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Otimização de Simulações de Treino Militar: Desenvolvimento e Otimização da Segurança da Plataforma de Simulação da SisTrade

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Optimizing Military Training Simulations: Development and Security Optimization of SisTrade's Simulation Platform

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Porto, June 2024

Declaration of Integrity

I declare that I have conducted this academic work with integrity.

I have not plagiarised or applied any form of misuse of information or falsification of results throughout the process that led to its preparation. Therefore, the work presented in this document is original and of my own authorship and has not previously been used for any other purpose.

I also declare that I am fully aware of P.PORTO's Code of Ethical Conduct.

ISEP, Porto, 24 June 2024

Nuno Baptista da Rocha

«In preparing for battle I have always found that plans are useless, but planning is indispensable. » Dwight D. Eisenhower

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Resumo

No panorama contemporâneo do treino militar, a preparação completa e multifacetada, apta a cobrir uma ampla gama de cenários de combate é essencial para o funcionamento de qualquer exército. Neste contexto, os ambientes de treino imersivos surgem como uma solução indispensável. Estes ambientes que simulam cenários de combate, geralmente, com grande realismo, não apenas elevam a perceção de realidade nas situações de treino, mas também proporcionam uma compreensão mais profunda e detalhada das complexidades inerentes a tais cenários. Este aprofundamento contribui de forma substancial para o aumento da qualidade e para a eficiência em termos de custos nas práticas de treino militar, permitindo uma preparação mais eficaz e realista para os desafios do campo de batalha.

Com os recentes avanços em Realidade Aumentada e Ambientes Colaborativos, foi possível observar um papel vital destas tecnologias na melhoria da eficácia e do realismo dos simuladores. A integração destas inovações tecnológicas tem permitido a criação de cenários de treino mais interativos e envolventes, em que os participantes podem experimentar e reagir a situações complexas de forma segura, sem os riscos associados ao treino em condições reais. À medida que a tecnologia avança, o potencial para inovação e aperfeiçoamento no treino militar torna-se cada vez mais evidente e alcançável.

Neste âmbito, a preparação desta dissertação de mestrado centra-se no aperfeiçoamento da plataforma de simulação da SisTrade, com especial ênfase na interatividade e segurança dos dados. A pesquisa aborda a aplicação prática de Ambientes Colaborativos Virtuais, procurando explorar as suas capacidades em maximizar a eficiência do treino, enquanto a implementação de um modelo de Encriptação Baseada em Atributos visa garantir a segurança e a integridade dos dados manipulados. Este estudo visa não só melhorar a experiência de treino militar, mas também assegurar a proteção de informações sensíveis, um aspeto crítico na era digital.

Palavras-chave: Simulações Militares, Ambientes Colaborativos, Encriptação Baseada em Atributos

Abstract

In the modern military training landscape, a comprehensive and involved preparation capable of covering a diverse spectrum of combat scenarios is of the utmost importance. In this context, immersive training environments have emerged as an indispensable solution. These simulated environments not only provide a heightened sense of realism but also offer a more thorough comprehension of intricate scenarios. This significantly contributes to the improvement of quality and cost-effectiveness in military training practices, allowing for more effective and realistic preparation for battlefield challenges.

Recent advances in Augmented Reality and Collaborative Environments have played a pivotal role in elevating the efficacy and realism of these training tools. The integration of these technological innovations has allowed for the creation of more interactive and engaging training scenarios, where participants can experience and react to complex situations safely, without the risks associated with real-world training conditions. As technology advances, the potential for innovation and improvement in military training becomes increasingly apparent and achievable.

This master’s dissertation explores the enhancement of SisTrade's simulation platform, focusing on interactivity and data security. The research addresses the practical application of Virtual Collaborative Environments, seeking to explore their capabilities to maximize training efficiency, while the implementation of an Attribute-Based Encryption model aims to ensure the security and integrity of the handled data. This study aims not only to improve the military training experience but also to ensure the protection of sensitive information, a critical aspect in the digital age.

Keywords: Military Simulation, Collaborative Environments, Attribute-Based Encryption

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Abbreviations

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ABE	Attribute-Based Encryption
API	Application Programming Interface
AR	Augmented Reality
CP-ABE	Ciphertext-Policy Attribute-Based Encryption
CPR	Content-based Protection and Release
CVE	Collaborative Virtual Environments
DSR	Design Science Research
EDF	European Defense Funding
HSM	Hardware Security Module
IIS	Internet Information Services
JSAF	Joint Semi-Automated Forces
KMS	Software-Based Key Management Service
KP-ABE	Key-Policy Attribute-Based Encryption
MAK CST	MÄK Command and Staff Training
MIRICLE	Mine Risk Clearance For Europe
MVC	Model-View-Controller
NATO	North Atlantic Treaty Organization
OLP	Object-Level Protection
SSL	Secure Sockets Layer
SUS	System Usability Scale
VE	Virtual Environments
VR	Virtual Reality
WBVE	Web-Based Virtual Environment
WSS	WebSocket Secure
XR	Extended Reality

1 Introduction

The first chapter of this dissertation is an overview of the project “Optimizing Military Training Simulations: Development and Security Optimization of SisTrade's Simulation Platform”, carried out in the scope of the Master’s Degree in Software Engineering of the Instituto Superior de Engenharia do Porto (ISEP).

This chapter is divided into sections that contextualize the reader concerning the problem at hand, objectives to achieve and the approach to follow.

1.1 Context

Due to the inherent dangers of modern military training, soldiers and expensive equipment are frequently at risk during training exercises. Military operations require extensive planning for a variety of battle scenarios, from urban warfare to isolated locations, each of which has its own set of difficulties and perils. These training exercises were traditionally carried out in actual environments, which presented serious risks to both people and equipment.

However, advancements in computer technology have revolutionized military training by offering immersive and realistic simulation environments. These virtual platforms lessen the hazards involved with live exercises and offer a secure and affordable substitute for conventional training techniques. With interactive elements that improve training effectiveness, from tactical decision-making to team coordination, military personnel can train in highly realistic environments that replicate the complexities of real-world situations, such as urban landscapes, rugged terrain, and geographically distant locations.

Compared to conventional approaches, the capability to repeat training exercises offers substantial advantages that let military forces improve tactics, strategies, and procedures without jeopardising real-world locations or depleting resources. Staff members become more skilled and flexible as a result of this constant training, which makes them prepared for a variety of operating situations. Successful information technology integration into military training programmes requires striking a balance between the necessity of data security and realism.

1.2 Description of the Problem

The necessity of immersive training environments to help prepare personnel has never been so great. With the advances in the fields of simulation, augmented reality and computing power, these environments can be majorly expanded in terms of realism and training types. Nevertheless, these types of expansions can be expensive and can quickly become more headaches in the design and implementation process. Ranging from the security that all data should go through, to the interactivity and pleasure that the user has while using the simulator.

Due to the participation in the European Defense Funding (EDF) MIRICLE (Mine Risk Clearance For Europe), SisTrade intends to augment its prototype and acquire knowledge on the difficulties and necessities that developing such a project entitles. This project aims to address the intricate problem of designing and expanding the military simulation platform prototype.

This prototype was first developed as a constructive simulation, due to having low costs involved, being a prototype and the first step taken into the defence sector. However, it does not possess several functionalities required to become a full-fledged simulation, making the addition of new functionalities challenging, as there is not a fully completed base to the project. Nonetheless, the current implementation provides a strong base for the addition of collaborative tools. Currently implemented is the ability to create and edit scenarios, units and their components, basic scripting, such as movement, and detecting mines, and finally the ability to watch the scenario play out in 2D.

The challenge lies in striking a balance between the integration of innovative graphic and collaborative technologies. Furthermore, it requires the investigation and creation of a preliminary encryption model to protect proprietary military simulation models, thereby rendering these platforms technically and financially viable for military institutions seeking optimal security. This research endeavours to provide a comprehensive solution to these pressing issues in the realm of military training and simulation.

