtual Reality (VR)?
- Should the term Augmented Reality be limited solely to transparent see-through head-mounted displays?

While being directly connected and belonging to the same technology realm, the VR environment is one in which the participant is fully immersed in a completely synthetic world, which may or may not simulate the properties of a real-world environment, posing the possibility to exceed the bounds of physical reality by creating a world where our physical laws governing gravity, time structure and material properties no longer hold. Rather than regarding VR and AR as antitheses, it is more suitable to picture them as lying at opposite ends of a continuum, which it is referred to as the Reality-Virtuality (RV) continuum (Milgram et al. 1995).

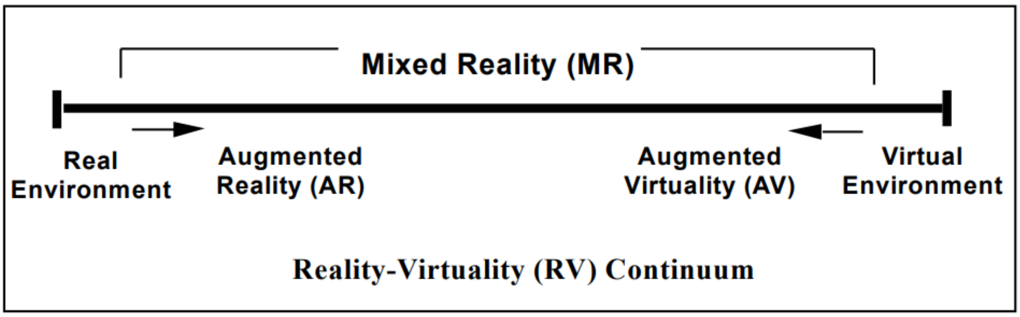

Figure 2.1: Simplified representation of a RV Continuum. (Milgram et al. 1995)

As shown in the Figure 2.1, the leftmost environment situated within the RV Continuum consists solely of real objects and includes whatever might be detected when viewing a real-world scene either directly in person, through some sort of window, or via video display. The rightmost environment consists solely of virtual components, including for instance computer graphic simulations that can be experienced either through a monitor or immersive display, such as the Occulus Quest 2 or the Oculus Rift.

After grasping the fundamentals on Augmented Reality, it is possible to contrast two possible use-case scenarios, those based on head-mounted see-through displays and those which are monitor based, although both cases are in compliance with the aforementioned definition as well as situated in the leftmost side of the Figure 2.1.

See-through AR Displays are a class of display that act as a medium between the observer and its surrounding world, thereby maximizing the extent of presence as well as provoking a superior degree of "realspace imaging" (Milgram et al. 1995). This class of display is mainly achieved by the usage of mirrors to superimpose computer generated graphics optically onto directly viewed real-world scenes. See-through AR Displays can be found incorporated in some aviation systems, as either panel-mounted or head-mounted displays (HMDs), installed in military vehicles for viewing sensor imagery, as well as embedded in medical visualization equipment as an aid in surgical procedures. (Spitzer, U. Ferrell, and T. Ferrell 2017).

This AR class implies the need of certain conditions in order to function. These include the need for low latency body and head tracking, adequate field of view, accurate and precise calibration and viewpoint matching, and the requirement for a snug (no-slip) but comfortable and preferably untethered head-mount. Apart from the physical hardware necessities, See-through AR Displays are still presented with issues correlated to their software and environment perception, including the conflicting effects of occlusion of apparently overlapping objects and other ambiguities emergent from the interaction between the computer generated images and the real objects (Owen et al. 2004).

Monitor-based AR displays are another AR class that refer to display systems where computer generated images are either analogically or digitally overlaid onto live or stored video images. This class of AR displays is non-immersive.

Apart from the aforementioned use-case scenarios, AR has six different types that fall under two overarching categories, which correspond to "Triggered" versus "View-based augmentation", as shown in Table 2.1. "Triggers" are characteristics or stimuli that "Trigger" the augmentation. Triggers can be all sort of materials such as object markers, paper, GPS locations, dynamic augmentation of objects or even a combination of the previous triggers that is classified as a Complex Augmentation. The second category is represented by the View-based augmentation, which includes both digitized augmentations regardless of the world seen by the observer or augmentation of a stored/static view.

From the six aforesaid types, four fall under the *triggered AR technology* category. As such, said category is composed by: Marker-based AR, thus requiring a marker to activate an augmentation. This markers can be represented by paper-objects or physical objects that exist in the real world. For instance, the app Aurasma's augments the appearance of a real $20 bill, which morphs into an entertaining, patriotic animation, corresponding to the perfect example of and object as a trigger stimulus; Location-based AR that requires location to trigger the augmentation, that with the usage of GPS coordinates manages to trigger augmentations based on the user's location; Dynamic Augmentation, which is responsive to the view of the object as it changes. For instance, Swivel is a shopping application that allows users to try on clothing and accessories digitally; Complex Augmentation which aggregates a real, dynamic view of the world with digital information typically accessed via the Internet. It is a combination of Marker/Location-based AR and Dynamic Augmentation. This last type can be seen in the original concept for the Google Glass, hence using geographic location to trigger certain stimuli and also presenting useful information about the objects in eyesight from an internet backend.

Apart from the "Triggered AR technology", the second category is represented by the Indirect Augmentation and Non-Specific Digital Augmentation and falls directly under the "View-based augmentation" realm. This type of AR intelligently augments a static view of the world. Commonly this AR type involves the augmentation of images. A good example of this category includes applications that allow the users to take a photo of an object. Supposing that the aforementioned object was car, it would be possible to change features such as the color or dimensions. The application is able to successfully filter the other objects from the said picture apart from the car. Non-Specific Digital Augmentation's objective relies on digitizing a dynamic view of the world without a direct connection from what is being viewed. This type is usually found in mobile games, where the augmentation is unrelated to the background that encompasses it (Edwards-Stewart, Hoyt, and Reger 2016). The Table 2.1 contains some examples for the AR categories and types.

Table 2.1: Augmented Reality categories and types with examples (Edwards-Stewart, Hoyt, and Reger 2016)

Category	Type	Examples	Characteristics
Triggered	1a. Marker-based: Paper	String (string.co) Blippar (blippar.com)	Paper marker activates stimuli.
	1b. Marker-based: Object	Aurasma (aurasma.com)	Most objects can be made into markers.
	2. Location-based	Yelp (yelp.com) PAJ (t2health.dcoe.mil/ positiveactivityjackpot) Instagram (instagram.com)	Overlay of digital information on a map or live camera view. GPS may activate stimuli.
	3. Dynamic Augmentation	Video Painter (itunes.apple.com/us/app/video-painter/id581539953?mt=8) Swivel (Motion; facecake.com)	Meaningful, interactive augmentation with possible object recognition and/or motion tracking.
	4. Complex Augmentation	Google Glass (google.com/glass)	Augment dynamic view and pull internet information based on location, markers, or object recognition.
View-Based	5. Indirect Augmentation	Wall Painter (itunes.apple.com/us/app/wall-painter/id396799182?my=8)	Image of the real world augmented intelligently.
	6. Non-specific Digital Augmentation	Swat the Fly (inengy.com/swatthefly) Bubbles (virtualpopgames.com)	Augmentation of any camera view regardless of location.

2.1.1 Theoretical Examples of Augmented Reality

This section will help to demonstrate some theoretical projects that have been completed in the Augmented Reality realm that have increased its use and generated numerous ideas that can be employed in the implementation of this dissertation. These projects have not yet been realized, but they are provided to illustrate how some of the previously described AR types (Section 2.1) can be used in real-world projects.

AR in Construction

AR is employed throughout a construction project's many phases and departments. Many academics believe that AR is the most obvious technology to utilize in a construction project for bringing automation to the construction industry. It was undeniable that AR would play a significant role in transforming the construction industry's culture to a fully automated sector in the near future. Effective communication and information retrieval from the construction site is a crucial prerequisite for a successful construction project. It was inferred that the introduction of several AR applications considerably improves access to project information on-the-job site and effective communication when compared to more traditional information sources. Figure 2.2 depicts how AR technologies are employed in the construction industry for field data collecting and distribution to users. It also symbolizes the means by which project participants and project information are communicated (Ahmed 2019). Since this AR project relies on external data as well as marker-based and environment-triggered augmentation, the Complex Augmentation type is employed to provide information to its users.

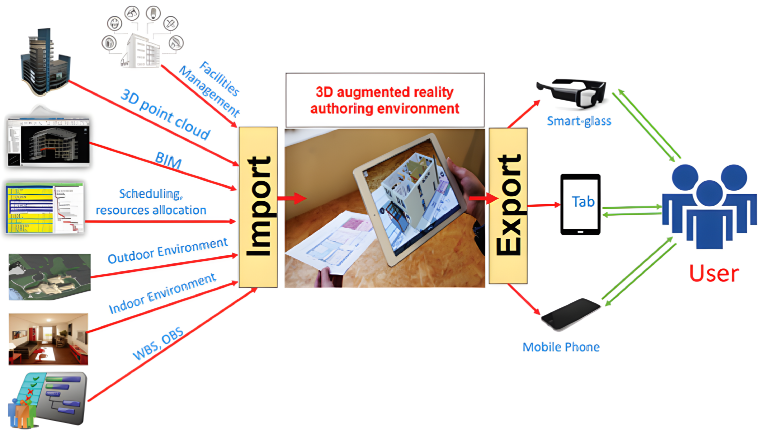

Figure 2.2: Construction field data and design information acquisition process using AR technologies (Ahmed 2019)

Law Enforcement Traffic Stop

Law enforcement scenarios focusing on data gathering, such as Traffic Stops, are typically low-risk, but they have the potential for risk escalation due to operational uncertainties that might lead to situations that endanger both officer and civilian safety. The time gap between acquiring data about the vehicle and its occupants and verifying the information obtained causes these uncertainties.

To completely understand the scenario, the officer must approach the motorist, request documentation, and run the data through several databases. When an officer is dealing with a criminal, he or she may not know it until it is too late. Furthermore, when the police wants to utilize the in-car computer to verify the information, he may lose track of the vehicle's occupants. Grandi and his colleagues devised a next-generation AR user interface to aid police officers during a traffic stop.

The prototype system was built using knowledge gained through analyzing law enforcement processes and practices, and it had two high-level features: a situational awareness interface and an on-demand information display. These features, when combined, provide for rapid and easy access to information while reducing the risks. Their ideas foresee technology that can scan and search for a vehicle's license plate, driver's license, facial recognition, and object detection in real time (see Figure 2.3), as these functions are likely to be enabled by future technology (Grandi et al. 2021). Since the information was obtained through police channels, and there is triggered augmentation caused by the interaction with the driver's face and the car's license plate, as well as real-time augmentation caused by proximity sensors, it is apparent that this system is based on the Complex Augmentation type.

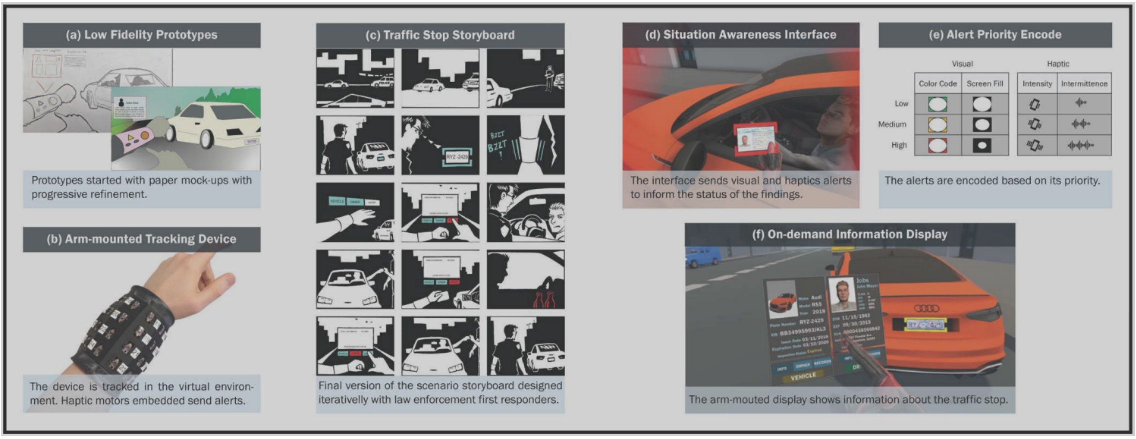

Figure 2.3: The traffic stop scenario design process (Grandi et al. 2021)

2.2 Augmented Reality History

Augmented Reality has gained a major importance in nowadays technologies, either in utility technologies or even games. From its use in NASA's spacecraft in the nineties with the purpose to aid the navigation, to the fiery popularity of Pokemon Go, which after launching in July 2016, hit its peak in August of almost 45 million users (Javornik 2016). Augmented reality has prevailed and has evolved to emerge as one of the most enticing technologies in the present.

First and foremost, the first step in the Augmented Reality realm was taken when Ivan Sutherland in 1968 at Harvard created an Augmented Reality head-mounted display system. This futuristic device was called *The Sword of Damocles* (see Figure 2.4) and contemplated a virtual environment with graphics that comprised of simple wireframe rooms. Sutherland's System displayed output from a computer program in a stereoscopic display. The software's displayed perspective would vary according to the user's gaze, hence the need for head tracking (Schmalstieg and Hollerer 2016).

Figure 2.4: The Sword of Damocles - 1968. (Schmalstieg and Hollerer 2016)

In 1992, the term *Augmented Reality* was then coined by one of Boeing researchers and engineers, Tom Caudell. This new term emerged while Tom Caudell and David Mizell were developing a device which sought to aid workers in an airplane factory by displaying wire bundle assembly schematics in a see-through HMD (see Figure 2.5) (Schmalstieg and Hollerer 2016).

Figure 2.5: Researchers at Boeing used a see-through HMD to guide the assembly of wire bundles for aircraft. (Schmalstieg and Hollerer 2016)

In the same year of 92, Louis Rosenberg created the first fully immersive AR system at the U.S Air Force Research Laboratory. The system allowed military personnel to virtually control and guide machinery to perform tasks like training their US Air Force pilots on safer flying practices.

In 1994, the Australian writer and produce, Julie Martin, brought Augmented Reality to the entertainment industry for the first time when producing the theater piece called *Dancing in Cyberspace*. The show featured acrobats dancing alongside projected virtual objects on the physical stage (Schmalstieg and Hollerer 2016).

As one of the most famous and profitable sports in the United States, in 1998, *Sportsvision* broadcasts the first live National Football League (NFL) game which feature the *virtual 1st & Ten graphic system* – also known as the yellow yard marker. The system is still used to this day, although admittedly more advanced than what it was in the late '90s. Although viewers have become more accustomed to the virtual yellow line marker and the other additional graphics, most don't realize that this technology belongs to the Augmented Reality realm.

In 1999, NASA developed a hybrid synthetic vision system of their X-38 spacecraft. The system leveraged AR technology in order to provide better navigation during the test flights. NASA researchers and engineers incorporated real time data regarding map information directly into the pilot's screen (Poetker 2019).

Regarding the latest year of the 20th century and the current 21st century, technology has evolved at a higher pace. In 2000, Hirokazu Kato developed an open-source software library called the ARToolKit. This library helps other developers build augmented reality software programs. The library uses video tracking to overlay virtual graphics on top of the real world. However, under the ownership of *ARToolworks*, it continued with an open source variant until 2015, when it was sold (ARToolkitX 2017).

Three years later, in 2003, the aforementioned *1st & Ten graphic*, the yellow yard marker AR system developed in 1998 for the NFL, was enhanced, comprising a new feature that provided viewers with an aerial shot of the field with graphics overlaid atop it, denominated *Skycam*.

In 2008, Bayerische Motoren Werke (BMW) was the first car brand to make use of Augmented Reality for commercial purposes. The company embedded Augmented Reality functionalities into their ads and utilized it to promote the Z4 Roadster, associating the brand with cutting-edge technology.

A new era for magazines and newspapers arrived when, in 2009, *Esquire Magazine* used augmented reality inside the magazine's print for the first time in an attempt to make the pages come alive. When readers scanned the cover, the augmented reality equipped magazine featured Robert Downey Jr. speaking to the readers.

In 2013, Volkswagen debuted the MARTA app (Mobile Augmented Reality Technical Assistance) which primarily gave car engineers step-by-step repair instructions within the service manual. This use-case of Augmented Reality technology was groundbreaking, as it could and would be applied to many different industries to align and streamline processes.

The Augmented reality bombshell was dropped in 2014, when Google unveiled its Google Glass devices (see Figure 2.6), a pair of Augmented Reality glasses that users could wear for immersive experiences and to overlay all kinds of information atop real world objects gazed by the users. This device allowed users to fully utilize Natural language processing (NLP) in order to fully control and access google applications within the google glasses.

Figure 2.6: Google Glass Wearable. (Google 2022b)

In 2016, Microsoft took its own approach to Augmented Reality, releasing their own wearable denominated HoloLens (see Figure 2.7). The HMD runs on Windows 10 and 11 and is essentially a wearable computer. It also allows users to either interact or scan their surroundings and create their own AR experiences (Poetker 2019).

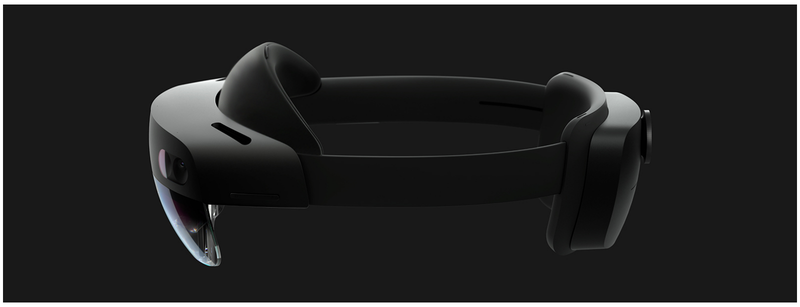

Figure 2.7: Microsoft HoloLens. (Microsoft 2022)

Also in 2016, *Nintendo* alongside *Niantic* launched *Pokémon Go* (see Figure 2.8), a game that rapidly expanded within the video-game market and became world-wide known for its Augmented Reality capabilities, as well as its incentive for the players to travel and acquire different types of virtual creatures, also known as *Pokémons*. *Pokémon Go* consists in a game that uses Augmented Reality to overlay said *Pokémons* onto the real world through the use of a smartphone as a medium. As previously stated, *Pokémon Go* after launching in July 2016 hit its peak in August raising almost 45 million users. On the 20th October of 2020, the game registered more than one hundred million downloads, having its latest update being on January 27, 2022 (Google 2022d).

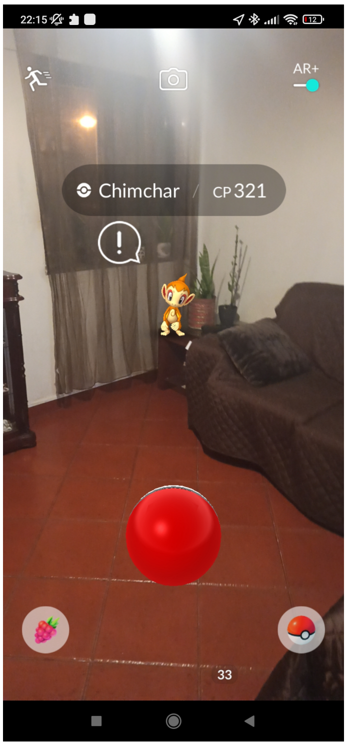

Figure 2.8: Pokemon Go.

Lastly, in 2017, IKEA released its own Augmented Reality app, called IKEA Place (see Figure 2.9), that marked a turn point in the retail industry. This new application allowed its users to freely change the scanned comportment's decorations and furniture in order to virtually generate a preview of the compartment's decor before the purchase was made (Poetker 2019).

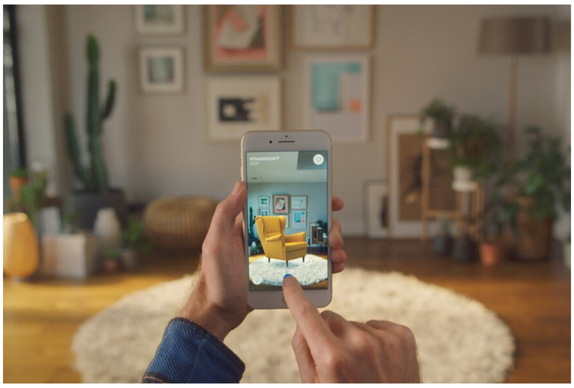

Figure 2.9: IKEA Place (Ayoubi 2017)

2.3 Optical Character Recognition (OCR)

OCR is a method for classifying optical patterns in digital images that match to alphanumeric or other characters. Segmentation, feature extraction, and classification are all key phases in character recognition. OCR technology allows us to transform many types of documents into editable and searchable data, including scanned paper documents, pdf files, and digital camera photos.

OCR is a type of machine recognition method that allows for automated identification. Automatic identification is the process by which a recognition system automatically recognizes items, obtains data about them, and enters that data directly into computer systems, without the need for human intervention. Images, audio, and movies are analyzed to acquire external data (Eikvil 1993).

Pattern recognition has a special significance for OCR systems. Their distinguishing feature is that they do not necessitate control over the information-generating process. The challenge of identifying optically produced characters is addressed by OCR. Optical recognition is done offline after the writing or printing is finished, whereas online recognition is done as the letters are drawn. Although both handwritten and printed characters may be detected, the quality of the input documents has a direct impact on performance. The performance of the OCR system improves as the input becomes more limited. However, OCR machines' effectiveness in completely unrestricted handwriting is still debatable (Chaudhuri et al. 2017).

The primary idea behind automated pattern recognition is to first tell the machine which pattern classes are possible and what they look like. Letters, integers, and special symbols such as commas, question marks, and other characters are all included in OCR patterns. Machine learning is accomplished by providing machine samples of characters from various classes. The computer creates a prototype or description of each class of characters based on these samples. The unknown characters are compared to previously acquired descriptions and allocated to the class that best matches them. Character recognition training is conducted in advance in most commercial systems. However, some systems provide training facilities in the event that additional classes of characters are added (Chaudhuri et al. 2017).