1.2.1 Objectives

In the analysis of the problem, two main parts of the system were identified, (1) the visualization platform, and (2) the attributed-based encryption. In this context, the following main objectives were defined:

- Extend SisTrade's web-based and collaborative military simulation prototype so that it can be used for scenario design and military game simulation;
- Integrate new graphic and collaborative technologies to develop a multi-user and collaborative interface;

- Using Attribute-based encryption to control access to information.

The final solution is intended to improve the proof-of-concept present by the company, as a way to increase the knowledge in the defence sector.

1.3 Schedule of Activities

Table 1 presents the planning defined for this dissertation at the beginning of its execution.

Table 1 - Planning of Activities

	Start Date	End Date
Literature Review	2023/10/18	2024/01/06
Research Process	2023/10/29	2024/12/17
State of the art	2023/11/07	2024/12/17
Revisions	2024/12/27	2024/01/06
Design of the Solution	2024/01/15	2024/03/01
Requirements gathering	2024/01/15	2024/02/05
Specification of the architecture	2024/02/05	2024/03/01
Implementation of the Solution	2024/03/04	2024/05/14
Validation of the Solution	2024/15/05	2024/06/14
Conclusions	2024/06/15	2024/06/30

However, due to the delays in the implementation and scarcity of time, the actual timing of the projects is presented in Table 2.

Table 2 - Scheduling of Activities

	Start Date	End Date
Literature Review	2023/10/18	2024/01/06
Research Process	2023/10/29	2024/12/17
State of the art	2023/11/07	2024/12/17
Revisions	2024/12/27	2024/01/06
Design of the Solution	2024/02/12	2024/03/01
Requirements gathering	2024/02/12	2024/02/19
Specification of the architecture	2024/02/26	2024/03/01
Implementation of the Solution	2024/03/03	2024/05/19
Validation of the Solution	2024/05/05	2024/05/31
Conclusions & Revisions	2024/06/01	2024/06/30

1.4 Ethical Considerations

Ethical considerations are crucial in the field of software engineering research as they directly influence the integrity and social impact of the work. This section addresses these considerations as they apply to the research and development of the new functionalities and data encryption of SisTrade's simulator.

It should be noted that this was carried out under all ethical standards and guidelines set forth by the Order of Engineers (*Ordem dos Engenheiros, 2016*), the Code of Good Practices and Conduct of P.Porto (*Instituto Politécnico do Porto, 2020*) and the Institute of Electrical and Electronics Engineers Code of Ethics (*IEEE, 2020*).

First, SisTrade's simulator is a system being developed with the possibility that in the future it could be sold as a product to interested parties, be it military personnel or private companies. However, it should be noted that the simulator itself is not capable and should not be used to dictate whenever the user is ready to be sent to an active front or similar. This system is a small part of the whole process to train, educate, and ready personnel.

Second, along with the purpose of being sold as a final product, it is intended to implement new functionalities, such as Augmented Reality and Collaborative Environments. As such to facilitate and speed up the development timeline and process existing available projects and frameworks will be used. Licenses of the external projects, frameworks, and tools used must be followed and obliged, be it morally and legally.

Third, with the advent usage of Attribute-Based Encryption, virtual information will be transmitted and stored in the company's database, adding the responsibility of security and protection of that data. Naturally, regulations such as the General Data Protection Regulation (*Regulation (EU) 2016/679, 2016*), and the Information Security, Cybersecurity and Privacy Protection (*ISO, 2022*), must be followed and ensure compliance.

Fourth, with military simulators often involving sensitive information related to national security, tactics, and strategies, considerations must prioritize the security and confidentiality of this information to prevent unauthorized access or disclosure. Robust encryption protocols and access control mechanisms should be implemented to safeguard classified data from cyber threats and espionage.

Finally, clear communication regarding the simulator's capabilities, limitations, and potential risks to military personnel and decision-makers must be publicized by developers and stakeholders as transparency fosters trust and confidence in the simulator's reliability and effectiveness for training and operational purposes.

1.5 Research Methodology and Process

Regarding the research process, the Design Science Research (DSR) (*Wohlin and Runeson, 2021*) methodology was used. The main objective is to enhance SisTrade's military simulation platform, which can be subdivided into two sub-objectives as previously mentioned:

1. Integrating a Collaborative Environment for better usability and ease of use.

2. Implement a more secure data model by employing Attribute-Based Encryption.

Using this methodology involves a cyclic process of problem identification, solution design, implementation, and evaluation, allowing for the continuous refinement of the simulation platform. As the research unfolds, insights gained from each iteration will alter subsequent design decisions, ultimately leading to a more robust and effective system *(Wohlin and Runeson, 2021*).

Alan Hevner *(Hevner et al., 2004*) suggests a set of guidelines for this type of methodology, as presented in Table 3.

Table 3 - Design Science Research Guidelines (*Hevner et al., 2004*)

Guideline	Description
Guideline 1: Design as an Artifact	Design-science research must produce a viable artefact in the form of a construct, a model, a method, or an instantiation
Guideline 2: Problem Relevance	The objective of design-science research is to develop technology-based solutions to important and relevant business problems.
Guideline 3: Design Evaluation	The utility, quality, and efficacy of a design artefact must be rigorously demonstrated via well-executed evaluation methods.
Guideline 4: Research Contributions	Effective design-science research must provide clear and verifiable contributions in the areas of the design artefact, design foundations, and/or design methodologies
Guideline 5: Research Rigor	Design-science research relies upon the application of rigorous methods in both the construction and evaluation of the design artefact
Guideline 6: Design as a Search Process	The search for an effective artefact requires utilizing available means to reach desired ends while satisfying laws in the problem environment.
Guideline 7: Communication of Research	Design-science research must be presented effectively both to technology-oriented as well as management-oriented audiences

By applying the guidelines to this dissertation, the following is achieved.

1. Design as an artefact. Several artefacts that resulted from this research were as follows:
    - An integrated graphic multi-user and collaborative new interface will be produced;
    - An Attribute-based encryption model to control access to information will be implemented;
2. Problem Relevance. The relevance of the problem is emphasized by identifying the state-of-the-art limitations and needs for non-existent functionalities (Chapter 2).

3. Design Evaluation. In terms of evaluation methods, the ones to be used are analytical, experimental, and evaluative. This is due to the software nature of the artefact (Chapter 4).

4. Research Contributions. By exploring and evaluating, this research is capable of shedding light on the applicability and effectiveness of Collaborative Environments and Attribute-Based Encryption in enhancing military simulation platforms (Chapter 2).

5. Research Rigor. The Rigor is maintained through a structured schedule of activities, ensuring systematic and thorough execution (Chapter 1.3).

6. Design as a Search Process. The research process applied in this document utilizes available means to acquire relevant and sufficient information to be able to make assumptions, decisions, and conclusions (Chapter 3).

7. Communication of Research. This document will be publicly accessible to disseminate its content. Furthermore, most of the proposed and described artefacts could be submitted to conferences and, therefore, evaluated by the respective research community.

Regarding the search, a relevant workflow was defined. Firstly, the relevant research questions will be presented, in addition to the data sources used. Followed by presenting and explaining the search query utilized to obtain relevant articles and the eligibility criteria that each article must adhere to. Finally, the data collection process is explained in detail.

1.5.1 Research Questions and Data Sources

As previously explained, there are two main parts to this research, one regards the improvement of the existing simulation platform, and the other is directed to the research and creation of a model using attribute-based encryption.

As such the research questions (RQ) addressed in this report are:

RQ1: What are the key elements and features of immersive training environments that positively impact training quality in military settings, and how can these be effectively integrated into military simulation platforms?

RQ2: What are the potential advantages of integrating innovative graphic technologies and collaborative technologies into the military simulation platform, and how can these technologies enhance the training experience?

RQ3: What kind of collaborative tools exist?

RQ4: What is Attribute-Based Encryption, and how is it utilized in applications and security contexts?

RQ5: What are the current challenges and limitations in ensuring data security and confidentiality and what effective strategies can be implemented to address these issues?

The identification of the data sources to use in the systematic review is the first step of the research process. The electronic databases selected are shown in Table 4.