As indicated in Figure 2.10, a typical OCR system comprises of various steps. The first step is to use an optical scanner to digitize an analog document. When text-containing sections are found, the segmentation procedure extracts each symbol. To make feature extraction easier, the retrieved symbols are pre-processed to remove noise. By comparing retrieved attributes with descriptions of symbol classes gained during a previous learning phase, the identification of each symbol is discovered. Finally, contextual information is employed to recreate the original text's words and numbers.

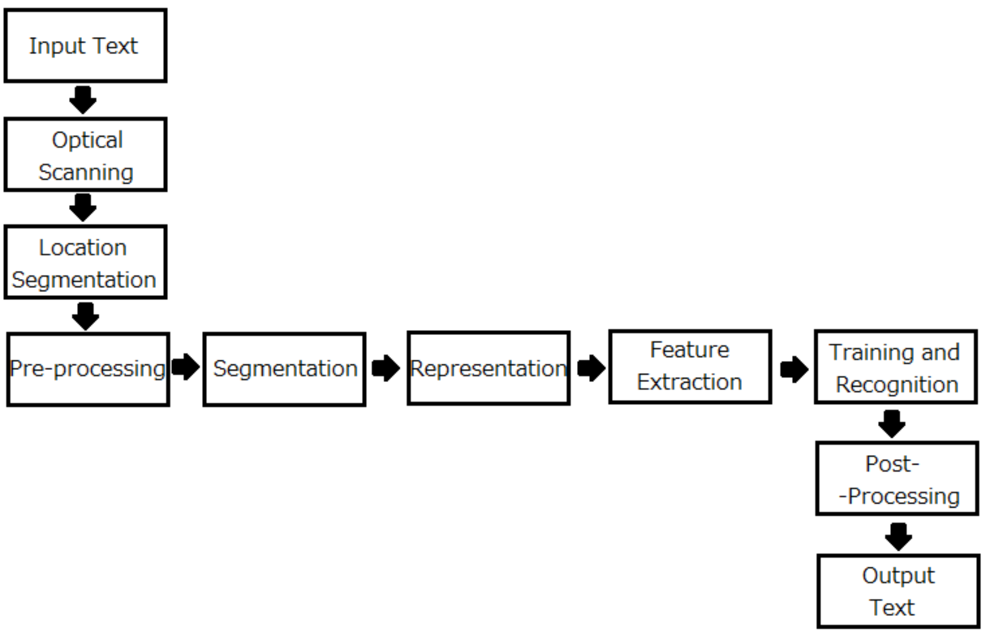

Figure 2.10: The components of an OCR system (Chaudhuri et al. 2017)

2.4 Related Works

Augmented Reality is a cutting edge technology that has been improved throughout the years. Although there are very successful implementations in various fields, as it was described in the previous section (section 2.2), the Police force still lacks the assistance of this emergent technology in order to expedite some of its work, however, there are already some real cases where Augmented Reality was successfully tested and revealed promising results to the Police Forces. This section will contemplate some works that were analysed and have a similar scope to the research done within this thesis.

2.4.1 Augmented Reality within Dutch Police

The Augmented Reality company *Twnkls* rooted in Rotterdam, Netherlands, released in 2018 an AR system that was tested in collaboration with the Dutch Police, the Netherlands Forensic Institute and the Dutch Fire Brigade. The mentioned system was developed by *Dragos Datcu*, a researcher from the *Twnkls* company, that alongside his colleagues at the Delft University of Technology, took roughly around five years to prepare it for its final tests phase. *Dragos Dactu* also revealed that the after testing, the final product would be available to the police force in about six months.

The system itself was prepared to allow the most relevant experts to get actively involved in the search, even if they were not physically present. Using the prototype, a police officer can have access to a new perspective with an Augmented Reality version of the crime scene on a smartphone or an HDM (Google Glass). As officers explore the area, footage from a camera on their vest is sent to people at different locations, such as forensic scientists or chemical specialists. These remote colleagues can add information and notes to the officer's AR perspective, varying from a request to explore a particular area to an indicator such as an arrow pointing to specific evidence. This system has a similar principle to the one registered in *Pokémon Go*, a game where players can catch virtual creatures that appear transposed over the real world when viewed through a smartphone.

Dragos Datcu and his team developed a framework named *DECLARE - DistributEd CoLlaborative Augmented Reality Environment*. This framework is based on a centralized architecture for data communication, to support virtual co-location of users. DECLARE consists of four major components:

- Local user AR support: A local user wears a wrist-mounted smartphone as well as a shoulder-mounted smartphone to interact with the augmented scene. The video captured by the camera of the shoulder-mounted smartphone was sent to the other components of DECLARE framework.
- Remote user AR support: The user interface for remote users runs can be accessed from a desktop computer or a similar system. A remote user interacts with DECLARE by using regular keyboard and mouse devices.
- Localization and mapping: The localization and mapping component was based on an implementation of *RDSLAM (Robust Dynamic Simultaneously Localization And Mapping)* and it was provided by an external supplier.
- Shared memory space: All DECLARE components communicate through a shared memory space. Regarding the video streams provided by the local users, a synchronization mechanism was implemented in the shared memory, ensuring that the same video frame was played for both local and remote user as well guaranteeing that the localization and mapping component are shared simultaneously. In case one component undergoes a temporary failure, the video is automatically recovered. The shared memory mechanism further ensures that data updates from the RDSLAM camera position and orientation, as well as the virtual annotations made by the users, are synchronized with the recovered video stream as well as all its content (Datcu, S. G. Lukosch, and H. K. Lukosch 2016).

Both local and Remote systems incorporate *Unity* as their Graphical User Interface, utilizing it as the intermediate between both user's video input (Local User) and Augmented reality Viewer and Input (Remote User) with the Network (Shared Memory Space). The following Figure 2.11 showcases a diagram that represents the communication and integration between the *DECLARE* components and the existent interfaces.

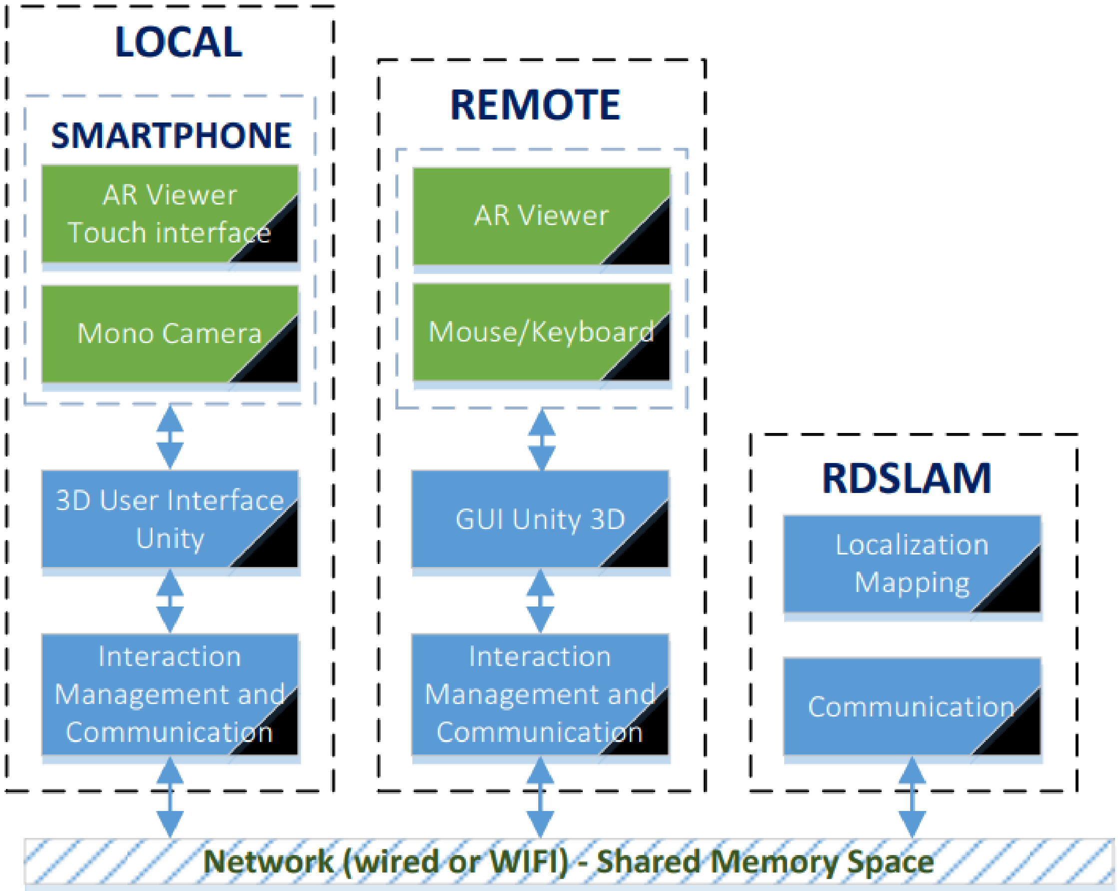

Figure 2.11: Diagram of the main DECLARE components. (Datcu, S. G. Lukosch, and H. K. Lukosch 2016)

To perform the tests alongside the Dutch police officers, the procedures followed the system architecture represented in the Figure 2.12. As such, regarding hardware necessities, the experimental setup for one Remote user and two Local users required 8 distinct hardware devices (see Figure 2.12):

- Three laptops: One laptop belongs to the Remote user (D1) and two laptops to the Local users (D2 and D5).
- 2 Samsung Galaxy S6 Edge smartphones (D3 and D6): The smartphones are wrist mounted and execute the Local User Interface (via Unity 3D Remote).
- 2 Samsung Galaxy S4 Mini (D4 and D7): Each Local user mounts one of these devices on the shoulder to stream a video and share it with the Network (Shared Memory Space).
- 1 WIFI access point (D8): The access point interconnects all devices that relied on the wired network (the three laptop computers D1-D3) along with

the devices that used the WIFI network (the 4 smartphones D4-D7) (Datcu, S. G. Lukosch, and H. K. Lukosch 2016).

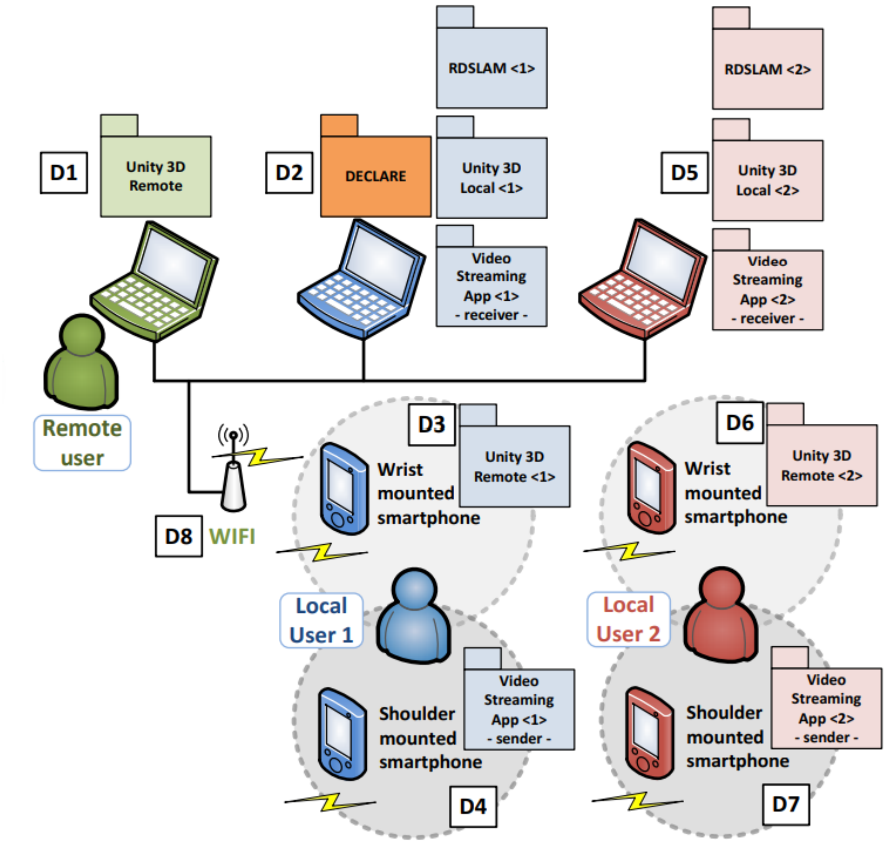

Figure 2.12: System architecture used in the experiment for one remote expert and two local users. (Datcu, S. G. Lukosch, and H. K. Lukosch 2016)

The experiment also featured three radio stations to support audio communications alongside two video recording cameras registering the activity of both Local and Remote user actions throughout the trial. The Remote user's User Interface was executed on the laptop (D1). Both Local user's laptops (D2 and D5) were loaded with three software:

- Unity 3D user interface.
- A component that received the video stream feed resultant from one of the two Samsung Galaxy S4 Mini smartphones (D4 and D7).
- An instance of the localization and mapping component based on RDSLAM.

Local user's were then able to interact systems executing on D2 and D5 through the user interface via Unity 3D Remote displayed on the wrist mounted smartphones (D3 and D6) (Datcu, S. G. Lukosch, and H. K. Lukosch 2016).

After testing the system, *Nick Koeman* from the National Police of the Netherlands, confirmed its potential as well as the added value to the various areas of policing. This technology is not very suitable to use when processing an arrest, since officers can find the overlay of additional information distracting. The system was able to keep the number of investigators at a crime scene to a minimum, without sacrificing thoroughness. Every piece of information could be firstly analysed through video input without physical interaction, reducing the risk of accidentally contaminating evidences. According to *Michael Buerger*, professor of criminal justice at Bowling Green State University in Ohio, with this Augmented Reality system, it is possible to virtually recreate the crime scene with the potential to be used as reliable evidence to present in court. However, *Buerger* still affirms that legal challenges will arise regarding the use of this system as video evidence in court (Revell 2018).

2.4.2 ARCRIME

Crime scene investigation deems the necessity of handling and preserving the evidences with utmost precaution. Cases can often be mishandled mostly tanks to human error when processing the crime scenes and suspects, possibly leading to incorrect verdicts. *Shaheryar Ehsan I Haque* and *Shahzad Saleem* affirmed that the human error can have multiple sources. Firstly, due to lack of training in evidence handling of the first responders or other scenarios where the investigation is erroneous, it might lead to tampered evidence that will be of no use in the case trial. The second problem resided in the criminal profiling where each district had its own method of storing information about suspects and criminals.

ARCRIME was intended to become a digital pillar in the police investigation, solving the aforementioned problems. As such, with the system, a police officer would be able to create a 3D digital copy of the crime scene so that it could be presented in courts or in forensics labs. Additionally, *ARCRIME* would be able to identify suspects and witnesses on the crime scene and transmit relevant information as well as the criminal records to the investigator on site in order to facilitate the arrests process.

The architecture of the system involves various technologies such as:

- *Cloud Computing*: the system is reliant in multiple datastores, linked through the usage of modular base frameworks, for convict identification. Also, while interviewing a person of interest, a police officer would have access to information about the person in question, in real-time, using a cloud-based network linked to the Pakistanis *National Database and Registration Authority (NADRA)*.
- *Augmented Reality*: usage of Augmented Reality to: aid in criminal investigation (e.g. highlighting possible clues), share live video with the digital forensics experts in the department for assistance in finding clues and potential evidence and to overlay relevant information about the person of interest that would be interviewed.
- *Machine Learning*: Facial recognition to share relevant traits and habits of suspects with the investigators that are interviewing them.

The system is divided into two main parts. The first part allows the investigator, who is wearing the headset, to digitally map the crime scene and create digital copies of every object by defining boundaries. This digitized scene can be later used as proof for prosecutions in court. The second part consists of a 2D digital event dashboard comprised by notes and indications that are shared and used to communicate by the officers in the crime scene. This 2D digital event creates a map of the crime scene. When a solved crime scene has been digitally mapped and saved, it can be transferred directly to the headquarters for posterior use (e.g. Training new recruits or even to present it as evidence).

As previously stated, it is important to attest the authenticity of the statements made by the interviewed person. As such, to perform interviews with persons of interest, the system is using the *Azure Cognitive Service app*. Then, with the *HDM* equipped and the aid from the *Azure Face API* alongside the *OpenCV*, which have the capabilities to recognize know faces based on preregistered data in a cloud repository, an officer can have access to exclusive information, in real-time, about the interviewed person (Haque and Saleem 2020).

2.4.3 Street Smart

As declared in the Article 3 of the *Universal Declaration of Human Rights (UDHR)*, *"Everyone has the right to life, liberty and security of person."* (*Universal Declaration of Human Rights* 1948), security of the individuals is a major concern for both men and women. Although men and women are equal in every aspect besides the biology, women have a higher rate of being harassed when travelling through unknown areas.

As such, *Street Smart* was created with the intent to distinguish the safety level of a specific area by incorporating Augmented Reality. The project aims to recommend areas that have a safer security level, aiding women who travel alone, to tourists who have limited knowledge about the area and to women who are working late-night. When a user is passing through an unknown area, the user needs to hold the smartphone and aim the camera to that zone, revealing reviews and articles related to that area. The user can review the popups and articles of the location, retrieved by the system and accordingly decide whether the area is safe or not. Furthermore, while in a dangerous situation, the system allows the user to send emergency messages/calls to the police and the user's registered contacts. The user can submit its personal experience and reviews through the system interface. The *Street Smart* application follows the architecture defined in the Figure 2.13 (Chaudhari et al. 2018).

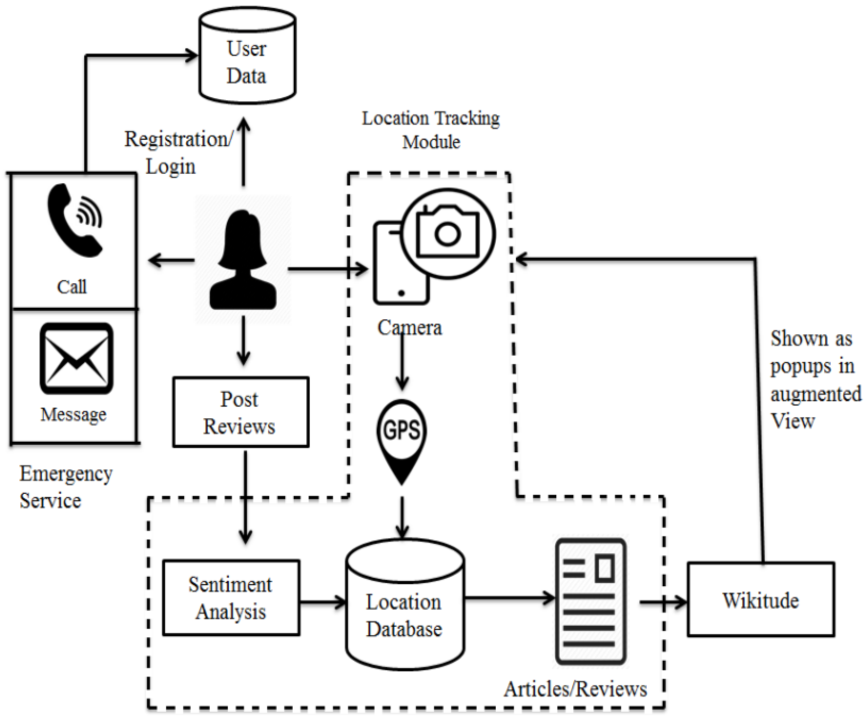

Figure 2.13: Architecture of Street Smart App. (Chaudhari et al. 2018)

The *Street Smart* application contains the following modules: Registration/Login Module, Location Tracking Module, Wikitude, Emergency Message/Call Service and User Reviews.

Regarding the Registration/Login Module, in case of being a new user, it is necessary to register in the application by providing the necessary information such as the ID, Name and Password. If the user is already registered, the user needs to enter his login credentials in order to use the system. Additionally, the user has to register the contact information of three persons to whom the system will send the messages/calls when the user is found in the middle of a hazardous situation.

The Location Tracking Module contains a Global Positioning System recording the location of the user while saving it in the application's database. The saved location will have the corresponding articles and reviews associated, that are then delivered to the user through the system interface. Also, this module includes the Sentiment analysis that is responsible for the calculation of the three possible values in this scenario: positive, negative, and neutral sentiment. For every sentence, the local polarity in the text is evaluated and the relationship between them is determined which finally results in a global polarity value for the whole text. If the value of positive sentiments is more than the negative and the neutral sentiment, the street is labelled as safe. Similarly, if the value of negative sentiment is more than the other two sentiments, then the street is considered unsafe. Likewise, if the value of Neutral is more than the other two sentiments, it not display any result. In line with the result obtained from the sentiment analysis, the message is displayed on the mobile screen as 'Safe Street' or 'Unsafe Street'.

Wikitude is a technology used to apply augmentation in Android mobiles. As such, it provides user's current location-based Augmented Reality experiences by utilizing location triggered augmentations. Using this approach, it is possible to trigger the augmentation through the GPS location and consequently fetch the associated articles and reviews about that location.

If the user finds finds himself in an atypical situation, the user can trigger the system to automatically message/call the police or the the three persons which contacts were given during the registration. The message contains a link with the user's current location.

Lastly, the application allows the user to post reviews and articles about the area that is detected by the device. The sentimental analysis is applied whenever a new review or a post of the location gets added. The next user passing through the same are will have access to the reviews and articles posted by previous users (Chaudhari et al. 2018).

The *Street Smart* system is implemented using *Android studio 3.1*. It is supported on devices that run on Android, contain a camera with 5 Megapixels and requires GPS tracking functions. *MySQL* database is used to store the user credentials, location, articles and reviews. Implementation is done using scripting languages such as HTML, JavaScript and CSS. Wikitude SDK is used for representing articles and reviews in the augmented view.

2.5 AR Technologies

Augmented Reality technologies have thrived in today's software development market. In this section, the most prominent technologies, both open and closed source, will be analysed in order to infer the best one required for this research prototype. According to some articles and posts regarding Augmented Reality software for development, the ones that were prominently referred were: *ARCore*, *ARKit*, *Vuforia Engine*, *AR Foundation* and *Wikitude* (G2 2022, Ilyukha 2022, Program-Ace 2021).