Table 4 - Articles Database

Identifier	Database	URL
DS1	ACM Digital Library	https://dl.acm.org/
DS2	IEEE Xplore	https://ieeexplore.ieee.org/
DS3	Schoolar Google	https://scholar.google.com/

These databases contain relevant peer-reviewed academic publications, and they were chosen because they are considered highly relevant by researchers in information technology.

1.5.2 Search Terms and Eligibility Criteria

Regarding the search query, two queries will be used, as the research has two main groups.

The keywords for the search query regarding the improvement of the platform are Military simulation platform, immersive training environments, training quality, collaborative, and training experience. Using these keywords, a search query was created, "Military training AND Collaborative”.

For attribute-based encryption, they are Attribute-Based Encryption (ABE), data security, military settings, and data protection. The search query formed was “*(*Attribute-Based Encryption OR ABE*) AND (*data security OR data protection*) AND* military settings”.

The inclusion criteria for an article to be selected were:

- The source explores the field of military simulations or the field of attribute-based encryption;
- The source compares the use of different types of attribute-based encryption;
- The source provides the pros and cons of military simulation platforms.

The exclusion criteria for an article to be discarded were:

- Studies that do not focus on attribute-based encryption for data security;
- Source does not provide practical scenarios/applications of attribute-based encryption, or simulation platforms;

- Source is not published in the English or Portuguese language.

Later on, the need to search for collaborative tools, such as WebXR and Y.js, arose and as such a new search query was added “WebXR OR Y.js”.

Due to a lack of articles regarding these technologies, it was necessary to have broader inclusion and exclusion criteria.

The inclusion criteria for an article to be selected were:

- The source belongs to the field of augmented or virtual reality;
- The source explores the use of WebXR or Y.js;
- The source compares several technologies related to the field.

The exclusion criteria for an article to be discarded were:

- Source does not provide practical scenarios/applications of WebXR or Y.js;
- Source is not published in the English or Portuguese language.

1.5.3 Data collection process

To obtain the relevant articles, PRISMA (*Page, McKenzie, et al., 2021; Page, Moher, et al., 2021*) systematic review process was followed. This process consists of three steps:

1. Identification consisted of obtaining all the articles from the data sources that met the included eligibility criteria. 170 valid articles were identified.
2. Screening, which itself consists of two parts:
   - 2.1. The first was an abstract screening conducted on all identified articles. During this part, the articles were categorized as either "Relevant", "Irrelevant" or "Possibly Relevant." Subsequently, "Possibly Relevant" articles underwent a secondary screening to be categorized as either "Relevant" or "Irrelevant." This yielded a total of 40 articles deemed "Relevant";
   - 2.2. The second part focused on an in-depth examination of the relevant articles with the goal of finding information that fit the research questions. Ultimately, 19 articles were found to address at least one of the research questions.
3. Inclusion consists of gathering each of the remaining articles' information that was relevant to the research.

By using this meticulous approach, it was possible to ensure the selection of relevant literature, enhancing the credibility and validity of the research findings on military simulation platforms.

1.6 Structure of the Report

This document consists of four more chapters. Chapter 2 consists of a state of art, addressing the fundamental concepts for the understanding of the developed project, from a technological and logistical perspective. In Chapter 3, the analysis of the existing solution is performed, contemplating the specification domain concepts, architectural approaches taken, and the existing user interface. Chapter 4 covers the implementation of the alterations to the solution previously analysed, exemplifying the iterative flow of the development process. Finally, Chapter 5 contemplates the conclusions at the level of what was achieved and the possible future work.

2 Literature Review

This chapter presents the topics describing some elements of the usage of collaborative technologies in simulation platforms and data security measures, more precisely the usage of attribute-based encryption.

2.1 Training Platforms

According to Hill and Miller (*Hill and Miller, 2017*), simulations serve as a means to deploy a model over an extended duration, being a model a simplified representation of an entity. Additionally, they function as a technique for testing, analysing, or training, whereas the model replicates the real world and its conceptual systems.

As such, simulations can be developed in several ways (*Hill, Miller and McIntyre, 2001*):

- **live simulation**, which “involves real people using real systems”, normally characterized as field exercises;
- **virtual simulation**, which “involves real people using simulated systems”, being able to “include combined exercises where real people, using real systems, interact with and react to the actions of simulated people or systems combined”;
- **constructive simulation**, which “are what we usually think of as models, war games, and simulations”, which are solely contained in themselves.

Following virtual and constructive simulations will be explored, and some examples of existing simulators will be shown. Due to the expanse of existing simulators, the article of José Padila (*Padilla, 2012*) will be used to narrow down some examples.

Live simulations will not be explored as they are real-life training done in real locations in the real world, so, they do not fit the criteria.

2.1.1 Virtual Simulations

Virtual Simulation involves the use of computer-based models and environments to replicate real-world scenarios. In this type of simulation, real individuals interact with computer-generated environments using real systems, such as flight simulators. They can also include combined exercises where real people, using real systems, interact with and react to the actions of simulated people or systems *(Cheung and Loper, 1994; Hill, Miller and McIntyre, 2001*). They often incorporate elements of Augmented Reality (AR) or Virtual Reality (VR). An example of this type of simulation is Virtual Battlespace 4.

2.1.1.1 Virtual Battlespace 4

Virtual Battlespace 4[1] is a simulator created by a private company, Bohemia Interactive Simulations, whose aim is to train and rehearse missions at a tactical level. Its database is diverse and includes not only military entities and objects, but also civilians, like car batteries and journalists. These capabilities make the simulations more realistic and add a new level of difficulty, the presence of civilians (*Padilla, 2012*). This simulator has the capability of having users, for example, controlling a vehicle by being in a physical simulator, while the fireteams are exercising fully on a computer like in a game. This makes it a mesh of a constructive and virtual simulator.

2.1.2 Constructive Simulations

Constructive Simulation refers to simulations that are self-contained models, war games, or simulations. Unlike virtual simulations, constructive simulations don't involve direct interaction with real people or systems. Instead, they focus on modelling and simulating the behaviour of entities within the simulated environment (*Cheung and Loper, 1994; Hill, Miller and McIntyre, 2001*). These simulations are often used for strategic planning, scenario analysis, and decision-making exercises. Examples of these types of simulations are Joint Semi-Automated Forces and MÄK Command and Staff Training.

2.1.2.1 Joint Semi-Automated Forces

Joint Semi-Automated Forces (JSAF), developed in 1990 by a program of the United States of America Department of Defence, is a simulator used in the generation of scenarios with low-level entities, i.e., soldiers, ships, and ammunition. By being low level, it seeks to achieve an elevated level of realism in the entities, for example, expenditures on ammunition, obstacles, and Line of Sight affect them. JSAF is an open environment where an entity’s attributes, tasks and behaviours can be modified. This adds flexibility but can generate consistency issues with other systems that are known to be capable of interoperating (*Padilla, 2012*).

[1] https://bisimulations.com/products/vbs4

2.1.2.2 MÄK Command and Staff Training

MÄK Command and Staff Training (MAK CST) is a system for practising and executing training exercises. This system was created in an attempt to correct weaknesses that other simulators have, such as the high costs of maintenance and support, and the large team of technicians that accompany it (*Padilla, 2012*). These weaknesses make them impractical for smaller nations and use in a classroom, an issue that MÄK CST has taken as a priority *(MAK Technologies, 2024*).

2.1.3 Comparison between simulators

Observing all the information presented about the simulators, to facilitate the comparison between all, it was decided to create a table, that being Table 5.

Table 5 - Comparisons between simulators

Aspect	Features	Advantages	Disadvantages
JSAF	Open Environment	Flexibility in entity's attributes, tasks, and behaviours	May generate consistency issues with other systems
VBS2	Diverse Database	More realistic and difficult scenarios	Limitations as a training tool
MÄK CST	Balance between ease of use and utility	Practical for smaller nations and use in a classroom	Limitations on several fronts due to its light system
SisTrade's Simulator	Easy learning curve	In-house creation, meaning full control of the development process	Still in a prototype phase, having very few functionalities

Having a working simulator is a major step, but not the only one. Among others, the ability to train together with other people brings forth a great advantage. This advantage can be by making a more cohesive unit by forcing them to learn and adapt to each other. Or by making the user learn to adapt and overcome unexpected challenges due to the dynamic way of the other users' actions.

2.2 Collaborative Environments

Collaborative environments are digital spaces where individuals, often geographically dispersed, can interact, share information, and work collectively, facilitating real-time communication and cooperation (*Ahmed et al., 2007*). Presented are several types of environments, along with their main characteristics, and existing tools that are representative of them:

- Online Collaboration Platforms (Microsoft Teams[2])
    - Real-time communication
    - File Sharing
    - Project Management
- Augmented Reality Collaborative Environments (Google ARCore[3])
    - Real-world integration with digital overlays.
    - Shared augmented experiences among users.
- Mixed Reality Spaces (Magic Leap[4])
    - Integration of virtual and real-world elements.
    - Interaction with 3D holograms and digital content.
- Collaborative Virtual Environments (VRChat[5])
    - Shared virtual spaces for real-time interaction.
    - Virtual presence through avatars.
- Web-Based Virtual Environments (Spatial.chat[6])
    - Browser-based access without additional installations.
    - Real-time collaboration on web-based content.
    - Shared virtual spaces accessible via URLs.

Deeper research will be done on Collaborative Virtual Environments and Web-Based Virtual Environments, as they are the more adequate environments for the company's final product.

2.2.1 Collaborative Virtual Environment

Collaborative Virtual Environment (CVE) is a distributed 3D application that allows users to interact and collaborate with shared objects in a Virtual Environment (VE) *(Diabi et al., 2006; Boukerche, Zarrad and Araujo, 2008*). Each user is represented in the form of an avatar. This concept enables users to observe and listen to one another, while also providing a visual representation of the actions undertaken by other participants.

The environments can be of different sizes and complexities, creating a burden on the devices used, which can range from fixed to mobile ones, as users may have the possibility to collaborate from anywhere. When the burden becomes too much, a zoning system is normally implemented. This ensures that each client processes a manageable amount of data that fits

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[2] https://www.microsoft.com/en-us/microsoft-teams
[3] https://developers.google.com/ar/overview
[4] https://www.magicleap.com/en-us/
[5] https://www.vrchat.com/
[6] https://spatial.chat/

into the local memory of their device. This is a response to one of the first challenges that this environment poses, the scalability of the system *(Benford et al., 2001; Ahmed et al., 2007*).

Activities within these zones are organized into sessions, and users can participate in multiple sessions. A node is defined as a user or player with a device. To pinpoint the physical user position in the VE, a CVE profile can be introduced, defined as a triple *<UserID, Session ID, Zones IDs>* (Boukerche, Zarrad and Araujo, 2008). This set represents the zones where the user is currently subscribing/publishing in the VE, influenced by their visibility radius or Area of Interest.

In relationship to the type of network architecture normally used, two types appear peer-to-peer (P2P) and multi-server. In P2P, there is no central server, and each peer maintains its copy of the virtual environment states, exchanging data directly. In multi-server architecture, multiple servers control the CVE, and participants exchange data with one or more servers (*Ahmed et al., 2007*).

2.2.2 Web-Based Virtual Environment

On the other hand, a Web-Based Virtual Environment (WBVE) is any virtual space or simulation that is accessible and interacted with through a web browser. Unlike traditional virtual environments that may require specialized software or hardware, WBVEs leverage web technologies to provide users with access to virtual spaces directly through standard web browsers. Another advantage is accessibility through desktops, mobile devices, and VR headsets (*Sermet and Demir, 2022*).

Figure 1 presents a possible system architecture of a WBVE, designed by (*Sermet and Demir, 2022*).

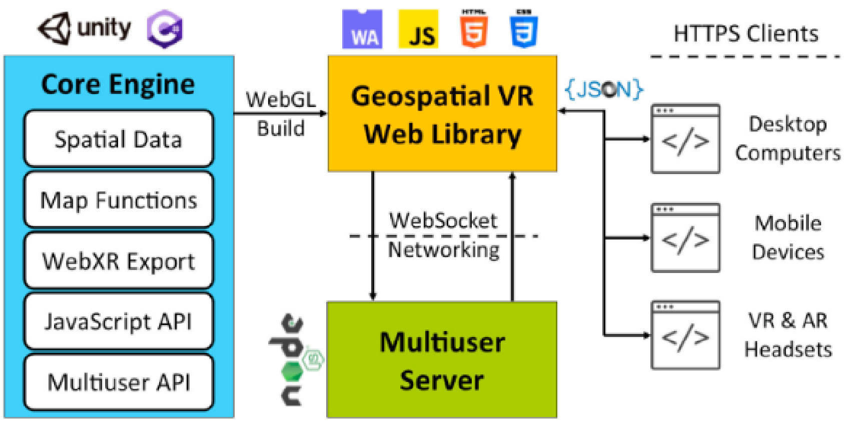

Figure 1 - System architecture of GeospatialVR framework (*Sermet and Demir, 2022*)

As can be observed, it mainly consists of 3 components, (1) the Core Engine, (2) the Multiuser Server and the (3) Web Application.

1. The Core Engine, or as colloquially called, the backend, is responsible for providing:

- Spatial data and map functions, such as geo-streaming services and vector tiling systems;
- 3D visualization and virtual reality on the web, with compatibility goals with different devices using, for example, WebXR or WebVR and allows conventional web access;
- Communication APIs for the multiuser server and clients, allow users to interact with the 3D scene, alongside action triggering, and to facilitate collaboration between users and the synchronization between them.

2. The Multiuser Management Server is responsible for acting as the main hub for managing multiple users.
3. The client Web Applications are responsible for incorporation into the web platforms, and for being the point of communication with the 3D environment.

2.2.3 Comparison between environments

Having analysed both main environments, a comparison between them is done, as presented in Table 6.

Table 6 - Comparison between Collaborative Environments

Aspect	Online Collaboration Platforms	Augmented Reality Collaborative Environments	Mixed Reality Spaces	Collaborative Virtual Environment	Web-Based Virtual Environment
Access and Platform	Web-based, various platforms	AR devices, specialized platforms	Mixed reality devices	Typically requires specific software and hardware	Web-based
Interaction	Varied (text, file sharing, etc.)	AR interaction, object manipulation	Varied	Can offer immersive interaction with avatars and objects	Mouse, touch, keyboard
Collaboration	Real-time, asynchronous	Real-time collaboration	Real-time collaboration	Real-time collaboration	Collaboration, but real-time interaction might be limited
User Base	Widespread	Specific to AR users	Varied	Widespread	Widespread
Immersiveness	Limited	High immersion, physical-world interaction	High immersion	High immersion	Limited compared to VR
Development Complexity	Moderate	High complexity	High complexity	Moderate to complex	Generally simpler using standard web technologies
Data Security	Relies on web security practices	AR-specific security concerns	Mixed reality security	May have specific security concerns	Requires attention to web security practices
Cost and Accessibility	Cost-effective and accessible	Initial costs might be higher for AR hardware	Varied costs	Initial costs might be higher for AR hardware	More cost-effective and accessible

Due to SisTrade's existing simulator being 100% web-based, as well as the company's product, the type of environment to be used will be Web-Based Virtual Environments. By selecting this type, future developments and integrations will be more easily executed, and when assistance is needed, a larger pool of knowledge will be available.

2.3 Collaborative Tools

After the desired virtual environment is defined, there is now the need to analyse possible technologies for the environment to be implemented. These tools are of two kinds and functions. The first type is responsible for the display of Augmented Reality or Virtual Reality, while the second is responsible for the ability to have shared data and multiple users editing it.

2.3.1 Augmented Reality Frameworks and WebXR

The fusion of Augmented Reality and web technologies expanded the number of possible users that can use and experience it. By allowing the common user to use their web browsers along with their mobile device, it expanded the interactivity of existing software. WebVR and later WebXR stand as the backbone for AR application development.