2.5.1 ARCore

In 2014, Google launched the *Tango SDK*, beings its first SDK dedicated to Augmented Reality. This SDK required a smartphone with a depth sensing camera. Besides the AR capabilities that were included at launching, *Tango* was designed to feature 2D and 3D environment mapping. *Lenovo phab 2 pro* was the first equipment to integrate *Tango* technology. The *Tango SDK* was a short lived project, since it was limited to a specific amount of smartphones that included essential sensors that weren't normally featured in regular smartphones.

Despite the bumpy start, Google managed to revive their Augmented reality project when, in March 2018, launched the *ARCore* project. Unlike *Tango*, *ARCore* is multiplatform, being released for both Android (Android Nougat (7.0) or superior) and IOS, the latter requiring that the device was compatible with *ARKit*. Even though *ARCore* was based on the *Tango SDK*, Google opted to release less features that were dependent on exclusive hardware compatibility (specialized cameras), encompassing a larger number of devices that could use the software. As its main functions, *ARCore* features motion tracking, space understanding and brightness estimation (Oufqir, El Abderrahmani, and Satori 2020).

When tracking, *ARCore* uses the device's camera to retain the characteristic points of the viewed scene and the data from the *Inertial Measurement Unit (IMU)* sensor.

Also, it determines the position and orientation of the device as it moves, allowing the virtual objects to be properly positioned in the environment (see Figure 2.14).

Figure 2.14: ARCore virtual object positioning. (*Arcore 1.0 - a realidade aumentada em Crescimento no Android* 2018)

To understand the environment, *ARCore* uses the device's built in sensors in order to detect horizontal surfaces using the same feature points it uses for motion tracking.

Lastly, to perfectly blend the 3D elements into the real world, the software uses the the device to estimate the ambient light (Google 2022c).

The released versions of *ARCore* that have brought major changes in functionalities are the following (Google 2022a):

- version 1.0: World tracking and horizontal plane detection.
- version 1.2: Allows *ARCore* applications to detect images and add the ability to detect vertical surfaces.
- version 1.7: Enable Augmented Faces with the front-facing (selfie) camera.
- version 1.9: tracking moving images in the scene with the possibility to follow the images even if they are no longer visible by the camera. *ARCore* can detect up to 20 images at a time.
- version 1.10: New Environmental HDR mode added to Light Estimation API.
- version 1.11: *ARCore* now targets 60fps on supported devices. Use new camera configuration filters to target 30fps on all *ARCore* devices.
- version 1.19: New Instant Placement API for Android, Android NDK, and Unity as well as new guidance for building for Android 11 with Unity.
- version 1.23: New support for dual camera AR operations.

The remaining released versions corrected various bugs in *ARCore*, made improvements on previous features or some upgrades to the interfaces used by other software, for instance *Unity*. It's worth noting that, at the time, ARCore does not officially enable object identification and recognition (Google 2022a), which can only be done with the help of third-party applications like *OpenCV* or *Vufuria Engine*.

ARCore supported files for 3D objects are: *.obj .glTF .fbx*. These 3D objects can be generated by software such as *Blender* or *SketchUp*.

2.5.2 ARKit

In June 2017, Apple, released its Augmented Reality Application Development denominated *ARKit*. This kit was designed for *IOS* and it allows the development of augmented reality applications for Apple devices with *IOS* 11 or higher. The Apple *ARKit SDK* is available for download for all IOS developers who have an Apple Developer Account.

Similarly to *ARCore*, the *ARKit SDK* features tracking, understanding the environment and brightness estimation. Additionally, the kit also includes Static 2D image recognition.

ARKit allows the user to track the smartphone's position in the real world in real time. To do this, the SDK combines the *Visual Inertial Odometer (VIO)* with data received from the camera and the motion sensor of the device.

Apple devices, with *ARKit*, can identify real-world vertical and horizontal flat surfaces in real time for realistic integration of virtual elements.

As far as detecting the environment brightness, *ARKit* is able to utilize the device's sensor to determine the amount of light in the surrounding scene to apply the degree of brightness to the virtual object. *ARKit* can also create reflections of real objects on virtual metal or glass.

Lastly, *ARKit* includes Static 2D image recognition, which allows storing images within the application and to detect them in the real environment, in order to display and superimpose virtual information on said images (Oufqir, El Abderrahmani, and Satori 2020).

Currently there are various available versions of *ARKit*. Nonetheless, *ARKit 5* is the latest version, mainly providing the following functionalities (Apple 2022b & Apple 2022c):

- *ARKit 5* allows the scanning of 3D objects (see Figure 2.15), compressing the extracted information into a file with an *arobject* extension, which then allows the object to be recognized in the real world and augmented with virtual information.
- Motion tracking when the image to which a virtual object is associated moves in the scene.
- The software includes the face tracking, following the movements and facial expressions using the device's front camera. The use of this feature is limited to device's that integrate the *TrueDepth* camera.
- During a first augmented reality experience in an unknown environment, the user can save a digital card containing all its information. The said card can be reloaded in the same environment, optimizing the detection and tracking processes since the information is already preloaded.
- *ARKit 5* allows multi user in augmented reality applications or games. As such, Augmented reality experiences can now be shared and fixed in real locations between two or more users.
- It allows placing AR experiences at specific places, such as cities and famous landmarks as *Location Anchors*, which permits the user to anchor his AR creations at a certain latitude, longitude, and altitude. Users can move around virtual objects to see them from different perspectives, exactly as real objects are seen through a camera lens.
- People occlusion is a functionality integrated in *ARKit 5*, where AR content realistically passes behind and in front of people in the real world, making AR experiences more immersive while also enabling green screen-style effects in almost any environment.

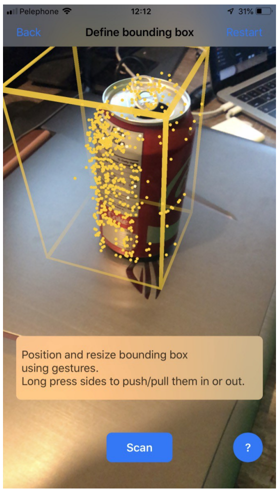

Figure 2.15: ARKit object detection. (Novick 2018)

Lastly, regarding virtual objects rendered into a scene, *ARKit 5* supports several 3D formats with those being the following: *.abc .usd(.usda, .usdc) .usdz .ply .obj .stl* (Apple 2022a).

2.5.3 Vuforia Engine

Vuforia Engine is a popular AR development platform that works with a broad range of phones, tablets, and eyewear. To create AR experiences that genuinely interact with objects and the environment, developers can quickly integrate, with Vuforia libraries, powerful computer vision technology to Android, iOS, and UWP apps. Vuforia Engine can track a wide range of items and locations, which are divided into three categories: Images, Objects, and Environments. Image Targets, Multi Targets, Cynder Targets, and VuMarks are the four subcategories of Image Tracking (Vuforia 2022).

Content attachment to flat pictures, such as print media and product packaging, is included in the image targets. Image Targets can be created at runtime or from a database (see Figure 2.16).

Multi Targets combine several Image Targets into conventional geometric forms (such as boxes) or any arbitrary configuration of planar surfaces. Images wrapped around cylindrical or near-circular objects can be recognized using Cylinder Targets (e.g. beverage bottles, coffee cups, soda cans).

VuMarks are customizable data encoding markers that may encode a variety of data formats. For AR applications, they support both unique identification and tracking.

Model Targets, which are used to recognize items by shape using pre-existing 3D models, make up the Object category. It also allows AR material to be placed on a variety of products such as industrial machinery, vehicles, toys, and home appliances. Vuforia also offers a model target generator which eases the creation of a Model Target.

There are two components to the tracking environments: Area Targets and Ground Plane (Vuforia 2022).

The Vuforia Area Target Creator app or a commercially available 3D scanner can be used to scan Augmented Real Environments, which are used to depict the targets. It enables for the precise creation of aligned persistent content in a variety of commercial, public, and recreational settings in order to enrich locations with augmented experiences.

The Ground Plane allows users to place material on horizontal surfaces such as tables and floors in the environment.

Vuforia also has other elements that are important to this study, such as Vuforia Fusion. Vuforia Fusion is built to deliver the greatest possible AR experience across a variety of platforms. Fusion detects the underlying device's capabilities (such as ARKit/ARCore) and fuses them with Vuforia Engine's features, allowing developers to rely on a single Vuforia API for the best AR experience. This functionality works in conjunction with the AR Foundation platform (Vuforia 2022).

Figure 2.16: Vuforia Image targeting (Vuforia 2022)

2.5.4 AR Foundation

AR Foundation is an augmented reality development platform that allows developers to create rich experiences once and then deploy them across many mobile and wearable AR devices. AR Foundation combines fundamental capabilities from ARKit, ARCore, Magic Leap, and HoloLens with unique Unity features to allow developers to create comprehensive apps that can be distributed internally or on any app store. This framework enables the developer to use all of these capabilities in a single process.

When switching between AR platforms that do not have the functionality that were present in the initial AR Platform, the AR Foundation allows development using currently unavailable features. If a feature is enabled on one platform but not another, AR Foundation adds hooks to make it available later. When the functionality is enabled on the new platform, the developer is able to quickly incorporate it by upgrading the packages rather than rebuilding the app from the ground up.

AR Foundation enables multi-platform collaboration with augmented reality platforms within Unity. This package provides an interface for Unity developers to utilize, but it does not include any AR capabilities. To use AR Foundation on a target device, the developer must additionally have separate packages for the target platforms that Unity officially supports:

- ARCore XR Plug-in on Android
- ARKit XR Plug-in on iOS
- Magic Leap XR Plug-in on Magic Leap
- Windows XR Plug-in on HoloLens

As a multi-platform API that serves as a conduit for the usage of many platforms, AR Foundation supports a number of relevant specific features (See Table 2.2).

Table 2.2: AR Foundation supported specific features

	ARCore	ARKit	Magic Leap	HoloLens
Device tracking	✓	✓	✓	✓
Plane tracking	✓	✓	✓	
Point clouds	✓	✓		
Anchors	✓	✓	✓	✓
Light estimation	✓	✓		
Environment probes	✓	✓		
Face tracking	✓	✓		
2D Image tracking	✓	✓	✓	
3D Object tracking		✓		
Meshing		✓	✓	✓
2D & 3D body tracking		✓		
Collaborative participants		✓		
Human segmentation		✓		
Raycast	✓	✓	✓	
Pass-through video	✓	✓		
Session management	✓	✓	✓	✓
Occlusion	✓	✓		

2.5.5 Wikitude

Wikitude is an Austrian company that provides mobile augmented reality (AR) technology. Wikitude, which was founded in 2008, primarily focused on offering location-based augmented reality experiences via the Wikitude World Browser App. The business revamped its offering in 2012 by releasing the Wikitude SDK, a development platform that uses picture identification and tracking, as well as geolocation technology.

Wikitude announced its acquisition by Qualcomm in September 2021.

The Wikitude SDK is the company's main offering. The SDK, which was first released in October 2008, contains picture recognition and tracking, 3D model rendering, video overlay, and location-based AR. Wikitude introduced its SLAM (Simultaneous Localization And Mapping) technology in 2017, which enables object detection and tracking as well as markerless immediate tracking.

The cross-platform SDK is available for Android, iOS, and Windows, and it has been optimized for a variety of smart eyewear devices (Wikitude 2021).

Among other features, Wikitude mainly supports:

- Object & Scene Tracking
- Instant Tracking
- Image Tracking
- Multiple Image Targets
- Cloud Recognition
- Geo AR
- Cylinder Tracking
- Multiple Object Tracking
- Multiple Trackers

2.5.6 Technology Comparison and Decision

All of the technologies previously mentioned in this chapter have some common characteristics. Almost all of them incorporate the standard characteristics found in this sort of technology. The following Table 2.3 depicts some of the differences between the analysed technologies.

Table 2.3: Differences in the studied technologies

	ARCore	ARKit	Vuforia	Wikitude	AR Foundation
Device tracking	✓	✓	✓	✓	✓
Plane tracking	✓	✓	✓	✓	✓
Point clouds	✓	✓	✓	✓	✓
Anchors	✓	✓	✓		✓
Light estimation	✓	✓			✓
Environment probes	✓	✓			✓
Face tracking	✓	✓		✓	✓
2D Image tracking	✓	✓	✓	✓	✓
3D Object tracking		✓	✓	✓	✓
Meshing		✓	✓		✓
Raycast	✓	✓			✓
Cylinder Tracking			✓	✓	
No Costs associated	✓	✓			✓

AR Foundation and the Vuforia Engine were chosen as technologies for this thesis.

The reason to why the AR Foundation was chosen relies on its highly adaptable platform that integrates the best of several AR technologies, including ARKit, ARCore, Magic Leap, and HoloLens. AR Foundation is built with Unity, which was a crucial consideration for selecting this platform given the thesis author's previous experience. Unity also makes it easier to launch Android and iOS apps, streamlining the development and testing procedures. AR Foundation is an open source development with a good technical support, no additional costs and has an enormous community that can be relied upon when searching for the best solution.

As for Vuforia Engine, it was chosen since it is an open source solution that may also be used in conjunction with Unity; however, more particular capabilities may incur additional costs. Vuforia has a large community and strong technical assistance. During the research, Vuforia also revealed the prospect of using it in combination with AR Foundation, thereby aggregating features from both technologies. Vuforia also supports a broader range of AR internal cameras for usage in the app.

2.6 Unity Development Considerations

Since the above mentioned technologies are widely implemented in Unity, this section will review the main considerations to keep in mind while creating a Unity application. The following is a breakdown of the section: Scene creation, Unity scripts, Cameras and the UI Canvas.

2.6.1 Scene Creation

Scenes contain all of the application's components. They may be utilized to create a primary menu, several levels, and other things. Each Scene file should be treated as a different level. The developer may include settings, obstacles, and decorations in each Scene, basically building the program piece by piece.

The already established Scene objects, which correlate to the components such as obstacles or decorations utilized inside a Unity scene, are called GameObjetcs, and the developer may place them wherever he wants. Scenes are created with the Unity interface and may be interacted with as the program is being developed (Technologies 2022).

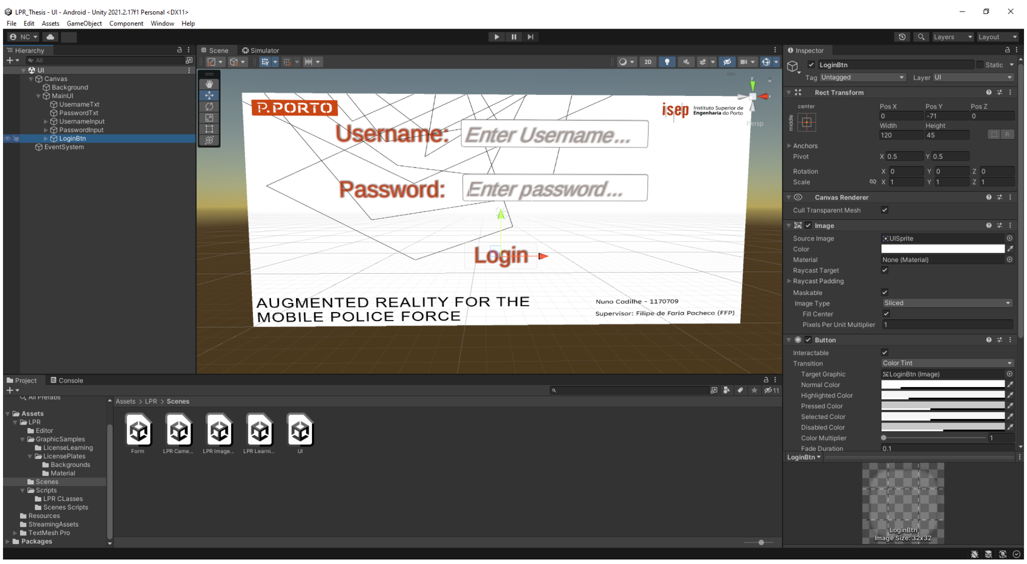

Figure 2.17: Unity Interface with a Scene

Figure 2.17 contains a Scene example that contains a Scene and its components and had the Login button selected in the Inspector. The inspector is located on the right side of the screen, and it allows the developer to fiddle with with the built components as well as add scripts. The developer may check and track the Project folders, hierarchy and components on the left and bottom sides of the screen.

2.6.2 Unity scripts

GameObjects' behavior is dictated by the Components that are associated with them. Although Unity's built-in Components are quite flexible, the developer must go above and beyond to achieve the needed interaction elements. Using scripts, Unity allows developers to design their own Components. These enable game events to be triggered, as well as the modification of Component attributes over time and the response to user interaction. Unity comes with built-in support for two programming languages:

- C# (pronounced C-sharp), an industry-standard language similar to Java or C++;
- UnityScript, a language designed specifically for use with Unity and modelled after JavaScript (Technologies 2022);

Many other.NET languages, assuming they can generate a suitable Dynamic-link library (DLL), can also be utilized with Unity.

A script connects to Unity's internal workings via implementing a class that inherits from MonoBehaviour, which is a built-in class. A class serves as a template for developing new Component types that may be added to GameObjects. When a script is added as a component to a GameObject, it produces a new instance of the blueprint's object. The class's name is derived from the name provided by the developer when the file was created. To attach a script component to a GameObject, the class name and file name must be the same (Technologies 2022).

```
using UnityEngine;
using System.Collections;

public class MainPlayer : MonoBehaviour {

    // Use this for initialization
    void Start () {

    }

    // Update is called once per frame
    void Update () {

    }
}
```

Listing 2.1: Example of a Script in C#

The two functions specified within the class (Listing 2.1) are the best to understand the inner-works of Scripts. The Update method is where the developer writes code to manage the GameObject's frame update. This might involve things like movement, initiating activities, and responding to user input, or anything else that has to be handled over time while playing. Before any game activity takes place, it's typically helpful to be able to set up variables, read preferences, and link with other GameObjects so that the Update method can perform its job. Unity will call the Start method before the game starts (i.e. before the Update function is called for the first time), thus it's a good location to conduct any initialization (Technologies 2022).

The developer may be surprised to learn that an object's initialization is not accomplished through the use of a constructor function. This is because, contrary to expectations, item building is handled by the editor rather than occurring at the start of Script. If a developer tries to write a constructor for a script component, it will disrupt Unity's usual functioning and potentially cause serious project errors (Technologies 2022).

2.6.3 Cameras

Cameras in Unity are used to present the game environment to the player in the same way that real cameras are used in films to display the plot to the spectator. In a scenario, the developer will always have at least one camera, but there is the possibility of having more. One may use several cameras to create a two-player splitscreen or complex custom effects. The cameras can be animated or physics-controlled. The camera's functionality is extremely versatile, allowing the developer to construct a unique version for each use case (Technologies 2022).

2.6.4 UI Canvas

All UI components should be contained within the Canvas. All UI components must be children of a Canvas, which is a Game Object with a Canvas component on it. If there isn't currently a Canvas in the scene, creating a new UI element, such as an Image, from the menu GameObject > UI > Image, instantly produces one. This Canvas's UI element is produced as a child. In the Scene View, the Canvas area appears as a rectangle. This allows developers to arrange UI items without needing to have the Game View open all the time (Technologies 2022).

Chapter 3

Value Analysis

While it is both an organized method to enhance the profitability of product applications and it employs many distinct strategies to achieve this goal, Value Analysis (VA) is regarded as a process rather than a simple technique (Rich and Holweg 2000).

This chapter is about value analysis, and it starts with a section about business processes and innovation, where the New Concept Development (NCD) model will be applied. Then moves on to customer value, value proposition with the canvas business model included, and an application of the Analytic Hierarchy Process (AHP) for multi-criteria decision to help choose the best Augmented Reality alternative to consider.

3.1 Innovation Process

According to Koen, the innovation process is divided into three distinct areas: the fuzzy front end (FFE), the new product development (NPD) process, and commercialization, as indicated in Figure 3.1 (Koen et al. 2001).

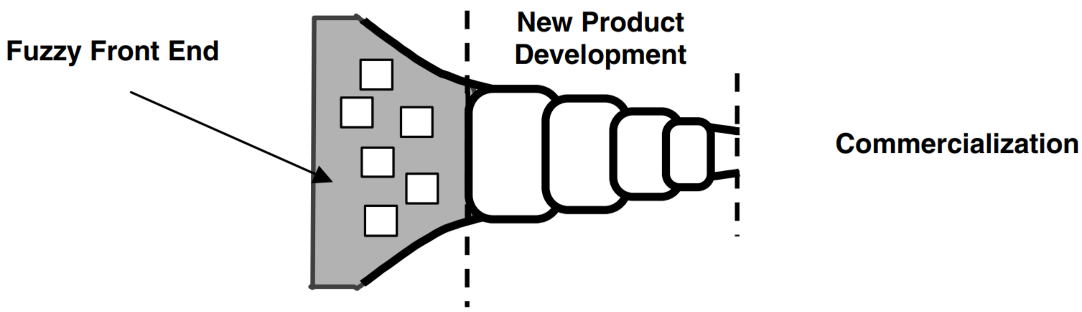

Figure 3.1: Innovation Process division diagram. (Koen et al. 2001)

The Figure 3.1 leftmost area, also known as the *Fuzzy Front End*, symbolizes an unstructured, chaotic, and experimental state in which commercialization and finance variables are uncertain, and where business concepts are improving and strengthening.

The *New Product Development* occupies the central area of the Innovation Process division diagram, contemplating the objectives-oriented specific plans, delineating concrete dates, and assigning teams focused on the development and testing of the products.

Lastly, regarding the rightmost position area of the Figure 3.1, the *Commercialization* represents the culmination of the previously analyzed areas that, when the innovative process reaches its ending stage, aims for the commercialization of the final product.

Because there were no common words and definitions for important parts, comparing *Fuzzy Front End (FFE)* between organizations was difficult. It may be impossible to create new information and distinguish between different stages of the process without a common language and terminology. When both parties mean distinct things, even when they use the same language, knowledge transfer is ineffective or unlikely. These findings prompted Koen and his colleagues to feel that better understanding of the *FFE* might be achieved by explaining it in words that were universally understood, resulting in the New Concept Development (NCD) (Koen et al. 2001).