WebXR, or Web Extended Reality, is an emerging technology standard that enables the creation of immersive virtual and augmented reality experiences directly within web browsers *(MacIntyre and Smith, 2018*). Introducing a set of JavaScript APIs, collectively known as the WebXR Device API (*W3C, 2022*), enables developers to more easily create Extended Reality (XR) applications. These applications are designed to operate across various devices, including virtual reality headsets, augmented reality devices, and conventional desktop or mobile browsers.

The transition from the previous WebVR (*WebVR, 2018*) standard to the WebXR Device API provides a platform-independent interface catering to the core capabilities shared by AR and VR devices. It does however still have several open problems, such as platform-specific sensing, computer vision, geospatial content integration, visual search, immersive-first web browsers, multi-user experiences, and precise localization with persistence (*MacIntyre and Smith, 2018)*.

2.3.1.1 Three.js

Three.js is an open-source cross-browser JavaScript library used to create and display animated 3D computer graphics. For rendering, Three.js uses WebGL if a browser supports it, and it can fall back to an HTML5 canvas or an SVG approach if WebGL isn't supported. Through the use of WebGL, it is possible to render the animations faster, as it uses the client's hardware for the rendering (*Dirksen, 2014*). Although when first engineered, Three.js did not support WebXR, the same is not true as of the latest version.

2.3.1.2 Babyloon.js

Babylon.js, an open-source real-time 3D engine, is a JavaScript library written in TypeScript, for displaying 3D graphics in a web browser. Developed by two Microsoft employees, it has gained large usage, especially in Microsoft products, such as Microsoft Teams' Reactions (*Irwin, 2021*). Outside Microsoft, it has been used in several fields such as blockchain worlds (*Nolan, 2018*), urban underground infrastructure modelling (*Jurado, Alvarado and Feito, 2018*), and most importantly for this project, military simulation *(Maxwell and Heilmann, 2017*). It natively supports WebXR.

2.3.1.3 Comparison between frameworks

Observing all of the information presented about the frameworks, to facilitate the comparison between all, it was decided to create a table, that being Table 7.

Table 7 - Comparison between AR Frameworks

Feature	Three.js	Babylon.js
License	MIT License	Apache License 2.0
Rendering Engine	WebGL-based, supports WebGL, WebGL2, and fallbacks	WebGL-based, supports WebGL, WebGPU, and fallbacks
Physics Engine	Optional integration with external physics libraries	Built-in physics engine
VR/AR Support	Works well with WebXR	Native support for WebXR
Open Source	Yes	Yes

Considering the comparison between the frameworks and the results of the study done by Julia Johansson (*Johansson, 2021*), either framework is more than adequate for this development. However, as the 3D elements already present in the SisTrade's simulator have already been developed in Babylon.js, that will be the framework used moving forward.

2.3.2 Collaboration Frameworks

Implementing collaboration into the system is one of the main objectives of this thesis and as such, it should not be taken lightly. To facilitate and speed up the process, it was decided to study and use already existing frameworks.

2.3.2.1 Y.js

Y.js (*'yjs/yjs', 2023*) is a real-time shared editing library designed to facilitate collaborative editing of shared documents and data structures within web applications, in peer-to-peer settings (*Nicolaescu et al., 2015*). It enables multiple users to concurrently edit and synchronize changes in real time, making it suitable for collaborative environments and applications.

Limitations such as scalability challenges in peer-to-peer environments and neglection of custom abstract data types, are addressed in Y.js by introducing a modular framework.

The framework supports various communication protocols such as WebRTC and XMPP and can be applied to text, JavaScript Object Notation (JSON), and Document Object Model (DOM) elements. Notably, it focuses on enhancing reliability and usability in ad hoc peer-to-peer scenarios, making it appealing for lightweight applications where collaboration logic can be easily implemented on the client side (*Nicolaescu et al., 2015*).

2.3.2.2 DerbyJS

DerbyJS (*DerbyJS, 2023*) is a real-time, full-stack JavaScript framework that facilitates the development of dynamic and collaborative web applications. It follows a Model-View-Controller (MVC) architecture, offering features for both client-side and server-side development.

This framework provides automatic two-way data binding, ensuring that changes to the data model are instantly reflected in the user interface and vice versa. This means that support for real-time collaboration is already built-in, facilitating the preparation work.

However, it possesses a learning curve due to the unique structure and concepts introduced and the community may not be as extensive as other popular frameworks like React or Angular. This framework is used in programs such as

2.3.2.3 Firebase Realtime Database

Firebase is a comprehensive platform provided by Google for building web and mobile applications. Firebase Realtime Database (*Google, 2023*) is a NoSQL database that enables real-time data synchronization between clients.

As mentioned, it is a NoSQL database offering a flexible JSON-like data structure, along with, support for offline usage meaning that changes made offline are synchronized when the device is online again. It does, nonetheless, possess limitations in terms of complex querying and indexing capabilities.

2.3.2.4 Comparison between collaboration frameworks

Observing all of the information presented about the frameworks, to facilitate the comparison between all, it was decided to create a table, that being Table 8.

Table 8 - Comparison between Collaboration Frameworks

Feature	Y.js	DerbyJS	Firebase Realtime Database
Type of Framework	Real-time collaboration library	Full-stack JavaScript framework	Backend-as-a-Service with real-time sync
Real-time Sync	Supports shared data structures	Automatic two-way data binding	Seamless real-time data synchronization
Data Binding	Shared data structures	Two-way data binding	Real-time synchronization with clients
Backend Integration	Can be used with various backends	Integrated with ShareDB	Integrated with the Firebase platform
Community Support	Active community support	Active community support, but small in comparison	Strong community support as part of the Firebase platform
Programming Language	JavaScript	JavaScript	JavaScript
Documentation	Documentation available on GitHub	Well-documented	Well-documented

Considering the comparisons, it was chosen to be used Y.js. This is due to the technology being the closest to already being used in the company, the fact that the front end of the simulator was coded in Angular, and the database used in the company is Microsoft Server SQL.

2.4 Data Security

With the increasing usage of cloud computing technology, it became paramount to ensure data protection, confidentiality, and data immutability. Additionally, when working on a European project such as MIRICLE, securing the data between partners is very important to ensure. However, safeguarding data protection has added several steps that have to be done to allow a user to send or access this encrypted data, creating a lack of flexibility and scalability.

Presented in Figure 2, are three types of encryption processes:

- Symmetric Encryption, also known as secret-key encryption, involves using a single shared key for both encryption and decryption processes. As such the key must be kept confidential between the communicating parties.
- Traditional Public-Key Encryption, also called asymmetric encryption, employs a pair of keys, a public key, and a private key. The public key is distributed openly, while the private key remains secret. This type of encryption is the most common and used encryption method, due to its ease of implementation.
- Attribute-Based Encryption, employs encryption and decryption methods that operate based on the user's specified property set.

Also depicted in Figure 2, it is possible to see this major problem in Symmetric Encryption and Traditional Public-Key Encryption, where when a new data user enters the system, the data owner must share his key, or create a new encryption process. In Attribute-Based Encryption, such a thing is not required.