3.1.1 New Concept Development

The NCD model shown in Figure 3.2 consists of three key parts:

- *Bull's-eye section*: The organization's leadership, culture, and business strategy drive the five essential factors that are controllable by the corporation, which is known as the engine or bull's-eye section.
- *Inner spoke*: The FFE's five controlled activity elements are defined by the inner spoke region (opportunity discovery, opportunity analysis, idea generation and enrichment, idea selection, and concept definition).
- *Influencing Factors*: Organizational capabilities, the external world (distribution channels, law, government policy, customers, competitors, as well as the political and economic climate), and the enabling sciences (internal and external) that may be involved are the influencing factors. These elements have

an impact on the entire innovation process, from conception through commercialization. These contributing elements are mostly outside the corporation's control (Koen et al. 2001).

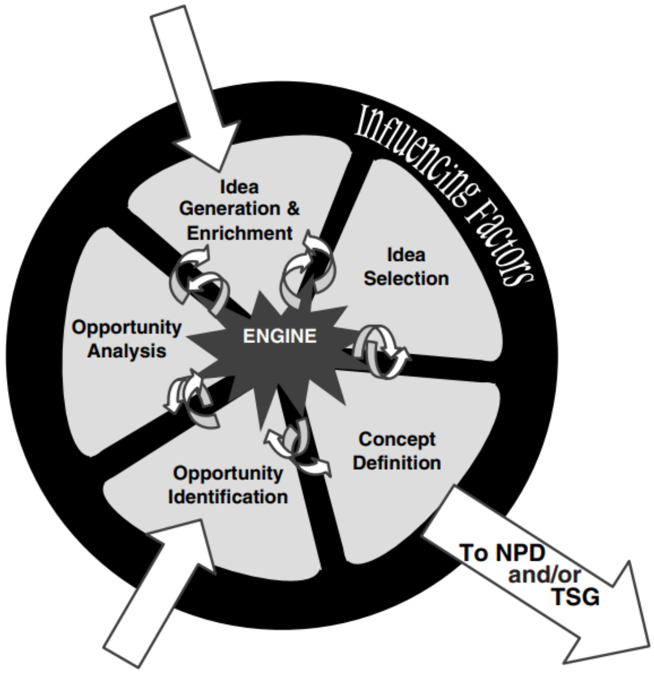

Figure 3.2: *NCD* model. (Koen et al. 2001)

Additionally, the two arriving arrows indicate that a project can begin at either the "opportunity identification" or "idea generation and enrichment" stage.

3.1.2 Opportunity Identification

Opportunities can manifest themselves in various ways, such as the introduction of a product or the addition of new features to current products/services.

As stated in the Section 1.2, despite all of the examples in Investigation TV Series and Movies where AR is employed as a catalyst to speed up police work, police officers still miss the help of those technology in their field job. For example, a police officer who wants to identify a specific car during a Stop Operation in order to issue an infraction ticket must perform a series of actions, such as entering data (plate, color, brand, model) about the vehicle into the system (computer, tablet, PDA, etc), and this process may take too long, slowing down the Stop Operation's efficiency.

As such, this research focus lies in the emergent need to use Augmented Reality to assist Police Officers in a daily basis.

3.1.3 Opportunity Analysis

An opportunity is evaluated to see if it is worthwhile to pursue. For transforming opportunity identification into specific business and technological opportunities, more information is required. Making early and often speculative technology and market judgments is part of this process. Focus groups, market surveys, and/or scientific trials may necessitate a significant amount of effort. The amount of effort expended, however, will be determined by the value of the information associated with reducing uncertainties about the attractiveness of the opportunity, the size of the future development effort expected given the fit with the business strategy and culture, and the risk tolerance of the decision makers (Koen et al. 2001).

As a result, the SWOT analysis was employed in order to have a deeper understanding of the highlighted opportunity. This is a crucial decision-making approach that lays the groundwork for situational and choice analysis. Although SWOT analysis has its roots in economics, it has since been used in a wide range of fields and research areas. It has four major benefits: it is simple, collaborative, flexible, and integrative. The above analysis is straightforward to understand, participatory, and adaptable to any importance scale. The presence of internal and external components with positive and negative characteristics results in a reasonably extensive and comprehensive SWOT instrument. Finally, because of these numerous benefits, the approach is still beneficial when evaluating an opportunity. (Gürel 2017).

The SWOT analysis is broken down into four sections:

- Strength: The positive internal influences that add value to the premise are represented by this metric.
- Weakness: Internal flaws that push back and produce fallacies and disadvantages for the opportunity as compared toward others.
- Opportunities: External circumstances that add value to the opportunity and drive it forward; this could be any external force that aids in the creation or success of the solution.
- Threats: Identifies external negative forces that could cause the project to come to a halt.

Table 3.1: SWOT table

strengths	weaknesses
• Nonexistent Bureaucracy. • Police work efficiency. • It makes the work of the police force more engaging.	• Lack of specialized hardware. • The development team has been reduced to only one member. • Lack of financial investment.
opportunities	**threats**
• On the current market, there are a variety of Augmented Reality technologies. • The market for augmented reality is growing. • The focus of existing solutions differs from the one investigated in this thesis.	• Highly competitive market. • Due to legal implications, acceptance of Augmented Reality is difficult. • There is a scarcity of specialized police information:

Strengths

- Nonexistent Bureaucracy: There aren't many limits on decision-making and choice-making because the project is just affiliated with this thesis author. As a result, faster integration, development, and adaptation are possible.

- Police work efficiency: As previously stated in Section 1.3, augmented reality will aid police officers in their daily work by assisting them with data insertion and analysis processes.

- It makes the work of the police force more engaging: The Police's work becomes more dynamic and interesting as a result of the introduction of new technology that is extremely adaptable. It also eliminates the monotony of some operations.

Weaknesses

- Lack of specialized hardware: This research currently lacks specialized devices capable of using Augmented Reality, such as *Google Glass* or the *HoloLens*. As a result, it is restricted to smartphone use.

- The development team has been reduced to only one member: Because the development team is solely made up of the author of this dissertation, the functionalities that can be implemented are constrained by the amount of time available. As a result, there is a disadvantage in comparison to other projects that include multi-element teams.

- Lack of financial investment: Because this is an academic research with no funding, the author must adapt to the circumstances and use open-source tools. Failure to use licensed software might cause delays in responding to requests and implementing new features.

Opportunities

- On the current market, there are a variety of Augmented Reality technologies: Various competent technologies are available on the market nowadays that can be used to construct an Augmented Reality solution. In Section 2.5, several of these technologies are mentioned.
- The market for augmented reality is growing: In 2020, the global Augmented Reality market was worth USD 4.16 billion. The market is expected to increase at a *Compound Annual Growth Rate (CAGR)* of 48.6% from USD 6.12 billion in 2021 to USD 97.76 billion in 2028. The global impact of COVID-19 has been unprecedented and startling, with demand in all regions showing a minor downward trend during the epidemic. According to Fortune Business Insights, the global market rised by 46.8% in 2020, compared to the average year-on-year growth from 2017 to 2019. The increase in *CAGR* is due to market demand and expansion, which will eventually return to pre-epidemic levels after the pandemic is finished (Insights 2022).
- The focus of existing solutions differs from the one investigated in this thesis: Existing Augmented Reality technologies aimed at assisting police work take a different approach from the ones investigated in this thesis, such as applications that aid in crime investigation or even personal protection (such examples are listed in Section 2.4).

Threats

- Highly competitive market: Despite their various objectives, there are numerous solutions that use augmented reality to assist police officers in their daily work (for example the solutions referred in Section 2.4).
- Due to legal implications, acceptance of Augmented Reality is difficult: The use of Augmented Reality may not be in accordance with the assurance of

appropriate access to the many data sources that are used, as well as any licenses or terms of use for the data. To authorize the usage of these types of systems, further formalities may be required (as previously stated in the Section 2.4.1).

- There is a scarcity of specialized police information: There is a scarcity of information on the Police *Modus Operandi*, which limits the system's development.

3.1.4 Idea Generation and Enrichment

Idea generation and enrichment is concerned with the emergence, development, and maturation of a concrete idea. The process of generating ideas is cyclical. Building, tearing down, combining, reshaping, modifying, and upgrading ideas are all part of the creative process. As it is reviewed, studied, discussed, and developed in connection with other aspects of the *NCD* model, an idea may go through a number of iterations and alterations. This work is frequently enhanced by direct interaction with consumers and users, connections with other cross-functional teams, and collaboration with other firms and institutions (Koen et al. 2001).

In this study, there were three main ideas that included Augmented Reality technologies that would ultimately improve the Police Department's productivity. Filipe de Faria Pacheco, the thesis's adviser, discussed the above ideas resulting in the following proposals:

- An application that employs augmented reality to help police question and identify suspects: It is critical to verify the veracity of the remarks given by the interviewee. As a result, the system would be equipped with a face identification Augmented Reality feature to conduct interviews with persons of interest. Then, using the smartphone and the aforementioned facial recognizing capability in conjunction with an image detection system like *OpenCV*, which can recognize known faces based on preregistered data in a database, an officer can get exclusive information about the person being interviewed in real time.
- An application that employs Augmented Reality to aid in the investigation and resolution of crimes: Even if professional criminologists were not physically present, the system would be equipped to allow them to participate actively in the search. A police officer can get a new perspective on a crime scene by using the prototype, which includes an Augmented Reality depiction of the scenario on a smartphone. As officers search the area, footage from a camera

on their vest would be routed to personnel at other locations, such as forensic scientists or chemical experts. These remote colleagues can contribute notes and information to the officer's AR perspective, which can range from a request to explore a specific region.

- An application that assists in the issuance of infraction tickets through the use of Augmented Reality: implementation of an Augmented Reality system to enable faster data collection in order to ease and streamline the infraction ticket issuing process, thus opening up the possibility of developing a solution that, using AR, can display relevant information to a police officer on a portable device and assist in gathering the needed information (e.g. identify the make and model of the vehicle, automatic recognition of license plate, etc).

3.1.5 Idea Selection

In most cases, the issue isn't coming up with fresh ideas, but rather executing them. There is never scarcity of new ideas, even when the enterprises are smaller. Most firms struggle with deciding which concepts to pursue in order to maximize profits. Making the right choice is crucial to the company's long-term health and prosperity. However, no single procedure can ensure a satisfactory selection. Most idea selection processes are iterative, involving many runs through opportunity identification, opportunity analysis, and idea development and enrichment, with additional insights from influencing factors and engine instructions thrown in for good measure (Koen et al. 2001).

Analytic Hierarchy Process (AHP)

After the alternative design process is completed, it's time to assess the options in order to come up with a concrete solution to the recognized problem. Given that option selection is a critical procedure for the project's future, it was chosen to use a multi-criteria decision support approach, denominated *Analytic Hierarchy Process (AHP)*. The latter, presented by Thomas L. Saaty, takes a rational approach based on the use of mathematical tools and the crossing of the alternatives with the established criteria (T. Saaty 1980).

To apply the AHP approach successfully, one must first create a Hierarchical Decision Tree, which specifies and frames the problem in a hierarchical diagram.

It entails breaking down the objective into criteria and their dependent alternatives (Nicola 2022). The alternatives for this project are those listed in Section 3.1.4:

- Alternative **A**: An application that employs augmented reality to help police question and identify suspects;
- Alternative **B**: An application that employs Augmented Reality to aid in the investigation and resolution of crimes;
- Alternative **C**: An application that assists in the issuance of infraction tickets through the use of Augmented Reality;

The following criteria were chosen to assess the best project to pursue in this research:

- Innovation: The goal of the Innovation criterion is to disclose the solution's uniqueness while also ensuring that its added value is distinct from what is currently available on the market.
- Impactfulness: The impactfulness criterion will determine whether the solution's proposed value is relevant to the customer, as well as the learning curve required to master the application.
- Time: Given the time constraints of this dissertation, the time criterion determines which alternative is the best to implement.
- Execution: The Execution criterion is to distinguish the optimal alternative that can better comply with the stated limitations, given the hardware, technology, and knowledge constraints.

The Figure 3.3 contains the representation of the Hierarchical Decision Tree.

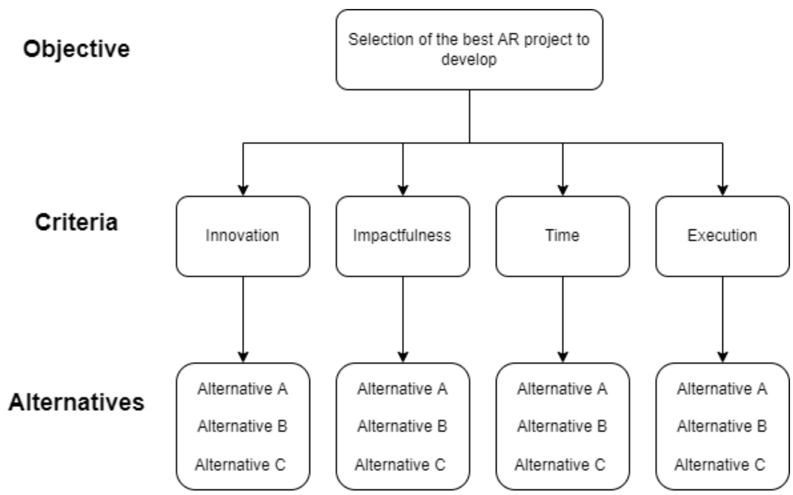

Figure 3.3: Hierarchical Decision Tree

Alternatives and Criteria

A comparison matrix is used to assign precedence to all alternatives and criteria in the following phase. The Saaty fundamental scale, which is referenced in Table 3.2, is used to assign priority levels to the criterion.

Table 3.2: Saaty fundamental scale (T. L. Saaty 1990)

Intensity of importance	Definition	Explanation
1	Equal importance	Two activities contribute equally to the objective
3	Weak importance of one over another	Experience and judgment slightly favour one activity over another
5	Essential or strong importance	Experience and judgment strongly favour one activity over another
7	Demonstrated importance	An activity is strong favored and its dominance is demonstrated in practice
9	Absolute importance	The evidence favoring one activity over another is of the highest possible order of affirmation
2, 4, 6, 8	Intermediate values between the two adjacent judgments	When compromise is need

It was possible to generate the following comparison matrix (Table 3.3) after comparing the recurrent Criteria to the Saaty fundamental scale.

Table 3.3: Comparison Matrix between Criteria

	Innovation	**Impactfulness**	**Time**	**Execution**
Innovation	1.000	3.000	2.000	3.000
Impactfulness	0.333	1.000	0.333	0.500
Time	0.500	3.000	1.000	3.000
Execution	0.333	2.000	0.333	1.000

Following the comparison matrix, all values are normalized by dividing each value by the sum of the column in which it appears. Second, in order to establish the importance hierarchy between the criteria, the priority vector is created using the arithmetic average of the normalized values from each line (Table 3.4).

Table 3.4: Normalized Comparison Matrix and Relative Priority Vector

	Innovation	**Impactfulness**	**Time**	**Execution**	**Priority Vector**
Innovation	0.462	0.333	0.545	0.400	0.435
Impactfulness	0.154	0.111	0.091	0.067	0.106
Time	0.231	0.333	0.273	0.400	0.309
Execution	0.154	0.222	0.091	0.133	0.150

When looking at Table 3.4, it's possible to deduce that the criteria are arranged in the following order: **Innovation** > **Impactfulness** > **Time** > **Execution**. Since the main goal of this thesis is to introduce an unique use of Augmented Reality to aid law enforcement that has yet to be seen in the market, this result was expected.

The Consistency Ratio (CR) is calculated last in the next phase to assess the consistency of the judgments. If the value of CR is less than 0,1, the judgments are regarded as reliable (Nicola 2022).

First, λ_{max} is calculated using the formula:

$$Ax = \lambda_{max} x \tag{3.1}$$

The normalized comparison matrix is A and the priority vector is x (which were calculated in Table 3.4), and its subsequent multiplication results are represented in the following Table 3.5.

Table 3.5: Consistency Matrix Comparison

Innovation	1.821
Impactfulness	0.429
Time	1.294
Execution	0.609

Resorting to the latter values from Table 3.5, the following formula can be used to infer the calculation of the λ_{max}:

$$\lambda_{max} = \frac{1.82/0.44 + 0.43/0.11 + 1.29/0.31 + 0.61/0.15}{4} \approx 4.12 \tag{3.2}$$

As result, with all the already calculated values it is possible to obtain the Consistency Index (CI) with the following equation:

$$CI = \frac{\lambda_{max} - n}{n - 1} \tag{3.3}$$

Where, when replacing the formula with the previously obtained values, it is possible obtain:

$$CI = \frac{4,12 - 4}{4 - 1} \approx 0.041 \tag{3.4}$$

The number of criteria is denoted by the letter n. The CI result is around 0,041. Finally, the following formula can be used in order to calculate the Consistency Ratio:

$$CR = \frac{CI}{RCI} \tag{3.5}$$

Thus the RC still needs the the Random Consistency Index for our matrix, which corresponds to the RCI. The RCI value is defined in Table 3.6.

Table 3.6: Random Consistency Index (Nicola 2022)

1	2	3	**4**	5	6	7	8	9	10	11	12	13	14	15
0.00	0.00	0.58	**0.90**	1.12	1.24	1.32	1.41	1.45	1.49	1.51	1.48	1.56	1.57	1.59

While performing this analysis, four criteria were used, hence obtaining an RCI of 0.90, resulting in the following formula:

$$CR = \frac{CI}{RCI} = \frac{0,041}{0,90} \approx 0.045 \tag{3.6}$$

Since the obtained CR value was approximately 0.045, which is less than 0.1, it is possible to infer that the priority values are regarded as reliable.

The next stage is to develop a comparison matrix for each criterion, taking into account all options, in order to determine which project is the best based on the criteria utilized by calculating the global relative priority. The process is completed by repeating the development of the comparison matrices (this time, between each criterion and alternative), the normalizing matrix, and the priority vector calculation.

Tables 3.7, 3.8, 3.9 and 3.10 show the initial comparison using the fundamental scale (Table 3.2).

Table 3.7: Comparison Matrix between Innovation in Alternatives

	Innovation		
	A	**B**	**C**
A	1.000	2.000	0.500
B	0.500	1.000	0.333
C	2.000	3.000	1.000

Table 3.8: Comparison Matrix between Impactfulness in Alternatives

	Impactfulness		
	A	**B**	**C**
A	1.000	3.000	0.333
B	0.333	1.000	0.250
C	3.000	4.000	1.000

Table 3.9: Comparison Matrix between Time in Alternatives

	Time		
	A	**B**	**C**
A	1.000	4.000	0.500
B	0.250	1.000	0.200
C	2.000	5.000	1.000

Table 3.10: Comparison Matrix between Execution in Alternatives

	Execution		
	A	**B**	**C**
A	1.000	3.000	1.000
B	0.333	1.000	0.333
C	1.000	3.000	1.000

The matrices are then normalized, and the local priority vector for each is determined, thus displaying the final results in Tables 3.11, 3.12, 3.13 and 3.14

Table 3.11: Normalized Comparison Matrix and Local Priority for the comparison between Alternatives regarding Innovation Criterion

	Innovation			
	A	**B**	**C**	Local Priority
A	0.286	0.333	0.273	0.297
B	0.143	0.167	0.182	0.164
C	0.571	0.500	0.545	0.539

Table 3.12: Normalized Comparison Matrix and Local Priority for the comparison between Alternatives regarding Impactfulness Criterion

	Impactfulness			
	A	**B**	**C**	Local Priority
A	0.231	0.375	0.211	0.272
B	0.077	0.125	0.158	0.120
C	0.692	0.500	0.632	0.608

Table 3.13: Normalized Comparison Matrix and Local Priority for the comparison between Alternatives regarding Time Criterion

	Time			
	A	**B**	**C**	Local Priority
A	0.308	0.400	0.294	0.334
B	0.077	0.100	0.118	0.098
C	0.615	0.500	0.588	0.568

Table 3.14: Normalized Comparison Matrix and Local Priority for the comparison between Alternatives regarding Execution Criterion

	Execution			
	A	**B**	**C**	Local Priority
A	0.429	0.429	0.429	0.429
B	0.143	0.143	0.143	0.143
C	0.429	0.429	0.429	0.429

Tables 3.11, 3.12, 3.13 and 3.14 results are then combined with Table 3.4's relative priority vector to create a new matrix. The Composite Priority Vector may be calculated using these values by multiplying the result of each alternative with the

priority vector. Based on the criteria, this vector will indicate the relevance of the alternative. Table 3.15 summarizes the findings.

Table 3.15: Criteria/Alternatives Classification Matrix and Composite Priority

	Innovation	**Impactfulness**	**Time**	**Execution**	**Composite Priority**
A	0.297	0.272	0.334	0.429	0.326
B	0.164	0.120	0.098	0.143	0.136
C	0.539	0.608	0.568	0.429	0.539

When using the AHP method to compare the composite priority of the Alternatives in Table 3.15, it is possible to deduce that the best option will be Alternative C, an application that assists in the issuance of infraction tickets through the use of Augmented Reality.

Conclusion

As a result, in collaboration with supervisor Filipe de Faria Pacheco, it was concluded that the best path to pave would be to choose the third idea: an application that uses Augmented Reality to assist in the issuance of infraction tickets. When compared to the aforementioned ideas, the application that speeds the infraction ticket issuing, recurring to Augmented Reality, provides significant advantages.

There were no available implemented solutions regarding this specific idea that fit the newly discovered opportunity described in Section 3.1.2, but this was not the case while analyzing the other offered ideas in the Section above (Section 3.1.4), which already had multiple solutions that are described in the Section 2.4.

The chosen concept was also in line with the SWOT analysis, while minimizing some of the vulnerabilities and threats identified. When choosing the infraction ticket streamlining application, for example, it would lessen the requirement for specific hardware, only requiring a smartphone, and the threat provided by other existing applications, as none of them perform with the same purpose.

Finally, when the AHP method was applied to the existing alternatives, the "Alternative C: An application that assists in the issuance of infraction tickets through the use of Augmented Reality" presented a higher Composite priority than the rest of the Alternatives, with a value of approximately 0.54.