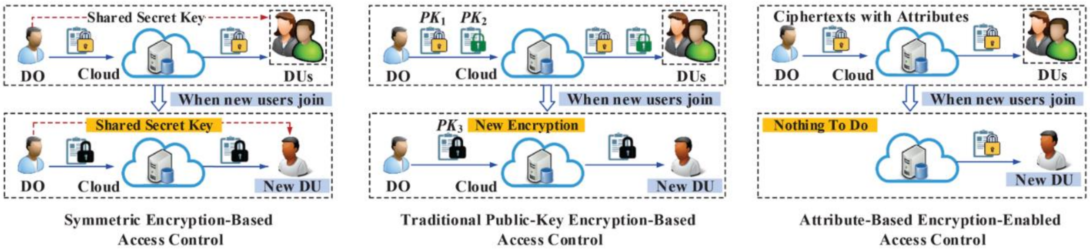

Figure 2 - Different access control mechanisms in cloud computing (*Zhang et al., 2020*)

As previously said, Attribute-based cyphers are encryption and decryption methods that operate based on the user's specified property set and the access policy defined by the provided attribute set (*Hwang and Lee, 2019*). Zhang et al. (*Zhang et al., 2020*) proposed the following taxonomy, as presented in Figure 3

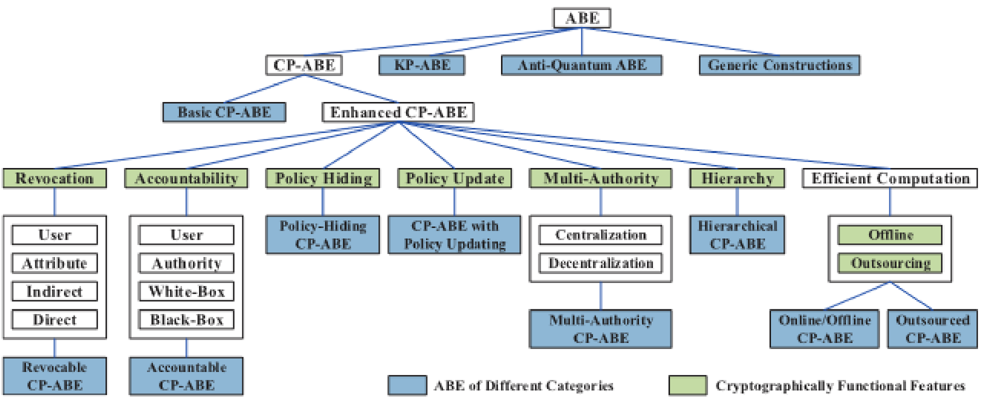

Figure 3 - Proposed taxonomy of ABE (*Zhang et al., 2020*)

As shown in Figure 3 there are four main categories, Ciphertext-Policy Attribute Based Encryption (CP-ABE) scheme, a Key-Policy Attribute Based Encryption (KP-ABE) scheme, Anti-Quantum, and generic constructions. The most used and studied are CP-ABE and KP-ABE, which will be the ones analysed in this literature review. Regarding Anti-Quantum and Generic Constructions, these will not be deeply reviewed.

Anti-Quantum ABE is the next step in the encryption field as with the technical advancements of quantum computation, many public-key encryption schemes including ABE need security enhancements to resist possible quantum attacks. Although lattice-based algorithms can resist quantum attacks, there are only a few lattice-based ABE constructions that are selectively secure (*Zhang et al., 2020*).

Generic constructions refer to a methodology or approach that can be applied broadly across different ABE schemes, allowing for transformations or enhancements while maintaining certain security properties. First presented by Shota Yamada (*Yamada et al., 2011*), it has since then been proposed different approaches such as Cheng Chen (*Chen et al., 2013*) and Nuttapong Attrapadung (*Attrapadung, Hanaoka and Yamada, 2015*).

2.4.1 CP-ABE and KP-ABE

As mentioned, CP-ABE and KP-ABE are the most used types, due to their fine-grained access control, flexibility, and adaptability. They were proposed in 2007 and 2005, respectably, allowing them to mature and be worked on

The main difference between the two types of cryptography is who creates the access policy, either the data owner or the recipient, respectively.

The normal workflow of CP-ABE flows as follows: When a data owner generates a ciphertext, they encrypt the data by formulating an access policy that corresponds to the attributes of the user seeking access to their data. The data owner subsequently transmits a passphrase to the recipient, who uses it to decrypt the ciphertext based on the recipient's attribute set. For instance, if the recipient possesses attributes [X] and [Y], the data owner constructs and encrypts the access policy, accordingly, utilizing attributes [X, Y]. Only recipients whose attribute set aligns with the access structure can then successfully decrypt the ciphertext (*Hwang and Lee, 2019*).

On the other hand, with the KP-ABE schema, the data owner assigns the attributes [X], and [Y] to the ciphertext and sends it to the recipient. The recipient creates an access policy based on his attributes and generates a key capable of decrypting the cypher text, being then able to decrypt the cypher text (*Hwang and Lee, 2019*).

CP-ABE offers a more intuitive approach than KP-ABE by enforcing access control on encrypted data. Consequently, cryptographic systems based on CP-ABE are regarded as an attractive option for simultaneously providing both confidentiality services and precise access control mechanisms (*Morales-Sandoval et al., 2020*).

However, most implementations have some drawbacks, the most important being the fact that the access policy is revealed in the cypher text. This would allow third parties to infer a user who wants to access the data. As described by *(Hwang and Lee, 2019),* in a situation of a hospital, if the data is encrypted by creating a policy with the attributes of the user, the insurance company, etc, a third party can infer the user attributes to access the data with the open access policy. Therefore, the patient's privacy may be violated.

To counteract this, through the years several Policy-Hiding CP-ABE schemes have been proposed such as the Lai scheme (*Lai, Deng and Li, 2011*), Yinghui Zhang scheme (*Zhang et al., 2013*), Li scheme (*Li et al., 2016*) and Leyou Zhang scheme (*Zhang, Cui and Mu, 2018*). But as pointed out these schemes are not efficient, because as the size of a cypher text increases linearly with the number of attributes in an access policy, they waste storage space and burden the user's decryption operation.

2.4.2 Military Environments

In the military world of cryptography, there are several concepts regarding the protection of virtual data, North Atlantic Treaty Organization (NATO) Object-Level Protection (OLP) is the most noteworthy for this project.

The concept of OLP was developed by NATO and is a system-wide standard approach to data protection; it is built on two fundamental pillars (*Wrona, 2015*):

- Protection is applied to individual data objects (or portions thereof) instead of a collection of data objects and systems;
- Metadata is bound to data objects and is used by protection enforcement mechanisms to determine the protection requirements for a data object.

The OLP space can be defined in three dimensions, as shown in Figure 4.

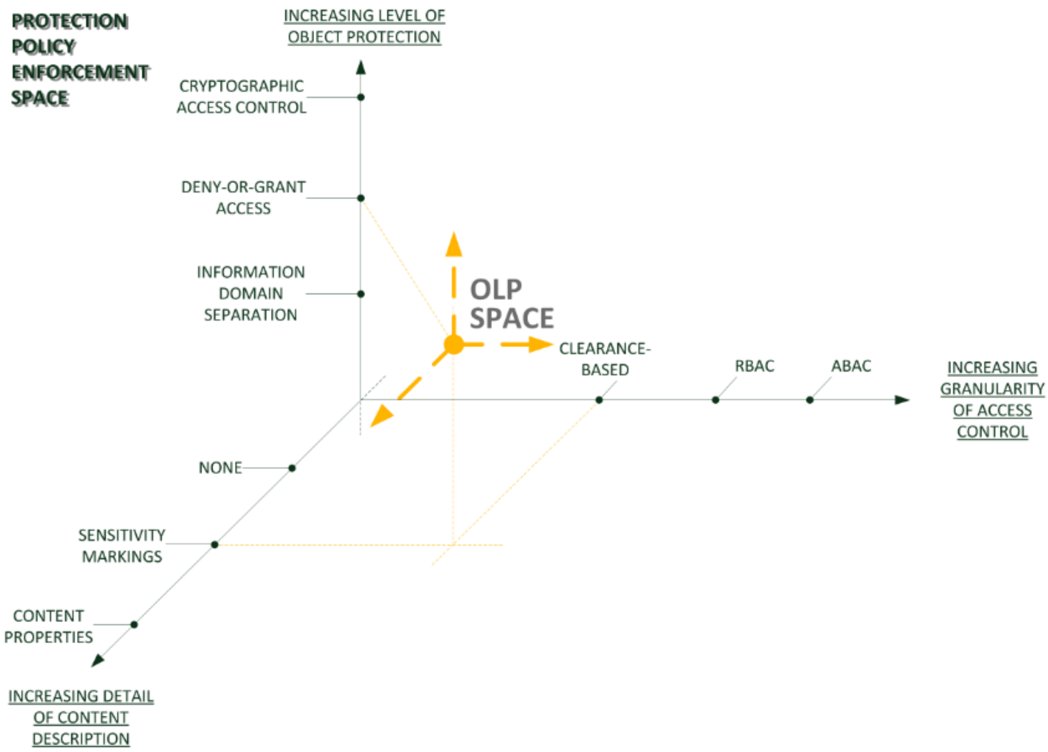

Figure 4 - The OLP Space extends into all directions of the PPES (*Wrona, 2015*)

These three dimensions are the level of Detail of Content Description, the Granularity of Access Control, and the Level of Object Protection.

The Detail of Content Description dimension focuses on the level of detail in the metadata describing an information object, and the Granularity of Access Control focuses on the granularity of information about the actor and environment supported by protection policy enforcement. Finally, the Level of Object Protection dimension concerns the extent to which an object can be protected, regardless of location and time.

Regarding the usage of either CP-ABE or KP-ABE, Sander Oudkerk (*Oudkerk and Wrona, 2013*) compared their usage by applying them to an architecture in which OLP is realized through Content-based Protection and Release (CPR). They determined that the most suited option would be the usage of CP-ABE, as demonstrated by the following conclusions.

Regarding the suitability of CP-ABE for CPR:

- In the context of CPR, content properties associated with an information object are correlated with the CPR policy to derive release conditions and protection requirements;
- Release conditions form an access policy (p_U) based on user attributes, while protection requirements form an access policy (p_T) based on terminal attributes;

- Access to the information object is granted if both p_U and p_T are satisfied.

Concerning the suitability of KP-ABE for CPR, CPR aims to determine whether a combination of user and terminal attributes provides access to an information object with specific content properties. When considering Key Policy ABE (KP-ABE), two options arise:

1. Content Properties as Message Attributes (MA) in which the encrypted information object (M') is linked to content properties (MA) through a policy (p_CP) specifying accessible properties, allowing the recipient to decrypt M' if MA meets p_CP;
2. Simple List of Attributes (MA), where the information object is linked to a simple list of user and terminal attributes, while the private key is linked to an access policy defining accessible attributes. This option was not explored by the authors.

Regarding Option 1 of the KP-ABE, they found two major disadvantages. Static access assumes content properties do not change frequently, granting perpetual access once a private key is distributed, even if the recipient loses authorization. The other disadvantage is the re-encryption challenges in which the re-encryption of information objects does not address the access issue, as it would be based on the same set of content properties.

As such a CP-ABE scheme will be used, due to its more intuitive approach, available examples, already implemented models, and its better compatibility with the OLP. Also, if SisTrade decides to sell the product to militaries or companies in the NATO space of influence, compatibility with OLP is very important.

3 Analysis and Design of The Solution

In this chapter, the existing solution will be analysed in terms of concepts and architectural aspects. As previously stated, the objectives of this thesis are to complement and improve the existing solution, and as such, the need to first analyse the solution is necessary. This analysis is intended to understand how the software was constructed, its flaws and strengths, and where it is necessary to tread cautiously.

3.1 Problem Domain

Starting with the problem domain, the existing software was implemented using Domain Driven Design. As such, the classes are configured in aggregates (Figure 5, Figure 6 and Figure 7), allowing for ease of modularity and ease of change. Due to confidentially regarding the whole domain model, only small parts will be shown. In a simplified manner, 3 major groups of models exist, (1) the asset group, (2) the scenario group, and (3) the session group.

1. The assets group, include the type of vehicle and its specific properties, speed in each terrain, and other assets it possesses, such as sensors, weapons, etc.

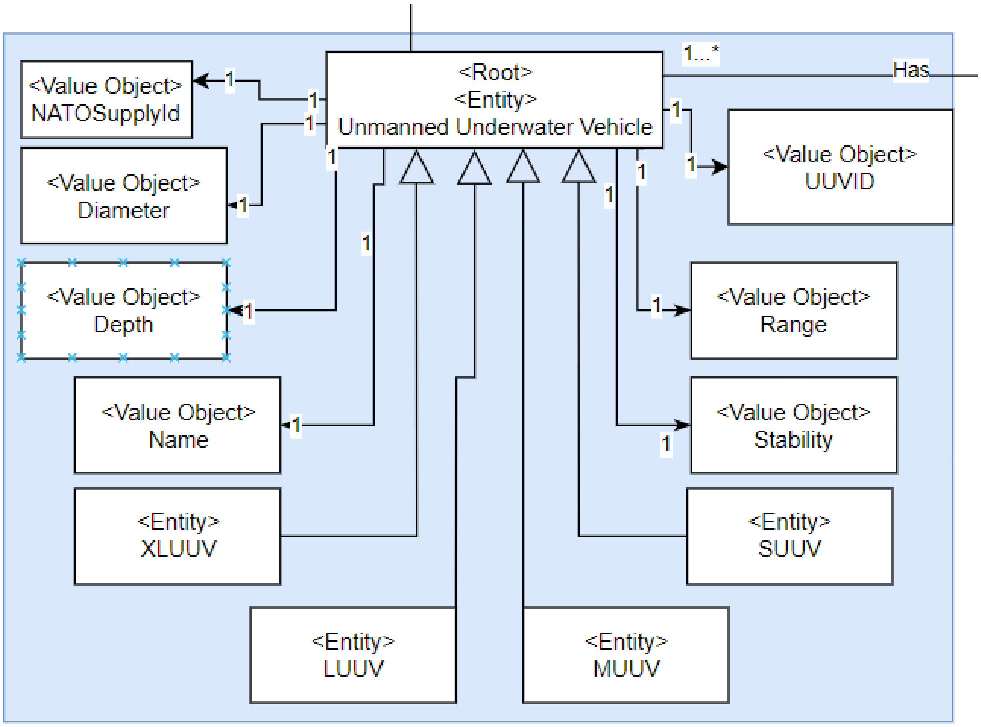

Figure 5 - UUV aggregate

2. The Scenario group includes the map, the tiles contained between the boundaries of the map, and the scenario information, such as the teams involved, assets being used, their location, their allegiance, etc.

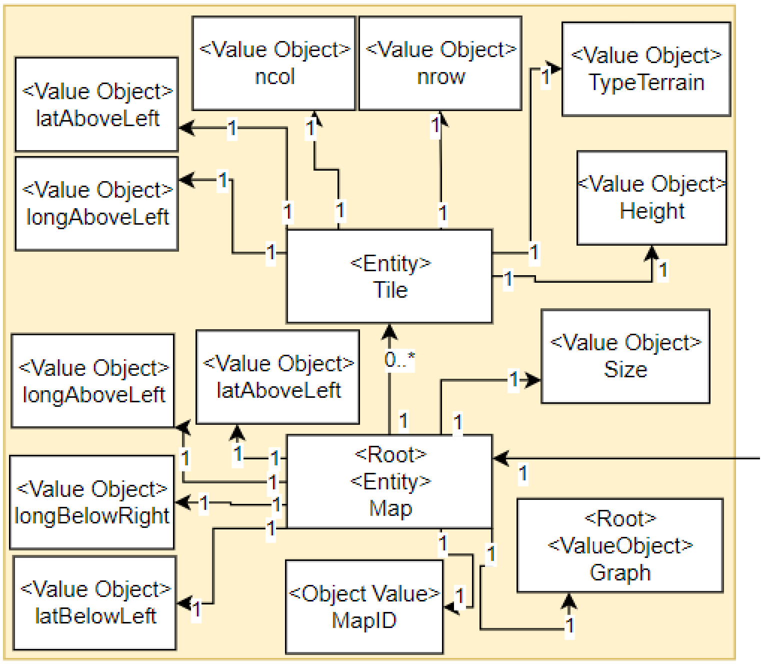

Figure 6 - Map aggregate

3. The Session group is responsible for the lobby, the communication between the users, the game itself and the summary at the end of each session.