3.2 Value Proposition

A business model is a conceptual tool that incorporates a set of elements and their interactions and enables for the expression of a company's business logic. A conceptual approach to business models allows you to capture, model, explain, communicate, track across time, and maybe measure and simulate them. Some authors consider it as a novel analytical unit and a useful tool for innovation. The "what," "who," "how," and "how much" of a firm, according to Osterwalder and Pigneur, may be broken down into four simple pillars. To put it another way, these pillars enable a company to express what it offers, who it targets with it, how it may be realized, and how much money can be made doing it (Osterwalder and Pigneur 2003).

The Value Proposition of the project resides in the implementation of an Augmented Reality system to enable faster data collection in order to ease and streamline the infraction ticket issuing process, thus opening up the possibility of developing a solution that, using AR, can display relevant information to a police officer on a portable device (e.g. identify the make and model of the vehicle, automatic recognition of license plate, etc). A police officer who adopts this system will be more engaged in his duties and will be able to operate more efficiently as a result.

3.3 Customer Value

Dr. Alexander Osterwalder created the Value Proposition Canvas as a framework for ensuring that the product and market are compatible. It's a close examination of the link between two components of Osterwalder's larger Business Model Canvas: client segmentation and value propositions. The Value Proposition Canvas can be used to improve an existing service or product or to create a new one from start.

3.3.1 Customer Profile

There are three major aspects in customer profiling: gains, pains, and customer jobs.

The Gains represent the benefits that the customer expects and requires, as well as the things that would pleasure customers and enhance the possibility of embracing a value proposition. As a result, the client, a police officer, will be able to: easily issue infraction tickets; have faster access to crucial information that will be directly superimposed onto real objects; and use real-time image processing to aid in object identification.

The negative experiences, emotions, and risks that the consumer has while getting the job done are represented by pains. The customer pains in this study are represented by a potential lack of interest in and adaption to the provided technology. Because this is a new way of doing things, it may take some time, and some police officers may not appreciate the new adjustments. There's also the possibility of application downtime or incorrect object identification.

Finally, customer jobs represent the functional, social, and emotional activities that consumers are attempting to do, as well as the difficulties and requirements that they wish to meet. As a result, the clients in this dissertation require a method to streamline the process of issuing infraction tickets as well as speedier object recognition.

3.3.2 Value Map

Gain Creators, Pain Relievers, and Products and Services are three distinct sectors that represent the value that is eventually delivered to the client.

The Gain Creators are illustrated by how the product or service adds value to the customer and creates gains for them. As a result, the system developed in this dissertation aims to give a solution to the client that: provides a transparent and expedited method of issuing infraction tickets; provides clear recognition of predefined real objects; and allows for speedier data cross-reference.

The Pain Relievers are a description of how the product or service helps customers with their pains. As a result, the produced system will reduce the disinterest in acquiring its relevant know-how by providing a well-designed, user-friendly interface. In order to reduce downtime, the application will also do regular data backups. Finally, the system will use numerous stored images to improve object detection.

The Products and Services sector includes products and services that generate profit and alleviate suffering, as well as those that support the production of value for customers. As a result, the system will provide the customer with a new possible use of AR for law enforcement departments, which will be incorporated into the aforementioned solution referred to in Section 3.2, which is a system that streamlines the infraction ticket procedure.

3.4 Canvas Business Model

Alexander Osterwalder's CANVAS business model can conceptualize an organization's characteristics through three factors (Joyce and Paquin 2016): how different parties organize themselves to deliver value to consumers, how they connect within the organization, and how the organization generates value through these links. Table 3.16 depicts the Business CANVAS model, which describes how the product developed in this dissertation operates and fits into a business.

Table 3.16: Canvas Business Model

<table>
<tr>
<td rowspan="2">Key Partners

Police Department: Will provide the information and procedures to incorporate in the application.</td>
<td>Key Activities

• display relevant information overlaid with real objects (e.g. identify the make and model of the vehicle, automatic recognition of license plate, etc) to a police officer on a portable device;
• streamline the infraction ticket issuing process;
• Real-time image processing;</td>
<td rowspan="2">Value Propositions

• Well designed and intuitive Interface;
• Simplification of the Infraction ticket issuing process;
• Higher level of engagement when using the system;
• Faster access to relevant Police data;
• Overlay of relevant data into real objects through the use of AR;
• Real-time Image Processing;</td>
<td>Customer Relationships

• Online documentation: All of the work will be documented adequately in online tools and in this dissertation;
• IT Service management (ITSM) ticketing: Rather than focusing on IT systems, it focuses on consumer demands and IT services for customers. ITSM emphasizes support (email or online tools);</td>
<td rowspan="2">Customer Segments

The system is aimed towards law enforcement agencies: The application's goal is to help police officers with the process of issuing infraction tickets, hence law enforcement agencies like PSP and PJ are the targeted segments.</td>
</tr>
<tr>
<td>Key Resources

• AR technologies;
• Portable Device compatible with AR (smartphone);
• Police work related data: Data comprised by the information that the Police retains in order to issue infraction tickets;</td>
<td>Channels

• Questionnaires to measure the satisfaction;
• Internal Police Force Communication Channels;
• Email for technical support;</td>
</tr>
<tr>
<td colspan="3">Cost Structure

Infrastructure costs: When the system reaches its final phase, it will include charges such as database queries and other necessary infrastructures, which are unimportant in the development phase because traffic is much lower than in a live service.</td>
<td colspan="2">Revenue Streams

Product delivered to the end costumer</td>
</tr>
</table>

Chapter 4

Analysis and Design

After completing the state of the art and gaining an overview of the existing competition, it is required to conduct a functional analysis of the project, and then begin the designing phase. This chapter focuses on the analysis of the project's functional and non-functional needs, as well as the description of the requirements gathering procedure and the subsequent design that emerges from the depicted requirements. Furthermore, all actors and interactions who are thought to be important to this project are mentioned and described.

4.1 Problem Domain

This project seeks to develop a proof-of-concept application that will detect license plates and, using AR, superimpose extra information onto the real-world view making the process of issuing infraction tickets easier for users. As a consequence, the resulting application will be tested in mobile smartphones, which are widely available devices. That stated, the application aims to demonstrate that using AR to assist police officers is feasible and has the potential for future purposes beyond those envisioned in this thesis.

4.1.1 Business Concepts

This section will describe all of the Business Concepts that were necessary in order to design the project's fundamental architecture in order to better grasp the situation at hand. The following are the essential elements:

- Graphical User Interface (GUI): This module provides the Graphical User Interface (GUI) that allows the user to interact with the application's services.

The user must do all essential steps in this UI, such as Login, Infraction Issuing Process, and others, in order for the services to be given.

- Integration System: The system that will combine the various required components. This system will serve as the interface between the many functionalities. As a result, this module will primarily function as a link between the OCR and Plate Recognition Training logic, the Camera and the external data.
- OCR: This module is the Optical Character Recognition Service, which is in charge of delivering recognized characters to the user interface. This component has a text file that has been previously trained. This text file is derived from an example picture including several alphanumeric typesets, each of which was categorized in order to create a model for learning and recognizing the characters.
- Resources/FileSystem: A resources/filesystem serves the system, holding information on the registered license plates. The details about the owner of the car with the recognized plate make up the information.
- Camera: This module is in charge of capturing photographs for use on various devices. In Windows, Linux, Android, IOS, and various Wearable systems, the camera is integrated to operate with AR Foundation.
- Plate Recognition Training: This module explains how to recognize plate contours and locate them in automobiles using Machine Learning methods. Image training sets with various European license plates and cars were feed into this module.

4.1.2 Domain Model

The following Domain Model may be drawn using the above described concepts (Figure 4.1). This figure depicts the interplay between business concepts while attempting to meet previously specified criteria at a high level.

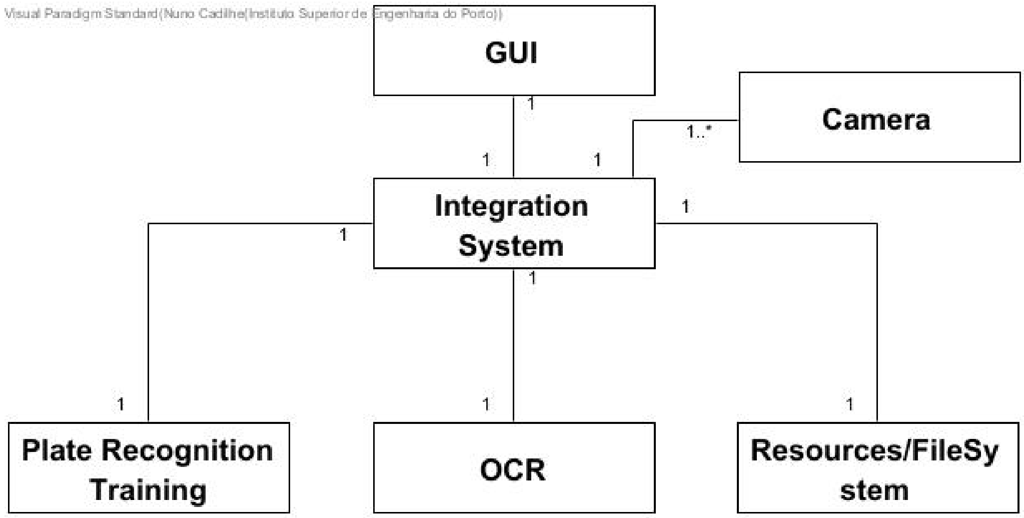

Figure 4.1: Domain Model

The camera is built into the intended device and provides real-time data about the environment. To enable for post-processing, this data is transmitted in the form of a video at a certain frame rate. The camera software is also written in AR Foundation, allowing it to run on a variety of devices, from Android and iOS to more advanced AR wearables.

The camera data stream is then sent to the GUI and Integration System, with the first component allowing the user to see the actual world through the device and the second component allowing post-processing of the acquired data.

The GUI is in charge of receiving the user's request to identify a certain License Plate, as well as the information associated with it, and lastly the choice to issue an infraction. The GUI will also interact with the Integration System in order to obtain processed data as well as external data from the Resources/FileSystem.

When it comes to processing data, the Integrated System is in charge of delegating responsibility. This responsibility is split between the component in charge of OCR and the component in charge of License Plate Recognition Training. This module will also be responsible for parsing external information obtained via the camera and the Resources/FileSystem.

The OCR is in charge of delivering the detected characters from the processed data stream to the Integration System. This module uses a trained data set saved in the application assets, and compares each of the possible characters in the current image with the stored data, returning information of the most probable match.

Plate Recognition Training returns the best feasible match of a License Plate's contours as seen in real-time image data. It then uses the OCR module with a dataset of various European license plates in order to identify in real-time the actual characters of the license plate. The Integration System then processes this data before delivering it to the GUI.

The Resources/FileSystem module performs functions comparable to a database. It stores information on the license plates that have been registered. The data is maintained using text files and then processed by the Integration System because this is a proof of concept. However, the system is prepared to receive information from other sources, including local (e.g. a database) or remote data (e.g. via an HTTP API).

4.2 Functional and Non-Functional Requirements

Requirements engineering is a complicated process that evaluates product demands from a variety of perspectives, roles, responsibilities, and goals. As a result, requirement engineering approaches must be used at all stages of the software development life cycle (Pandey, Suman, and Ramani 2010). The process that a system must go through in order to constantly be compliant with the requirements as well as the objectives is depicted in Figure 4.2.

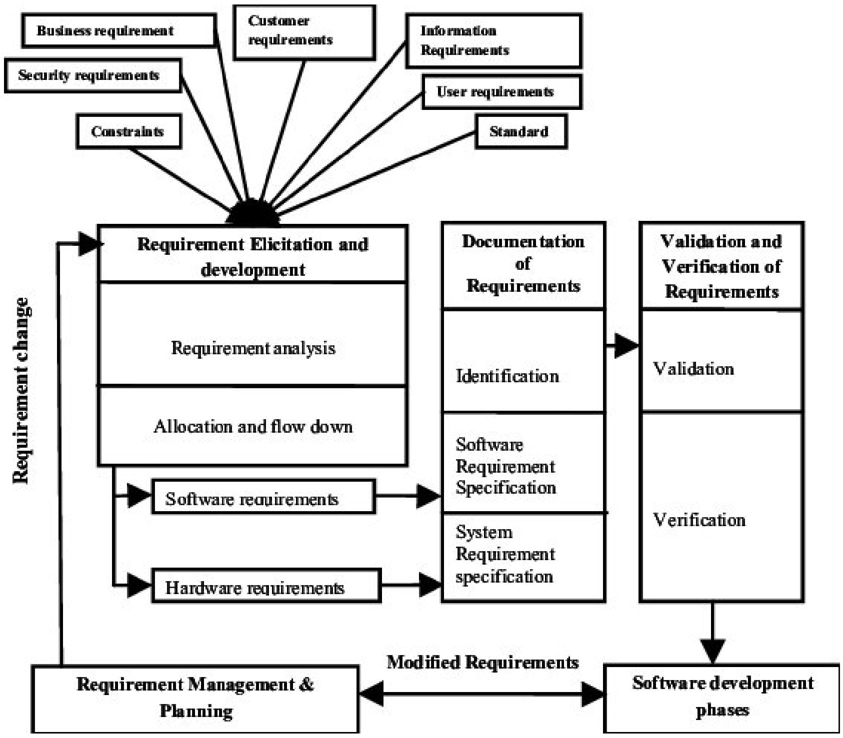

Figure 4.2: Requirement Engineering Process (Pandey, Suman, and Ramani 2010)

As a result, this initial research entails locating all relevant functional and non-functional requirements, as well as dimensioning them into User Stories that can be accomplished to add value to the system and meet the objectives while adhering to the criteria. Thus, the following requirements in Sections 4.2.1 and 4.2.2 were selected as critical for the system to accomplish the required objectives. They will be scrutinized and classified into functional and non-functional requirements.

4.2.1 Functional Requirements

These are the requirements that the end user expresses as essential features that the system should provide. As part of the contract, all of these functionalities must be included into the system. These are expressed or described as input to be delivered to the system, operation to be conducted and expected output. They are essentially the user's specifications, which can be seen in the finished product. As a result, the requirements that fulfill the the aforementioned description are the following:

- **R1**: The user is able to sign in in the software.
- **R2**: The user is able to sign out in the software.

- **R3**: The software allows the detection of viewed objects through the device's camera in real-time.
- **R4**: The system allows the superimposition o digitally created objects into the real world.
- **R5**: The system is able to correlate detected objects with known objects that are accessible in storage (initially locally with the possibility to migrate to a online server service).
- **R6**: The software shall be able to make use of visual tracking tags in the detected objects.
- **R7**: The system shall support the ability for the user to take snapshots.
- **R8**: The system allows the user to use the gathered information when submitting an infraction ticket.
- **R16**: The System should be able to easily receive uploaded models to its database in order to recognize objects.

4.2.2 Non-Functional Requirements

In software system engineering, non-functional requirements are software requirements that describe how the software will do something rather than what it will do, such as software performance requirements, software external interface requirements, software design constraints, and software quality attributes. Because non-functional requirements are difficult to test, they are typically assessed subjectively (Chung et al. 2012).

IBM Rational Software developed the FURPS+ technique, which emphasized comprehending the many forms of non-functional needs while complementing the preceding FURPS with the project's potential constraints (Zain, Mohd, and El-Qawasmeh 2011). The FURPS+ model will be used to analyze this project with the following requirements that have been identified as non-functional:

- **R9**: The software can be used in a wide selection of Android smartphones.
- **R10**: The software may require a specific version of Android Operative System (Android OS) that supports the select AR toolkit.
- **R11**: The software may use specific APIs to access existing law enforcement databases.

- **R12**: The software shall have a user interface that can be used by non-software literate personnel.
- **R13**: The object detection and recognition feature provided by the system should be effective helping the user identifying the objects present in the database.
- **R14**: All the features available in the system must be able to promptly answer the user's requests (e.g. Object recognition, menu loading, etc).
- **R15**: The System functionalities will only guaranteed while in exterior bright daylight conditions.

4.2.3 FURPS+

The FURPS model will be used to analyze non-functional needs, as previously described in Section 4.2.2. *"FURPS stand for functionality, usability, reliability, performance and supportability"* (Singh and Kassie 2018). Thus, it is now feasible to frame the non-functional needs within a FURPS quality attribute after they have been identified.

Functionality

The capability, reusability, and security of the functionality attribute are the three key considerations. However, none of the identified non-functional requirements fit this attribute.

Usability

Looking at, collecting, and defining needs based on user interface issues, such as accessibility, interface aesthetics, and consistency within the user interface, are all examples of usability. In this project, the identified non-functional requirement that fit this attribute was:

- **R12**: The software shall have a user interface that can be used by non-software literate personnel.

Reliability

Aspects of reliability include availability, accuracy, and recoverability, for example, computations or the system's ability to recover from shut-down failure. Thus, the identified requirement that complied with this attribute was:

- **R13**: The object detection and recognition feature provided by the system should be effective helping the user identifying the objects present in the database.

Performance

Throughput of information through the system, system reaction time (which is also related to usability), recovery time, and start-up time are all examples of performance. As a consequence, the suitable requirement discovered was:

- **R14**: All the features available in the system must be able to promptly answer the user's requests (e.g. Object recognition, menu loading, etc).

Supportability

Finally, the FURPS are completed by a section titled supportability, in which a variety of other needs are listed, including testability, adaptability, maintainability, compatibility, configurability, installability, scalability, localizability, and so on. As a result, there was not a specified requirement that met this attribute definition.

FURPS+ constraints

The "+" in the FURPS+ acronym allows limitations to be specified, such as design, implementation, interface, and physical constraints.

Design constraints

As the name implies, a design constraint restricts the design. For example, using a relational database limits the strategy we use in designing the system. As such, inside the project, the following requirement was identified:

- **R10**: The software may require a specific version of Android Operative System (Android OS) that supports the select AR toolkit.

Implementation constraints

An implementation constraint puts limits on coding or construction, for instance standards, platform, or implementation language. Hence the identified requirement was:

- **R10**: The software may require a specific version of Android Operative System (Android OS) that supports the select AR toolkit.

Interface constraints

A necessity to interact with an external item is known as an interface constraint. Interaction with external systems is frequently required when developing a downstream application. The requirement that fit this constraint is:

- **R11**: The software may use specific APIs to access existing law enforcement databases.

Physical constraints

Physical restrictions, such as shape, size, and weight, have an impact on the hardware utilized to house the system. As a result, two requirements were found within the non-functional requirements that matched this constraint:

- **R9**: The software can be used in a wide selection of Android smartphones.
- **R15**: The System functionalities will only guaranteed while in exterior bright daylight conditions.

4.3 Design Decisions

Throughout the Analysis, this section will describe how the application is modeled to achieve the established criteria and concepts. This approach is built on software engineering best practices.

First, a brief description of the system's desired Architecture will be given, followed by a brief explanation of each component's responsibilities.

Second, an investigation of several design choices will be conducted until a final conclusion has been reached.

Finally, several storyboards and mockups will be shown to better describe the direction in which this proof of concept wants to follow the stated architectural and component selections.

4.3.1 Architecture

The whole design was built on the single-responsibility principle, which decoupled the responsibilities across components, making maintenance easier and giving a more secure architecture to accommodate scalability. The architecture was previously built to provide for the potential of adding a database (locally or online) at a later date, with a parser module that is responsible for processing external information that is now saved in the application Resources/datasystem. In addition, the application is built to quickly accommodate new functions that complement the proof of concept created using the AR Foundation.

The architecture for this application is depicted in the figure below (Figure 4.3).

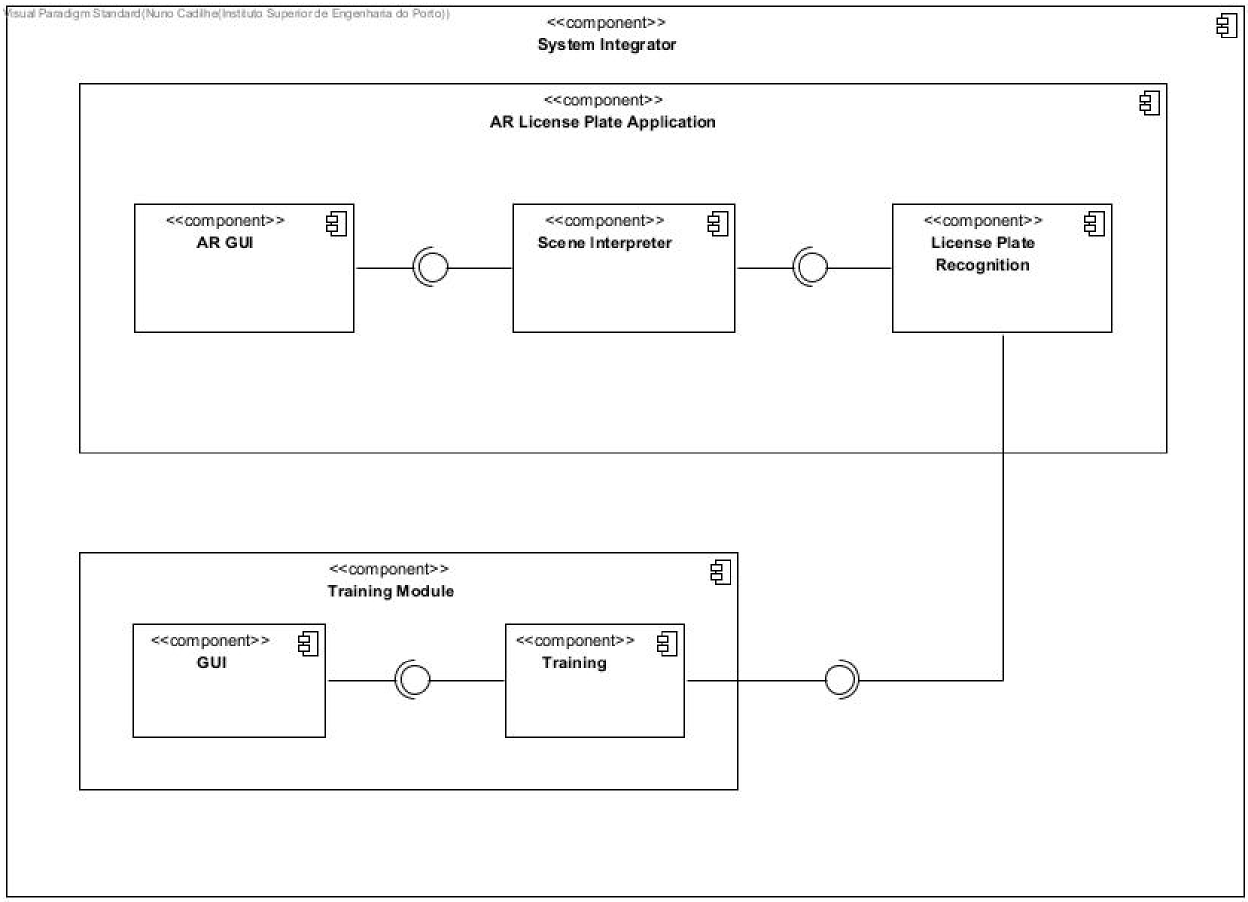

Figure 4.3: Application Architecture

This project's architecture is divided into three major modules:

- the System Integrator, which aggregates all the application in one unique module;
- the AR License Plate Application, which is composed by the AR GUI containing all the Unity Scenes with the AR components, the Scene Interpreter responsible for serving as an interface between the GUI Unity scenes and the recognition system and the License Plate Recognition which is in charge of the entire recognition system, including all calculations and direct comparisons of the obtained data-stream with the trained alphanumeric character files;
- finally, the Training module is in charge of the training data generated from the images in the dataset for recognition and comparisons of alphanumeric characters. The AR License Plate Application is served through the trained text file as an interface by the Training Module, which has a distinct GUI.

4.3.2 Design Alternatives

Diverse alternatives were examined throughout the design of the architecture for this thesis, but the one already described in the section Architecture was judged as the best match for the project.

For starters, because the proof-of-concept required the identification of license plates, the system was designed to include Machine Learning Models based on Neural Network trained models with larger datasets. Nevertheless, to employ a Neural Network to train with a defined dataset made of License Plates that would subsequently be input into the License Plate Recognition Module, it was required to use Pytorch, TensorFlow or a comparable technology.

The principle of developing a machine learning model relies upon six fundamental processes, to put it another way. To begin, there is a necessity to meet the data, which necessitates selecting an adequate dataset to meet the application's criteria, in this instance the license plates for the proof of concept. Second, a method for training the aforementioned data must be chosen. The dataset must then be prepped and cleaned to make the training process easier. Cross validations are performed once the dataset is divided. Finally, with the use of an algorithm, the data is trained and tested; in this example, the tested test case centred around Neural Networks. The model can then be used (Mueller and Massaron 2021).

However, this option was discarded due to its complexity, implied diversion from the thesis' primary concept, and significant influence on the time required to investigate this topic. A study was conducted to develop an Open Neural Network Exchange (ONNX) model. ONNX is an open-source artificial intelligence ecosystem comprised of technology businesses and academic institutions that build open standards for describing machine learning algorithms and software tools in order to foster AI innovation and cooperation. However, a large training dataset containing compiled photos with license plates was necessary to develop a model with sufficient training to reliably recognize license plates from the provided datastream.

Initially, the model would need to be trained in Pytorch before being transferred to ONNX. There have already been some trained models based on You Only Look Once (YOLO), a cutting-edge, real-time object identification method. However, in the dataset used for training, this object identification system does not include a model that includes license plates. Hereby, the hypothesis that would avoid the need to train the model was discarded, bringing the progress back to the stage where model training was required.

4.3.3 Wireframes

To ensure that the implementation as a smooth progression, certain wireframes were created ahead of time to help with development and to receive Professor Felipe Faria's approval. As a result, the GUI is divided into four primary sections: the License Plate Recognition (LPR) Learning Interface, the Login Interface, the LPR Camera Interface, and the LPR Form Interface. The UX Experience was one of the most important factors to consider when creating the wireframes. As a result, all of the developed displays use the same design patterns and styles, and the interfaces are simple and straightforward. It is also worth noting that the displays were made to maintain the same aspect ratio across a variety of screen sizes.

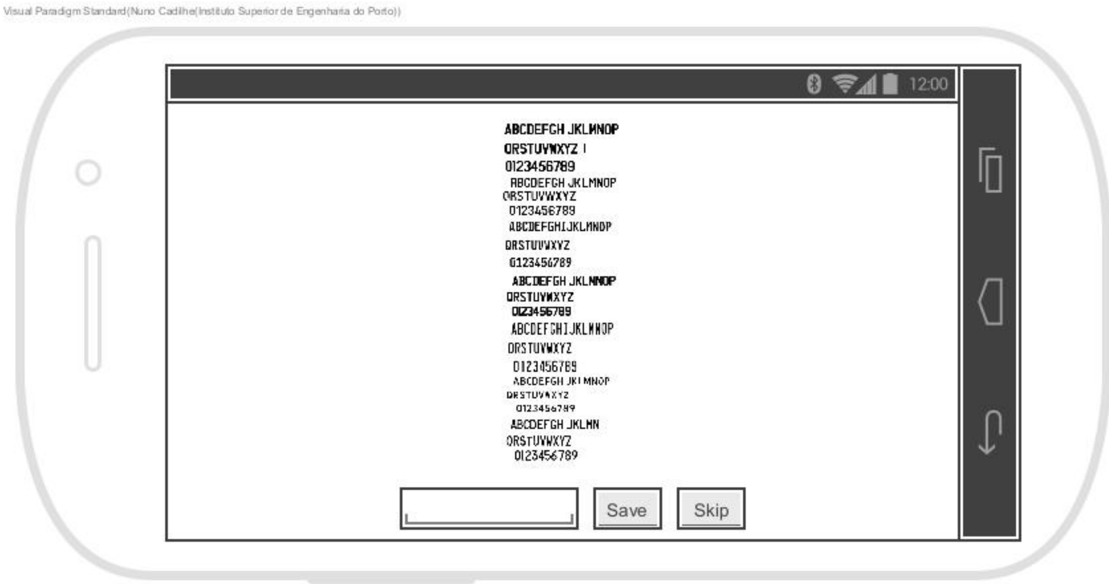

Figure 4.4: LPR OCR training Wireframe

The beginning screen for the LPR OCR training is shown in Figure 4.4. As a result, it contains an interface for cataloging each alphanumeric character from a training picture to a text file. That file will be kept in Resources and afterwards utilized in the primary recognition services of the program. The GUI contains a text input for the user to catalog the characters from the input training picture, as well as two buttons, one to save the input and the other to skip that character from being cataloged and recognized by the system when the video feed from the camera is received. This part of the application is used in a separate module.

Figure 4.5: Login Wireframe

The first screen that the user sees when they open the app is shown in Figure 4.5. This screen displays the application's login with a background. With the Username and Password Identifiers, there are two labels. For the Username and Password fields, there are two text inputs. The input characters in the password entry are encrypted. The program is then opened by clicking a button with the Login text on it.

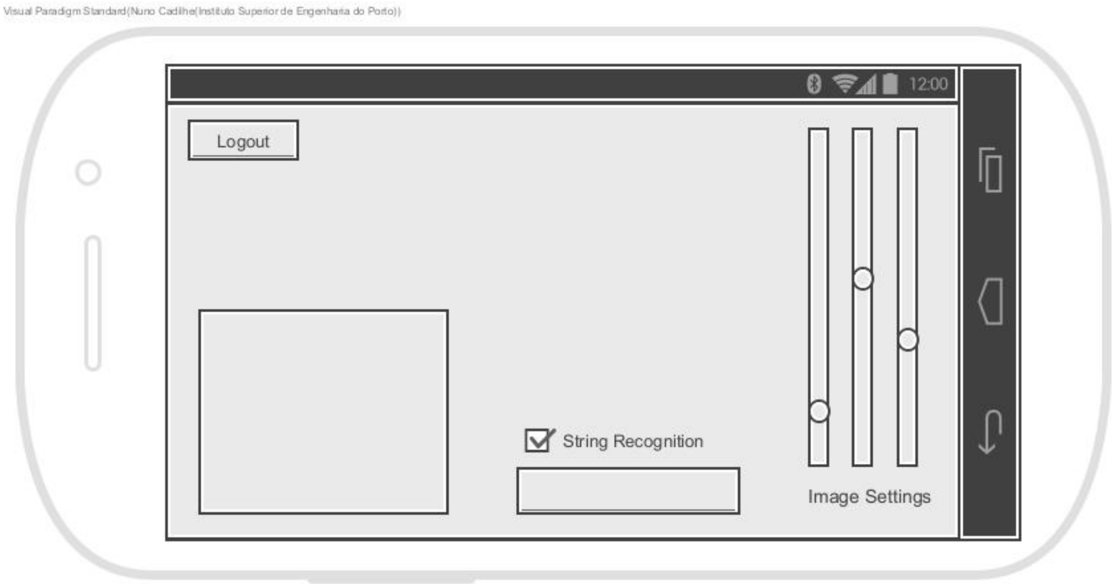

Figure 4.6: Camera Screen Wireframe

Figure 4.6 depicts the interaction between the camera input and the user on the screen. It's the user's initial screen after logging in. The user is presented with the main LPR function via highlighted text that may be clicked to examine the detected plates. The unprocessed camera image is displayed in the first video stream, which takes up the majority of the screen; the processed image is displayed in the second video feed, which is positioned in the left bottom corner (video feed with gamma correction). Two sliding bars can be used to alter the visual contrast and gamma correction settings on the processed video stream. Finally, the user may utilize the Logout option to return to the login screen.

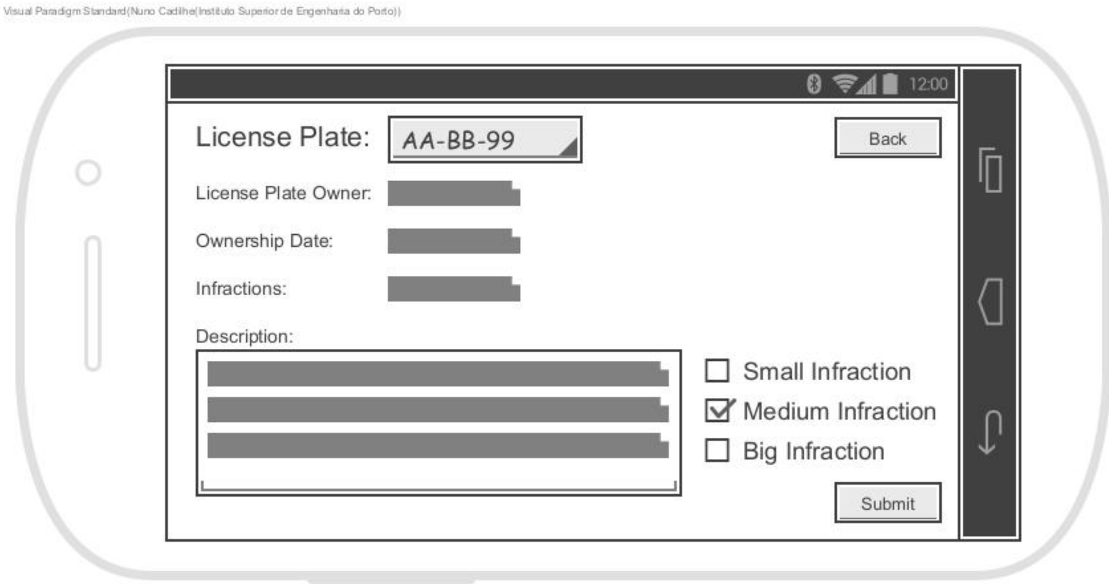

Figure 4.7: Form Wireframe

Figure 4.7 shows the last screen, which provides the Form with information on the identified plates. The plates detected by the system will be output to dropdown next to the "License Plate" label. If the plate is identified, information on the plate's owner will be provided in the Form, where the user may examine the owner's name, the date the ownership began, the number of prior infractions, and a brief description. Finally, the user will have access to three toggles to select an infraction type (small, medium, or large), as well as a submit button placed in the lower right corner. By pressing the back button in the upper right corner of the screen, the user can return to the previous Camera Screen whenever he wants.

Chapter 5

Implementation

The developer can safely begin the implementation phase after completing the Design phase, which includes the layout of all components and the definition of the Architecture. As a result, this chapter will concentrate on the implementation details and expose the required components in order for the reader to have a deeper understanding of the application's inner workings. First and foremost, this chapter will provide a brief explanation of the AR scenario that has been developed, as well as the use of License Plate Recognition (LPR) to record license plates and aid in the issuance of infraction tickets. Following the aforementioned AR description, the Unity development is documented, containing the details of both Unity Scenes and C# scripts.

The AR element is represented in this proof of concept by the information displayed in the left bottom corner. As a consequence, the gamma-corrected video feed is imposed into the GUI screen, which displays the same video feed with gamma modifications and the ability to modify the degree of gamma and contrast applied to that source. Because it acts as a medium between the observer and the surrounding world, this AR experience falls under the See-through AR displays category, maximizing the amount of presence and space awareness. As it only happens when a license plate is recognized in the real world view, it's a "Triggered" augmentation. As such, it fits under the category of Marker-based AR within the triggered augmentation, since it triggers when identifying the plate and its characters, with the license plate acting as a marker trigger. It is worth noting that the user does not have to type the plate itself and that the system may be used on any device that supports Windows, iOS, Android, Mac OS, and certain wearable apps.

5.1 Unity Scenes Implementation

To begin the project, it was essential to first install the AR Foundation packages, which contained the ARCore and ARKit bridges. The application's graphical user interface is provided by four Unity scenes:

- LPR Learning Stage Scene;
- Login Scene;
- LPR Camera Scene;
- Form Scene;

To begin, the user will have a distinct Scene within the program where he may catalog the alphanumeric characters from a selected training picture. The training's outcomes will be stored in a text file. The user will have access to the remainder of the scenes when opening the application. As a result, the Login Scene will be the first visible Scene, where the user may enter his credentials. The user may then begin using the recognition features via the LPR Camera Scene, which will record up to 15 identified license plates after logging in. When the user clicks the text of a recognized plate, he will be taken to a page where he may review the related details and report an infraction. It is worth noting that all of Unity's Scenes are designed to scale with screen size, allowing them to be utilized on a variety of devices.

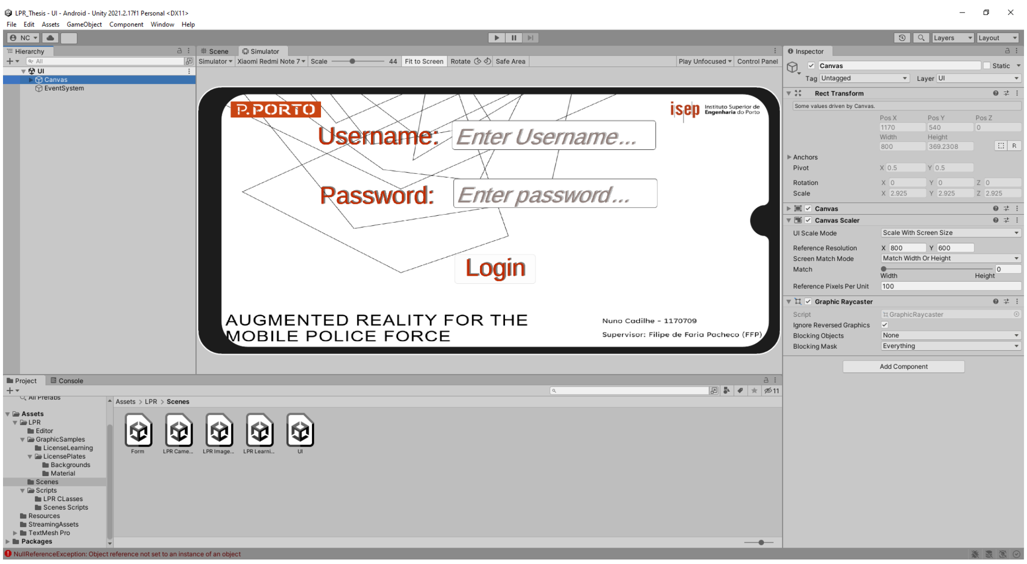

Figure 5.1: Unity Interface with a Scene

The Unity Interface, seen in Figure 5.1, is where the developer may create Scenes. It features a depiction of the Scene in the middle, as well as a simulator for presenting the scene on multiple devices, such as the Xiaomi Redmi Note 7 Preview in Figure 5.1.

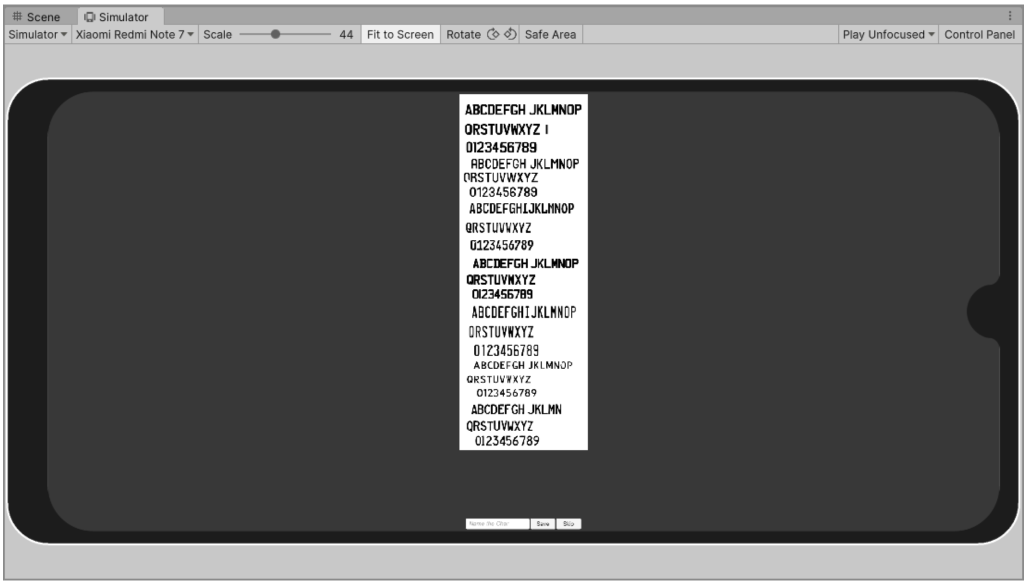

Figure 5.2: Learning Scene

The LPR Learning Interface is seen in Figure 5.2. As a result, it includes a user interface for cataloging each alphanumeric letter in a training image and saving it to a text file. That file will be saved in Resources and then used in the program's principal recognition services. The user may catalog the characters from the input training picture using a text input field, as well as two buttons to save the input and skip that character from being cataloged.

Figure 5.3: Login Scene

The login scenario is depicted in Figure 5.3. With a background, this screen shows the application's login. There are two labels for the Username and Password Identifiers. There are two text inputs for the Username and Password areas. The software is then launched by pressing the Login text on a button.

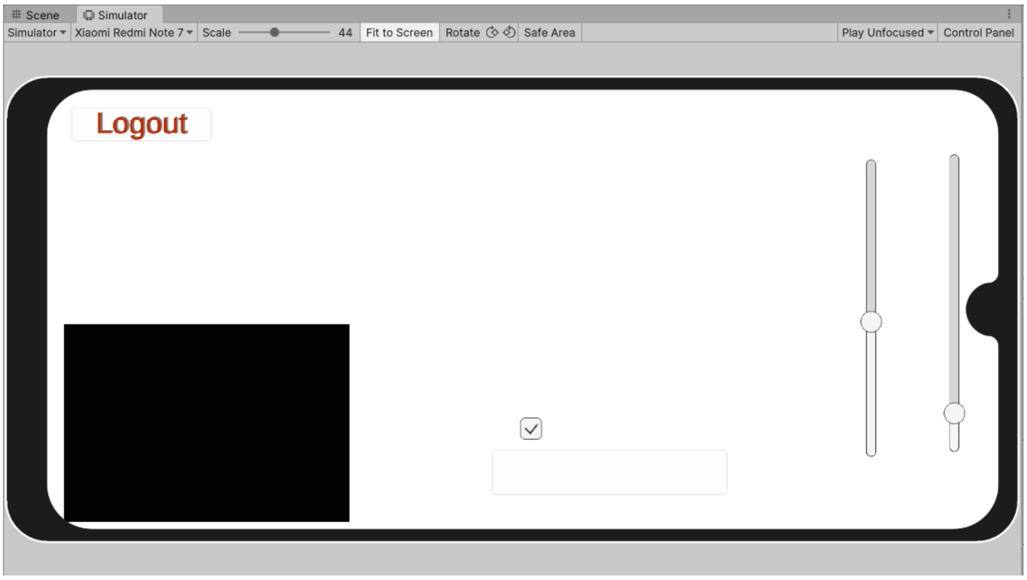

Figure 5.4: LPR Camera Scene

The interface between the camera input and the user is illustrated on the screen in Figure 5.4. It's the first screen the user sees after signing in. The main LPR function is delivered to the user via highlighted text that may be clicked to view the identified plates. The first video feed occupies the bulk of the screen and displays the unprocessed camera picture at 15 frames per second (FPS); the second video feed is a smaller one, located in the left bottom corner, and displays the processed image (video feed with gamma correction) at 15 FPS.

The alphanumeric characters of the detected plate will be highlighted in the gamma adjusted video feed while processing a plate. Only the highlighted recognized characters are shown in the gamma corrected video stream if the output string for the recognition is turned off (checkbox). The image contrast and gamma correction settings on the processed video feed may be adjusted using two sliding bars. Finally, the user can return to the login screen by using the Logout button in the left upper corner.

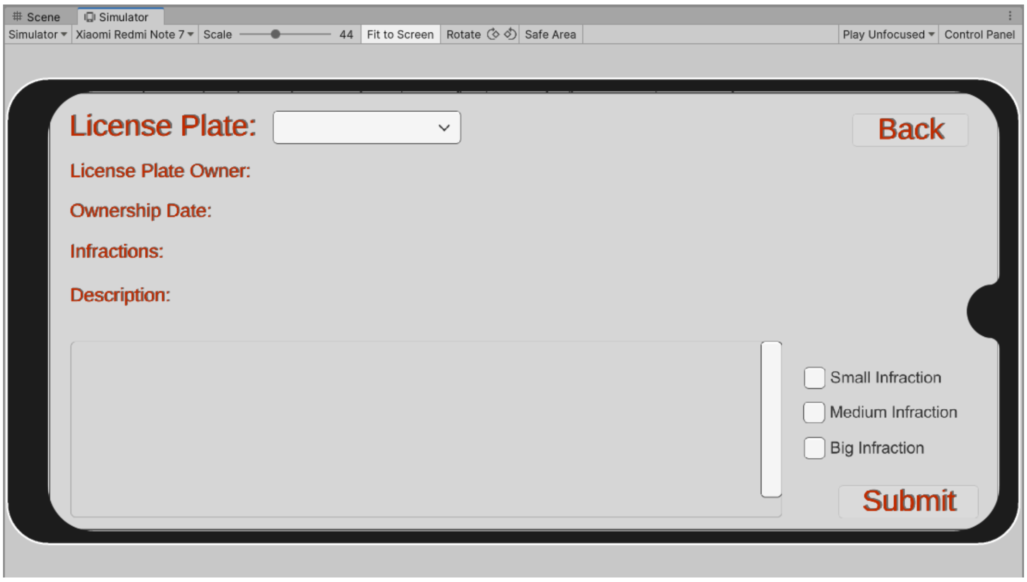

Figure 5.5: Form Scene

The last screen, shown in Figure 5.5, provides information about the recognized plates to the Form. If the plate is found, the user may look up the owner's name, the date the ownership began, the number of past violations, and a brief description in the Form. As a proof-of-concept example, this data was selected. Finally, the user will have three toggles to choose between minor, medium, and big infractions, as well as a submit button in the lower right corner. The user may return to the previous Camera Screen at any time by tapping the back button located in the upper right corner of the screen.

5.2 LPR Learning Functionality

This feature is in charge of deciphering alphanumeric characters derived from a picture. As a result, the user will be able to catalog the characters in the target picture and generate a trained text file using the interface shown in Figure 1 (Figure with LPR Learning image in Unity section). The user has the option of cataloging or skipping the characters.

```
1  private void ImageProcessing()
2    {
3      Color[] spritePixels = ReadImage.sprite.texture.GetPixels();
4  
5      width = ReadImage.sprite.texture.width;
6      height = ReadImage.sprite.texture.height;
7  
8      ConvertPixelArrayToGrayScaleMatrix(spritePixels);
9  
10     ContourPath.Clear();
11 
12     CalcualteBorders();
13 
14     CalculateRectangles();
15 
16     spritePixels = ConvertGrayScaleMatrixToPixelArray();
17 
18     WriteImage.sprite.texture.SetPixels(spritePixels);
19     WriteImage.sprite.texture.Apply();
20 
21     StartSaving();
22   }
```

Listing 5.1: Image processing for the target image used in *LPR Learning Functionality*

In Listing 5.1, both *ReadImage* (line 3) and *WriteImage* (line 18) are components passed down as arguments from the unity interface, with the Pixels from the *ReadImage* being saved as a gray scale matrix using the function *ConvertPixelArray-ToGrayScaleMatrix()* at line 8. As a result, with the sprite saved as a matrix, the boundaries of each character may be calculated using line 12's *CalculateBorders()* function, then it places rectangles in each character when detected using line 14's *CalculateRectangles()* method.

```
1 public class SaveLetter : MonoBehaviour {
2
3   public PlateRecognitionLearning SaveChars;
4
5   public void SaveLetters()
6   {
7     SaveChars.SaveLetter(GetComponent<Text>().text);
8   }
9
10   public void SkipLetters()
11   {
12     SaveChars.SaveLetter("*");
13   }
14 }
```

Listing 5.2: SaveLetters and SkipLetters used in *LPR Learning Functionality*

There are two options when processing the *textitReadImage()*: catalog the character inside the rectangle from the previous method in Listing 5.1, or skip that character and move on to the next one in the matrix. As a consequence, the *SaveLetters()* method in line 5 and the *SkipLetters()* method in line 10 may be found in Listing 5.2. Finally, if the letter is stored, the value will be extracted from the user's input in Figure 1 and printed in the trained text file; otherwise, the character will be skipped with a * and thus saved in the same trained text file.

```
private void ReadPixelsFromBoxesAndSave()
  {
    string createText = System.String.Empty;

    for (int i = 0; i < MaxPoints.Count; i++)
    {
      if (charToSave[i] != "*")
      {
        createText += ((int)MaxPoints[i].y - (int)MinPoints[i].y).ToString() + ":"
            + ((int)MaxPoints[i].x - (int)MinPoints[i].x).ToString() + ":"
            + charToSave[i] + ":";

        for (int y = (int)MinPoints[i].y; y < (int)MaxPoints[i].y; y++)
        {
          for (int x = (int)MinPoints[i].x; x < (int)MaxPoints[i].x; x++)
          {
            createText += (matrix[x, y] == 0) ? "0," : "1,";
          }
        }

        createText += ";";
      }
    }

    File.WriteAllText(Application.streamingAssetsPath + "\\textTrainedPlates.txt",
    createText);
  }
```

Listing 5.3: ReadPixelsFromBoxesAndSave used in *LPR Learning Functionality*

Finally, using the code in Listing 5.3, you can parse all of the stored characters into a trained text file while bypassing the * and save them to the *"textTrainedPlates.txt"* file in the application's streaming assets folder.

5.3 LPR Camera Functionality

This feature is responsible for managing the camera and its recognition. To summarize, the system identifies the presence of a camera in the device and gets the video feed. The visual feed is then split into two outputs. The video stream is first unprocessed and presented to the user through the GUI, after which it is processed with gamma adjustments and subsequent license plate identification.

```
1  public void InitializeComponents(MeshRenderer ReadImageMat, MeshRenderer
     WriteImageMat, int CameraIndex)
2  {
3    this.ReadImageMat = ReadImageMat;
4    this.WriteImageMat = WriteImageMat;
5
6    WebCams = WebCamTexture.devices;
7
8    if ((WebCams != null) && (WebCams.Length > 0) && CameraIndex != 0)
9    {
10 #if (UNITY_ANDROID || UNITY_IOS || UNITY_WP8 || UNITY_WP8_1) && !UNITY_EDITOR
11     CameraIndex = 1;
12 #endif
13
14     StreamingCamera = new WebCamTexture(WebCams[CameraIndex - 1].name, 512, 512,
     15);
15     StreamingCamera.Play();
16     this.ReadImageMat.material.mainTexture = StreamingCamera;
17   }
18
19   int ImageWidth = ReadImageMat.material.mainTexture.width;
20   int ImageHeight = ReadImageMat.material.mainTexture.height;
21
22   ImageRecognitionOptimized = new ImageManipulation(ImageWidth, ImageHeight);
23   EdgeCalculation = new CalculateEdges();
24   OpenDatabase = gameObject.AddComponent<OpenFileDatabase>();
25   LocalizePlate = new PlateLocalization(ImageWidth, ImageHeight, OpenDatabase);
26 }
```

Listing 5.4: Camera and Recognition used in *LPR Camera Functionality*

In Listing 5.4, the *MeshRenderer ReadImageMat* and *WriteImageMat* are handed down as inputs from the Unity interface. It's worth noting that the code is set up to collect video camera feeds from a variety of sources. As a result, in line 10, there is an if clause that defines the camera index based on the device on which the program is operating. The values acquired from the unprocessed camera (line 16) described in lines 14 and 15 will be absorbed by the *ReadImageMat*. The camera will generate 512 × 512 pixels at 15 frames per second.

As a result, as shown in Figure 5.4, it is possible to alter the gamma correction and picture contrast levels in line 22. Line 23 will compute the license plate contours from the saved training images with European License Plates, which will then be used to the recognition.

Line 24 ties the recognition of the characters to a previously stored text file containing the learned alphanumeric characters described in section LPR Learning Functionality , opening that file and loading the trained characters into memory in order to do the comparisons with the video feed. Finally, the function *PlateLocalization()* in line 25 will combine the plate and character recognition and send it as a Gamma corrected video feed to the previously constructed *WriteIMage* and a string to the GUI.

5.4 LPR GUI Functionality

This functionality is in charge of acting as an interface between the user's GUI instructions and the application's functions. As a result, the scripts are mapped into the GUI components so that they may be activated by the user's instructions.

```
1   public void login()
2   {
3       SceneManager.LoadScene(SceneManager.GetSceneByName("LPRCameraScene").buildIndex);
4   }
5
6   public void logout()
7   {
8       MainRecognition.StreamingCamera.Stop();
9       SceneManager.LoadScene(SceneManager.GetSceneByName("Ui").buildIndex);
10  }
11
12  public void back()
13  {
14      MainRecognition.StreamingCamera.Stop();
15      SceneManager.LoadScene(SceneManager.GetSceneByName("LPRCameraScene").buildIndex);
16  }
17
18  public void licensePlateForm()
19  {
20      MainRecognition.StreamingCamera.Stop();
21      SceneManager.LoadScene(SceneManager.GetSceneByName("Form").buildIndex);
22  }
```

Listing 5.5: GUI script used in *LPR GUI Functionality*

The GUI created using Unity's interface uses Listing 5.5 to switch between scenes, while keeping some of the components alive in memory and turning off the camera when it's not in use (lines 8, 14 and 20). As a result, the function calls related to the buttons implemented in the GUI using the Unity interface (such as the *login, logout, back and LPR buttons*) are listed in Listing 5.5. To load the scene by its *buildIndex*, there are several *SceneManager()* methods.

```
1  void Start()
2      {
3          ...
4
5          // Line bellow to  Read txt file from Mobile
6          string[] parts = OpenFileData(Application.persistentDataPath  + "\\LPRAssistTxt.txt", ';');
7
8          // Line bellow to Read txt file from Windows PC
9          string[] parts = OpenFileData(Application.streamingAssetsPath  + "\\LPRAssistTxt.txt", ';');
10
11         List<string> auxList = new List<string>(parts);
12
13         List<string> uniqueAuxList = auxList.Distinct().ToList();
14
15         List<string> finalList = uniqueAuxList.Where(f => f.Length == 6).ToList();
16
17         // Line bellow to Delete txt file from Mobile
18         File.Delete(Application.persistentDataPath  + "\\LPRAssistTxt.txt");
19
20         // Line bellow to Delete txt file from Windows PC
21         File.Delete(Application.streamingAssetsPath  + "\\LPRAssistTxt.txt");
22
23         _dropdown.ClearOptions();
24
25         _dropdown.AddOptions(finalList);
26
27         _dropdown.onValueChanged.AddListener(delegate { DropdownItemSelected(_dropdown); });
28     }
```

Listing 5.6: GUI Form script used in *LPR GUI Functionality*

The retrieval of data relating to recognized license plates is handled by Listing 5.6. The code also offers an Assist to the detection (lines 6 and 9) that contains the fifteen prior detections that the user may use to minimize the system's failures in identifying the characters or to assist the user in keeping track of several plates at the same time. Depending on the type of device the user is using, the Assist file must be accessed in a different way (lines 6 and 9). Finally, the listener on line 27 is responsible for fetching the appropriate data based on the user's dropdown selection in the GUI.

Chapter 6

Evaluation and Experimentation

Software testing is critical in ensuring the quality and reliability of software. It is an endless process that begins with the very first step of software development and ends with the Software Development Life Cycle. Depending on the sort of software in question, testing can take many different forms (Brar and Kaur 2015).

Validating if the developed product has any flaws, as well as whether it is complying with the proposed value and is well developed and proportioned, is critical. The testing will be carried out during the project's entire life cycle. As a result, several types of tests will be done to each phase of development in order to maintain the application's quality at all times.

By defining experiences, tests, and questionnaires, as well as analysing their results, this chapter tries to evaluate the solution generated both on a technical, usability and performance level.

6.1 Research Questions and Hypothesis

As stated in the Introduction (chapter 1), the research question are the following:

- How can AR technology be used to ease/improve the day-to-day tasks of the Law Enforcement forces?
- How do end-users perceive the deployment of AR-assisted functions in police force applications, such as the information presented by the system mixed with the real-world camera feed?

The first research question implies that the investigation must start by revealing some of the present technologies in the field of AR applications with a scope equivalent to that of this thesis. As a result, the investigation's State of the Art will focus on reporting possible technologies and systems that could be employed to create the proof of concept that was envisioned for this thesis. It also contemplates the dimensioning and completion of the gathered requirements. Finally, the last question allows the study to determine the system's usability, inferring whether the system is trustworthy, simple to use, and delivers information in a way that even software illiterate people can understand.

The question also tackles the system's response time, which in the ideal case would also be evaluated by some police personnel; however, because that scenario is difficult to achieve, non-related individuals would be required to answer questionnaires to verify their usability perspective and opinion.

The formulated Hypothesis regarding the predefined objectives and research questions are:

- The AR implemented solution contemplates a law enforcement task and fully integrates it into an application;
- At least 80% of end-users consider the application interface to be clear, simple to use and with short response times;

The first hypothesis requires a review of existing AR applications with a focus on law enforcement tasks, with the goal of selecting a specific task and incorporating AR to make it easier or better. The second hypothesis is met when user ratings of more than 80% are acquired through user tests and questionnaires. All of the hypotheses under investigation will be validated using questionnaires and the Quantitative Evaluation Framework (QEF), which will be discussed in the following sections. All of the questioned users' satisfaction must be at least 80% in order to achieve the desired outcomes.

6.2 Evaluation Methodology

The evaluation methodologies used in a project's evaluation are crucial. This process consists of a collection of tasks that will allow the assessment of the formulated objectives to proceed, based on the indicators to be defined. Methods, tests, and questionnaires were used in this context. The solution was evaluated in stages to ensure that each feature was properly assessed and analyzed. As shown in Table 6.1, all of the tasks to be completed in this module were divided into three distinct goals.

Table 6.1: Evaluation Proposal

Evaluation Proposal
Quantitative Evaluation Framework (QEF)
End-to-End (E2E) Testing
System Usability and User Satisfaction

Three methods were used to evaluate the system as a whole, as described in Table 6.1, in order to ensure that the generated solution satisfied the set objectives and followed acceptable engineering practices.

6.2.1 QEF

The usage of QEF throughout the development life cycle identifies weaknesses in the current version at the time of evaluation, allowing the development team to focus on fixing those flaws and directing the product to meet the desired criteria (Escudeiro and Bidarra 2008). The QEF will readily frame all of the required Functional and Non-Functional requirements to ensure the system's quality in this thesis. As a result, it will be possible to evaluate the aforementioned needs using predefined criteria that will determine the total completion of each requirement.

6.2.2 End-to-End (E2E) Testing

End-to-End (E2E) testing ensures that the application flow operates as intended by testing the full software product from beginning to end. It specifies the product's system requirements and guarantees that all integrated components function properly (Katalon 2022).

E2E testing is used to test from the perspective of the end user by recreating a real-world situation and verifying the system under test and its components for data integrity and integration.

Today's software systems are complicated and interconnected, with many subsystems. The entire software system might crash if one of the subsystems fails. This is a significant risk that can be mitigated by E2E testing.

Because of the following advantages, E2E testing has become more reliable and frequently used:

- Increase test coverage;

- Ensure application integrity;
- Reduce time to market;
- Lower costs;
- Detect flaws;

Technology improvements have enabled subsystem interactions in modern software systems. Subsystem failures can have a negative impact on the overall system, whether the subsystem is the same as or distinct from the main system, and whether it is inside or outside the organization (Katalon 2022). The following actions can be taken to reduce system risks:

- Checking the system's operation;
- Extending the test coverage area;
- Identifying problems with the subsystem;

The test cases must be designed to mimic the behavior of a typical user. It is vital to consider the perspective of a user who is using the app for the first time. Is it simple to locate all of the options? Are the characteristics properly labeled? Is it possible for people to achieve what they want in two or three steps? Questionnaires and other forms of data may be useful in elucidating the user's point of view (BrowserStack 2021). The E2E testing should concentrate on the app's aspects that will create the most problems if they fail. As a result, it is a good idea to experiment with these features and create more complex test cases to verify them.

6.2.3 User Test Considerations

Because a system is designed to be used by its customers, it is critical to conduct user acceptance tests to ensure that the program as a whole works as planned and meets the customer's expectations. In order to verify if the system is conforming to the requirements, specific User tests will be undertaken using the following test guidelines that will aim to recreate a relevant set of plausible real-world events that the system may meet:

- Action 1: Sign in to the app;
- Action 2: Try to recognize a picture on a plate shown through the device;
- Action 3: Superimpose a digital label into a recognized real-world object;

- Action 4: filling out an infraction ticket with the information gathered;
- Action 5: Test the application's flow between screens;
- Action 6: Test the License Plate Recognition in bright daylight conditions;
- Action 7: Test the system's usability (speed, simplicity of use, and information display);
- Action 8: Sign out from the app;

Since it will be difficult to ask law enforcement personnel to undertake tests, the system will be handled in an initial phase by thirty generic users who will subsequently have to complete a Questionnaire that contains the System Usability Scale (SUS) questions. SUS is a trustworthy instrument for assessing usability that consists of ten questions and five response alternatives for respondents, ranging from Strongly agree to Strongly disagree. This tool can be utilized at all stages of the manufacturing process, including hardware, software, and online applications (Brooke 1995).

6.2.4 System Usability Scale (SUS)

The SUS is similar to a Likert scale, which is sometimes misunderstood to be a series of forced-choice questions in which the respondent is asked to rate their level of agreement or disagreement with a statement on a five-point (or seven-point) scale. However, the Likert scale is more sophisticated in its development. While Likert scales are given in this format, the statements on which the respondent expresses agreement and disagreement must be carefully chosen (Brooke 1995).

The question used in the SUS are presented in the Table 6.2.

Table 6.2: SUS questions (Brooke 1995)

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

The SU scale is normally used after the respondent has had an opportunity to use the system being evaluated, but before any debriefing or conversation about the usage that took place. Rather than thinking about each item for a long time, respondents should be prompted to register their initial answer to each one of the questions. If a respondent is unable to react to a specific question, they should mark the scale's center point (Brooke 1995).

To calculate the SUS score for each user, it is necessary to take the following steps:

- Pair questions: 5 - x, where x represents the value obtained in the questionnaire question;
- Odd questions: x - 1, where x represents the value obtained in the questionnaire question;
- Sum all the values obtained from the previous calculations regarding each question;
- Multiply the previous obtained value by 2.5, obtaining the actual score;

After completing the aforementioned steps for each user, the total scores from all users are summed, and then the average is calculated to obtain the final result, which is equivalent to the usability score.

The usability is then defined according to the scales given in Table 6.3.

Table 6.3: SUS usability according to the scales (Bangor, Kortum, and Miller 2008)

Scale	Definition
100	Best Imaginable
[85,100[	Excellent
[73,85[	Good
[52,73[	Ok
[38,52[	Poor
[0,38[	Worst Imaginable

6.3 Results

This section will be in responsible for presenting the system's quality assessment. As a result, it provides the results of the system usability questionnaires utilizing the SUS, which were created in Google Forms. The questionnaires' data will be compiled and utilized to validate the FURPS and FURPS+ realms in the QEF.

6.3.1 Questionnaires Results

The questionnaires, as previously stated, were created using Google Forms and include questions from the SUS. As a result, the possible answers to each question are: Strongly Disagree (1 point), Disagree (2 points), Neutral (3 points), Agree (4 points), and Strongly Agree (4 points) (5 points). There were thirty users in total, with three of them being GNR and PSP police officers. The findings of the questionnaires are presented in Table 6.4.

Table 6.4: Questionnaire results

	Questions									
	Q1	Q2	Q3	Q4	Q5	Q6	Q7	Q8	Q9	Q10
User01	5	2	5	3	5	2	5	1	4	1
User02	5	2	4	2	4	2	5	1	4	1
User03	4	2	4	3	4	2	4	2	3	2
User04	5	2	5	4	5	3	5	1	4	1
User05	4	1	5	1	5	1	4	1	5	1
User06	5	2	4	1	4	2	5	1	4	1
User07	5	2	5	1	5	1	5	1	4	1
User08	5	1	5	1	5	1	5	1	5	1
User09	5	3	5	1	5	1	5	1	5	1
User10	5	1	5	1	5	1	5	1	5	1
User11	4	2	2	1	4	2	4	4	2	1
User12	5	1	5	1	5	1	5	1	5	1
User13	4	1	4	1	4	1	4	1	4	1
User14	5	2	5	2	5	2	5	2	5	2
User15	4	2	4	2	4	3	4	2	4	2
User16	4	1	4	1	4	2	5	2	5	1
User17	3	1	5	2	4	3	4	1	4	1
User18	4	2	4	2	3	2	4	2	4	1
User19	5	1	5	1	5	1	5	1	5	1
User20	5	1	4	2	4	1	5	1	4	1
User21	5	2	5	2	5	1	4	1	4	1
User22	4	2	4	2	4	3	4	4	3	1
User23	4	2	4	2	4	2	4	3	4	2
User24	5	1	5	1	5	1	5	1	5	1
User25	5	1	5	1	5	1	5	1	5	1
User26	4	2	4	2	4	2	4	2	4	2
User27	5	1	5	1	5	1	5	1	5	1
User28	4	1	4	2	4	2	4	3	4	2
User29	5	1	5	1	5	1	5	1	5	1
User30	4	2	5	1	4	2	4	1	4	1

With the obtained results from the questionnaires, it is possible to perform the calculations for each user indicated in the System Usability Scale (SUS) section (section 6.2.4).

Table 6.5 shows the users final percentage score as well as the final average score.

Table 6.5: Final percentage average score

	Score SUS	Final Score (%)
User01	35	87,5
User02	34	85
User03	28	70
User04	33	82,5
User05	38	95
User06	35	87,5
User07	38	95
User08	40	100
User09	38	95
User10	40	100
User11	26	65
User12	40	100
User13	35	87,5
User14	35	87,5
User15	29	72,5
User16	35	87,5
User17	32	80
User18	30	75
User19	40	100
User20	36	90
User21	36	90
User22	27	67,5
User23	29	72,5
User24	40	100
User25	40	100
User26	30	75
User27	40	100
User28	30	75
User29	40	100
User30	34	85
	Avg	86,91666667

As shown in Table 6.5, the average score was around 87 percent, placing the system in the Excellent usability category, according to Table 6.3.

6.3.2 Assessment Completion

The final outcomes are assessed using the QEF framework in Table 6.6, which depicts the three primary components:

- the Functionality component: which includes all requirements that fall under the functional requirements label;

- the FURPS components: which consider functionality, usability, reliability, performance, and supportability perspectives;
- the FURPS+ (the "+" part) component: which allows limitations to be specified, such as design, implementation, interface, and physical constraints;

Table 6.6: QEF assessment

q	D	Qi	Dimension	Qj	Wij (Factor Weight j in Dim i) [0,1]	Factor	rwjk (requirement weight k in Factor j) {2, 4, 6, 8, 10}	Requirement	wfk % requirement fulfillment k) [0,100]
94%	0,17	89	Functionality	100,00	0,22	User Realm	10,00	UR01 - The user is able to sign in in the software.	100
							10,00	UR02 - The user is able to sign out in the software.	100
				66,67	0,33	System Realm	10,00	SR01 - The system shall support the ability for the user to take snapshots.	50
							10,00	SR02 - The system allows the user to use the gathered information when submitting an infraction ticket.	100
							10,00	SR03 - The System should be able to easily receive uploaded models to its database in order to recognize objects.	50
				100,00	0,44	AR Realm	10,00	AR01 - The software allows the detection of viewed objects through the device's camera in real-time.	100
							10,00	AR02 - The system allows the superimposition o digitally created objects into the real world.	100
							10,00	AR03 - The system is able to correlate detected objects with known objects that are accessible in storage (initially locally with the possibility to migrate to a online server service).	100
							10,00	AR04 - The software shall be able to make use of visual tracking tags in the detected objects.	100
		100	FURPS	100,00	0,33	Usability	10,00	US01 - The software shall have a user interface that can be used by non-software literate personnel	100
				100,00	0,33	Reliability	10,00	REL01 - The object detection and recognition feature provided by the system should be effective helping the user identifying the objects present in the database.	100
				100,00	0,33	Performance	10,00	PERF01 - All the features available in the system must be able to promptly answer the user's requests (e.g. Object recognition, menu loading, etc).	100
		88	FURPS+	100,00	0,25	Design & Implementation Constraints	10,00	DIC01 - The software may require a specific version of Android Operative System (Android OS) that supports the select AR toolkit.	100
				50,00	0,25	Interface Constraints	10,00	IC01 - The software may use specific APIs to access existing law enforcement databases.	50
				100,00	0,50	Physical Constraints	10,00	PC01 - The software can be used in a wide selection of Android smartphones.	100
							10,00	PC02 - The System functionalities will only guaranteed while in exterior bright daylight conditions.	100

Throughout the QEF, a total of sixteen requirements were examined individually. Each one has its own rating system. Appendix A contains the used scales.

Only two out of the total of Functionality requirements were not fully completed, receiving a 50% score. The first is on the System Realm and corresponds to the requirement SR01 - "The system shall support the ability for the user to take snapshots." The given score is due to the fact that this feature was enabled through unity settings, but there is no developed feature that allows the system to take a snapshot by itself. The second is also from the System Realm, and it corresponds to SR03 - "The System should be able to easily receive uploaded models to its database in order to recognize objects". The SR03 requirement's score was due to the fact that a user can only upload a specific model to the local database and that there is no online database that accepts various types of models.

Only one requirement was not fully addressed in the FURPS and FURPS+ dimensions. The previously indicated criteria corresponds to the IC01, "The software may use specific APIs to access existing law enforcement databases", which received a 50% score. This grade was given because, as a proof of concept, the program did not fully progress to the point where a connection to a real law enforcement database could be made. The interfaces, on the other hand, are prepared in case the program has to connect to an external database and the application already utilizes mock data to simulate a real law enforcement database.

When all of the analyzed and developed dimensions are taken into account, the final system score is 94% of the ideal solution. This score responds to the first Research Question raised in the section on Research Questions and Hypotheses (section 1).

Chapter 7

Conclusions

This chapter will detail all of the findings made during the investigation. Its goal is to link the previously set objectives to the achievements that have been achieved. This chapter will show the accomplishments of the Objectives, which comprise Work Planning and Application Accomplishments. Second, it will consider the system's limitations and future work, which will include the enhancement of the proof-of-concept system with a new Object Recognition capability using AR in conjunction with Depth. Finally, there will be a section dedicated solely to the investigation's concluding considerations, which will signal the closure of the investigation.

7.1 Objectives Achieved

This section will include all of the goals that have been met as well as their significance in the overall picture of the research. As a result, this section will be divided into two smaller topics: the first will cover the work planning accomplishments and possible deviations from the original plan presented in the introduction, while the second will cover all of the applicational accomplishments as well as the benefits and discoveries gained from the development of the proof of concept application.

7.1.1 Work Planning Accomplishments

It is important to denote that it was of extreme importance to tightly follow the stipulated schedule for the investigation done in this thesis in order to accomplish every objective. As such, in Figure 7.1, it is possible to infer that the actual duration of each investigation phase did not differ by much when compared to the original timeframe defined in the Introduction (chapter 1.1).

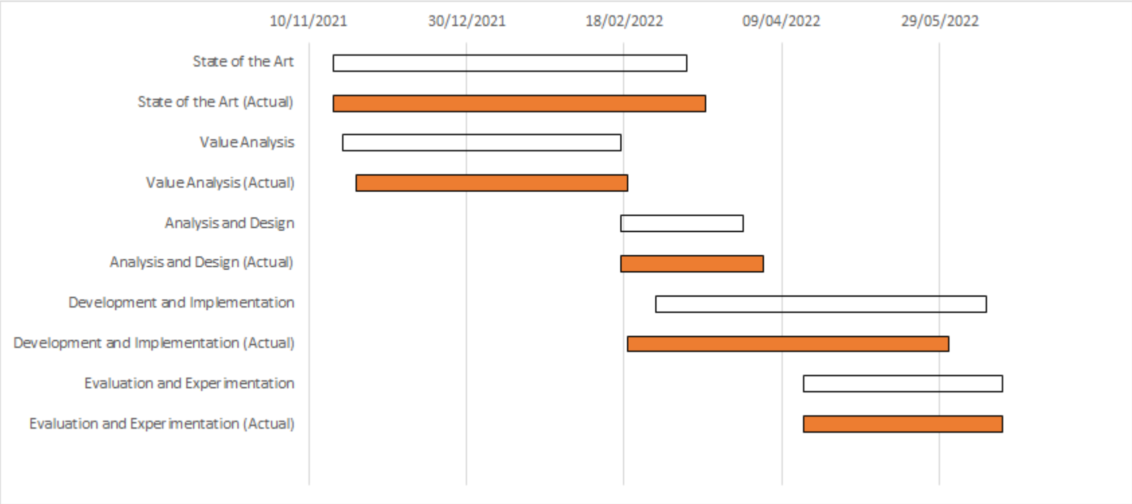

Figure 7.1: Gantt Diagram comparing the work plan with the real execution.

In addition to the previous Milestones stated in the introduction, the newly built Gantt diagram captures the real timeframe required to accomplish each of the defined tasks. The white bars represent the previously specified estimate period, while the orange bars represent the actual timeframe required.

Figure 7.1 depicts a little increase in the time required to complete the State of the Art research, owing to the explanation of some of the accessible AR technologies as well as the use of Unity.

Despite the fact that the Value Analysis study was accomplished in a lesser amount of time than expected, it was started later than predicted, resulting in a minimal delay in the finished date.

The Analysis and Design research began on schedule, but it took longer to finish owing to technology, software, and time constraints.

The Implementation started earlier than expected, took less time than anticipated, and was effectively finished sooner than scheduled.

Finally, the evaluation and experimentation research perfectly followed the timeline predicted in the first Gantt diagram (Figure 1.1).

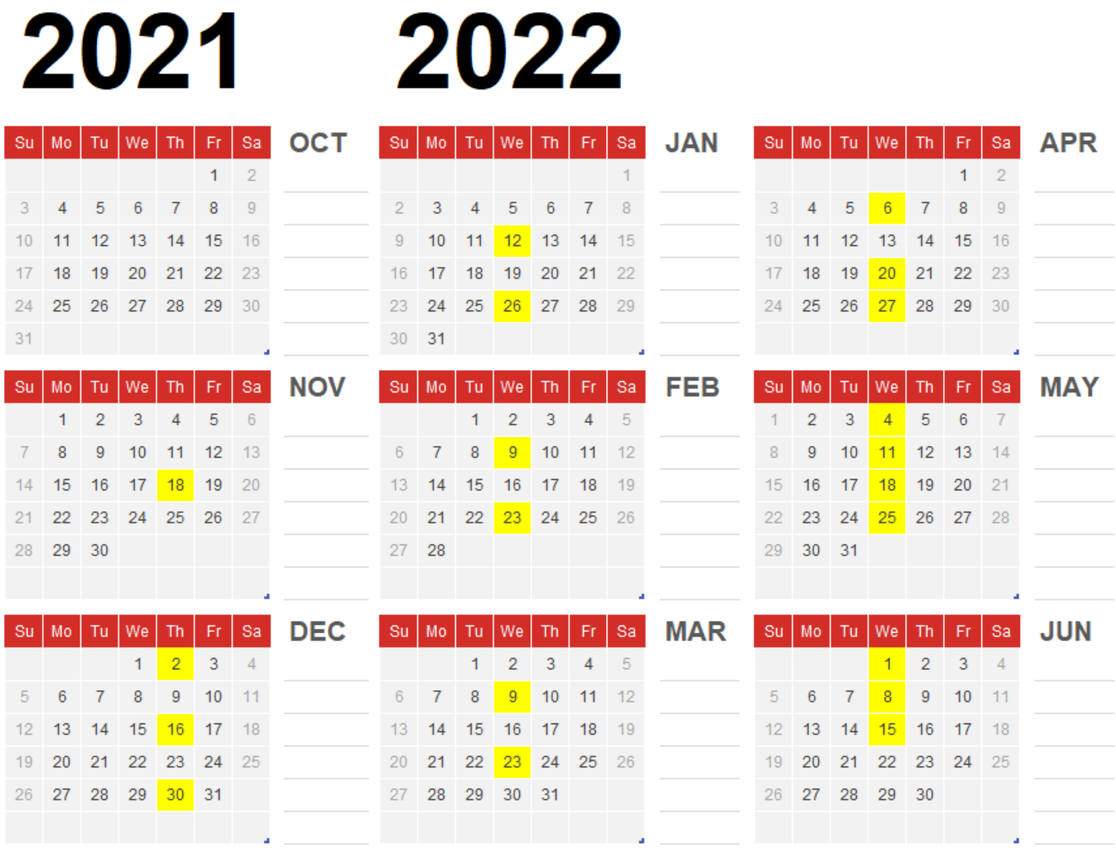

Figure 7.2: Calendar with the held Meetings by the thesis's Stakeholders

In the Introduction (chapter 1.1) in the section Work Planning (section 1.6), it was also devised that work would be planned for sprints and that there would be scheduled meetings with the thesis supervisor to align the work done and to plan the work for the subsequent sprint. The meetings would also serve as a PBR.

Figure 7.2 depicts the held meetings by the Stakeholders (the thesis's supervisor and the author). The days of the attended meetings are marked in yellow.

As a result, every two weeks, the thesis's Stakeholders met to discuss the sprint and work planning in order to ensure that the stated goals were met. These recurring sessions were held until mid-April, after which the sprint duration was reduced to one week and the meetings were held once a week.

7.1.2 Application Accomplishments

The goal of the proof-of-concept was to show that AR technology could be integrated into routine law enforcement tasks. As a result, the thesis portrayed such intent in the form of an application that assisted in the issuing of infraction tickets prompted by the recognition of license plates and then imposing the information onto the real-world. Although there are similar systems that capture license plates in order to issue infraction tickets (such as Police Radars), it is important to note that none of the applications have AR components, and this application is a proof of concept that aims to generalize the use of AR to aid Law Enforcement forces.

To begin with, it is crucial to note that nearly all requirements have been fully developed and reviewed. In the previously created QEF, the requirements analysis and completion rate are specified. The application's tests also yielded positive results, demonstrating that the AR License Plate Recognition can be used under the conditions described in the Evaluation and Experimentation chapter (chapter 6). The application was also well received by end-user testers, who gave it a high rating and applauded its practical applicability as well as the future growth of AR technology inside the Police Force.

The proof-of-concept application is compatible with a wide range of devices, including Windows, iOS, Android, Occulus Quest, Hololens, Google Glasses, and other supported wearables. The proof-of-concept also includes a License Plate Recognition Assist mode, which allows the user to save the last fifteen recognized license plates in order to reduce the recognition system's detection errors, as well as detect multiple plates and submit infraction tickets for all of them if they are registered in the system as recognized plates. The latter also allows the user to use less time to effectively manage more infraction tickets without having to bounce between numerous scenes, eliminating the difficulty of navigating several times and reusing the application's camera tasks rather than establishing new ones.

7.2 Limitations and Future Work

This section will focus on identifying all of the limitations that were discovered while doing the research, as well as the future work that was judged required to advance the proof-of-concept and enhance it so that it may have a greater influence inside law enforcement organizations.

7.2.1 Limitations

Regarding the limits encountered while investigating the thesis's main concept, it is feasible to deduce that the following constraints played a role in both concept research and implementation:

- Technology Limitations: Despite the fact that there are various AR technologies on the market with excellent documentation, the vast majority of them are paid options that could not be employed in this particular scenario. Because this project exclusively uses open-source technology, some of the features had to be manually implemented rather than being imported from an existing library, which hindered the progress.

- Hardware Limitations: Even though the entire development was designed for multiple devices utilizing Unity compatibility, there was a hardware limitation (the only testing devices available were an android smartphone and an iOS smartphone) that restricted the amount of devices on which the system could be evaluated. As such, the developed software was only test in mobile smartphones. Additionally, Unity applications for mobile use do not have multi-threading operations as of this date, which hindered the development of aiding the detection of license plates through the use of multi-threading.

- Information Limitations: Having full access to Law Enforcement information databases has been a goal that was recognized as likely impossible to materialize in the development of this work since its inception. All of the data is kept safe from external use. As a result, the developed software includes interfaces that may be readily updated to accept data from a remote sources. Because this system is a proof-of-concept, there was no need to connect it to a real data flow, so all of the data had to be mocked to replicate the actual flow. Future development could include connecting the proof-of-concept system to a real-world law enforcement database.

7.2.2 Future Work

Following the completion of the construction and documentation of the AR License Plate Recognition system to assist in the infraction ticket issuing process, it was identified that AR Depth Analysis could be a great addition to this proof-of-concept when implemented on an additional Object Recognition feature, specifically on vehicles.

The geometrical attributes of a target, such as normals and curvatures, have been the focus of depth-based object recognition techniques. By constructing local feature histograms from those attributes, a target object can be detected from depth images and models. RGB-D cameras, which capture color and depth images, aggregate the RGB and depth information for object recognition and pose estimation (Crivellaro et al. 2015).

To reflect the target's textures and geometrical attributes, a set of reference templates is generated not just from RGB images but also from depth images and models. To identify a target object, the reference templates are compared to incoming RGB and depth images in real time. The target's pose is estimated by aligning the 3D points of the current depth image with those of the reference templates once the target has been detected.

ARFoundation provides a Depth Scan as an integrated feature that already includes an RGB-D camera (Google 2022c). As a result, the initial stage would be to combine the ARFoundation Depth feature with trained neural network models that included the geometric features of the objects to be recognized, and cross them in real-time with the objects mapped from the camera's scan. The neural network models would be trained using feature histograms from the geometric attributes of the training objects.

To carry out such development, there are two major requirements:

- For the implementation to be successfully carried out, there will be a need to further investigate neural networks and machine learning models, such as Pythorch or ONNX models, which would allow the use of technologies like Vuforia and AR Foundation, which already have built-in libraries that export AR Depth sensorial implementations;
- Secondly, in order to fully verify the implementations done in that regard, specific hardware with depth sensors would be required. The majority of high-end smartphones have depth sensors that can be used for this. To properly carry out this improvement, however, considerably higher precision equipment would be required.

On the other hand, as previously stated in the Limitations section (section 7.2.1), there was no way to use real law enforcement data. As a result, in order to provide credit to the developed proof-of-concept, permission to use these data would be required, as well as the need to update the interfaces to read the external data.

To prevent data loss, a fail-safe system would be implemented, which would keep some of the information saved into the device to prevent data loss due to connectivity issues. Furthermore, since the program would be handling sensitive data, it would be necessary to conduct additional research into protection and encryption systems.

7.3 Final Considerations

Finally, since the majority of the objectives have been achieved, the author considers this thesis to be a successful endeavor. It is vital to highlight that the author had to interact with a technology denominated augmented reality, which has been gaining popularity in the present technological industry. This technology has a lot of potential and can be used in a variety of fieldwork situations. The everyday tasks of Law Enforcement were the subject of this study since the technology in this field could benefit from engagement with AR features. The author expects that this proof-of-concept has the possibility of being expanded upon in the future with additional features, and culminate in a significant impact on police officers' day-to-day work.

This was an endearing project that challenged the author to think about the best way to conduct research and how to efficiently manage the thesis and implementation components. Ultimately, the author views this project as a significant step into the Augmented Reality world, one that has the potential to expand the project's scalability to other areas, and one that has been highly satisfying as it provided the opportunity for the author to reflect on his own growth.

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Appendix A: QEF Support Scales

Dimension	Functionality
Factor	User Realm

Requirement	Metric Evaluation	Wfk - Fullfilment (%) 0	25	50	75	100
UR01 - The user is able to sign in in the software.	The User can login successfuly	Not implemented	-	-	-	Implemented
UR02 - The user is able to sign out in the software.	The User can logout successfuly	Not implemented	-	-	-	Implemented

Factor	System Realm

Requirement	Metric Evaluation	Wfk - Fullfilment (%) 0	25	50	75	100
SR01 - The system shall support the ability for the user to take snapshots.	The user can take a snapshot of the current screen inside the application	Not implemented	-	The app allows snapshots but does not have a specific feature.	-	Implemented
SR02 - The system allows the user to use the gathered information when submitting an infraction ticket.	The user can gather information on screen when detecting a license plate	Not implemented	-	The player can see the data with errors	-	Implemented
SR03 - The System should be able to easily receive uploaded models to its database in order to recognize objects.	The user can upload models to the database in order to enable the recognition	Not implemented	-	The user can upload a specific kind of objects to the local database	-	There is full access to an external database to where the user can upload the models

Factor	AR Realm

Requirement	Metric Evaluation	Wfk - Fullfilment (%) 0	25	50	75	100
AR01 - The software allows the detection of viewed objects through the device's camera in real-time.	The user can see the detection happening in real-time in the camera screen inside the application	Not implemented	-	Implemented with Bugs	-	Implemented
AR02 - The system allows the superimposition o digitally created objects into the real world.	The user can see the superimposition of digital information onto the real view when detecting a certain license plate.	Not implemented	-	Implemented with Bugs	-	Implemented
AR03 - The system is able to correlate detected objects with known objects that are accessible in storage (initially locally with the possibility to migrate to a online server service).	The user can find the information related to the recognized license plate in the for screen if the plate is registered in the database	Not implemented	-	Implemented with Bugs	-	Implemented
AR04 - The software shall be able to make use of visual tracking tags in the detected objects.	The user can see visual tracking tags around the license plate when trying the detection in the camera screen	Not implemented	-	Implemented with Bugs	-	Implemented

Figure A.1: QEF Functionality Scale

Dimension	FURPS					
Factor	Usability					
		Wfk - Fullfilment (%)				
Requirement	**Metric Evaluation**	**0**	**25**	**50**	**75**	**100**
US01 - The software shall have a user interface that can be used by non-software literate personnel	The interface follows the same built patterns, with matching buttons and colors to ease the navigation of the users.	0-20% of positive questionaries	20-40% of positive questionaries	40-60% of positive questionaries	60-80% of positive questionaries	80-100% of positive questionaries
Factor	Realiability					
		Wfk - Fullfilment (%)				
Requirement	**Metric Evaluation**	**0**	**25**	**50**	**75**	**100**
REL01 - The object detection and recognition feature provided by the system should be effective helping the user identifying the objects present in the database.	The interface reveals the information in a clear way that the user has direct access to.	0-20% of positive questionaries	20-40% of positive questionaries	40-60% of positive questionaries	60-80% of positive questionaries	80-100% of positive questionaries
Factor	Performance					
		Wfk - Fullfilment (%)				
Requirement	**Metric Evaluation**	**0**	**25**	**50**	**75**	**100**
PERF01 - All the features available in the system must be able to promptly answer the user's requests (e.g. Object recognition, menu loading, etc).	The interface response is in real-time and without lag issues.	0-20% of positive questionaries	20-40% of positive questionaries	40-60% of positive questionaries	60-80% of positive questionaries	80-100% of positive questionaries

Figure A.2: QEF FURPS Scale

Dimension	FURPS+					
Factor	Design & Implementation Constraints					
		Wfk - Fullfilment (%)				
Requirement	**Metric Evaluation**	**0**	**25**	**50**	**75**	**100**
DIC01 - The software may require a specific version of Android Operative System (Android OS) that supports the select AR toolkit.	The application works across all the compatabile devices listed in the toolkit framework.	Not implemented	-	-	-	Implemented
Factor	Interface Constraints					
		Wfk - Fullfilment (%)				
Requirement	**Metric Evaluation**	**0**	**25**	**50**	**75**	**100**
IC01 - The software may use specific APIs to access existing law enforcement databases.	The player should be able to use the real time map easilly	Not implemented	-	The application has interfaces ready to receive external data but it is not	-	The application has the connection with an external police database
Factor	Physical Constraints					
		Wfk - Fullfilment (%)				
Requirement	**Metric Evaluation**	**0**	**25**	**50**	**75**	**100**
PC01 - The software can be used in a wide selection of Android smartphones.	The application is deployable in various android devices with an OS greater than Android 7.1	0-20% of positive questionaries	20-40% of positive questionaries	40-60% of positive questionaries	60-80% of positive questionaries	80-100% of positive questionaries
PC02 - The System functionalities will only guaranteed while in exterior bright daylight conditions.	Application should be fully functional under bright daylight conditions	0-20% of positive questionaries	20-40% of positive questionaries	40-60% of positive questionaries	60-80% of positive questionaries	80-100% of positive questionaries

Figure A.3: QEF FURPS+ Scale