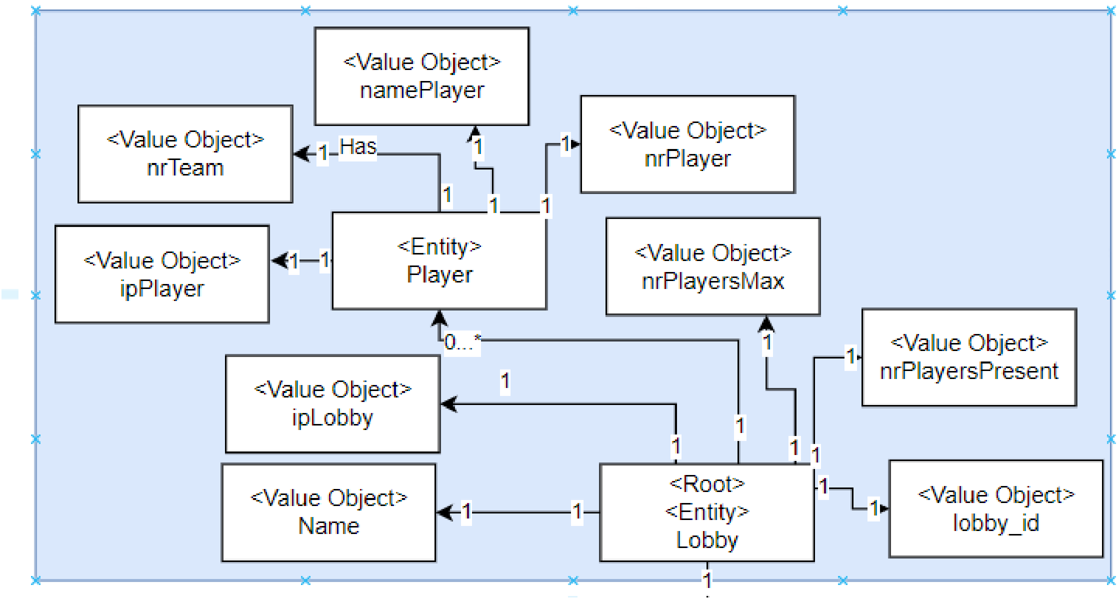

Figure 7 - Lobby aggregate

Having analysed the domain of the system, it is also necessary to visualize the architecture implemented. As viewed in Figure 8, the system was implemented in a standard web browser formation, having a frontend, a backend, a database, and finally, another database containing the information of the tiles of the entire world.

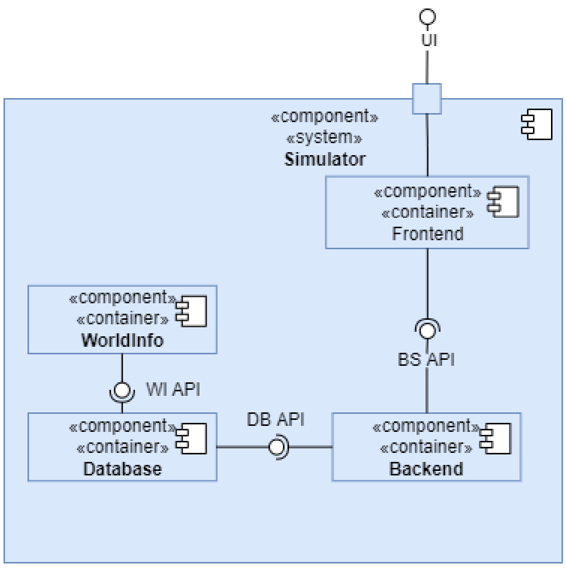

Figure 8 - Level 2 Logical View

3.2 Virtual Interface

As this thesis is more concerned with the interactivity of the user, the virtual interface must also be analysed. With the existence of several pages, the need to identify them, how the user flows through the pages, and what pages are significant to this thesis rises. In this sub-section, the screens will be displayed and explained, followed by a diagram composed of the workflow of the software, and finally a table with the alterations that should be done to them.

3.2.1 Existing Screens

Starting with the splash screen is the initial screen that users see when they enter the website. It displays the logo of the software, the input fields to be able to enter the program, and a video runs in the back. As presented in Figure 9, it is a simple splash screen.

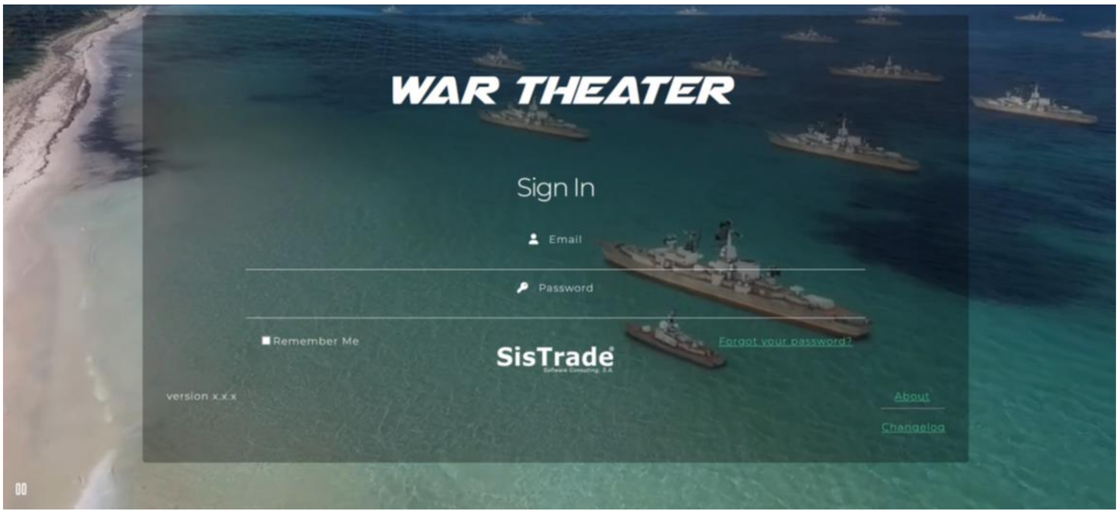

Figure 9 - Splash Screen

The home screen serves as the main hub of the application, providing users with the ability to check the existing lobbies and assign their nicknames. At the top of the screen, the navbar is also present, allowing the routing through the software, as seen in Figure 10.

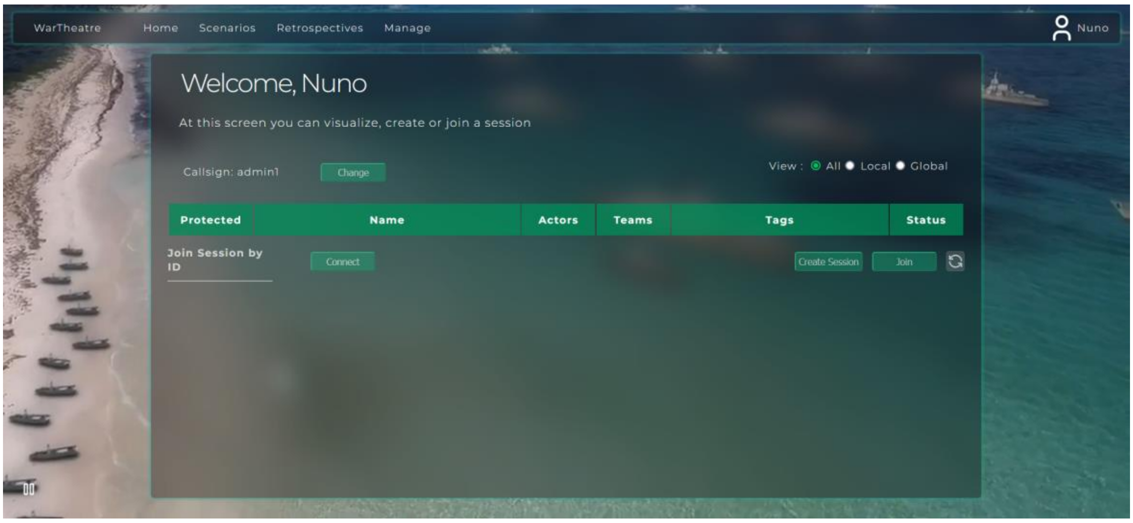

Figure 10 - Home Screen

The asset management screen allows users to view and manage the assets used in the application. When an asset is selected, its general information and specific will appear. This is seen in Figure 11.

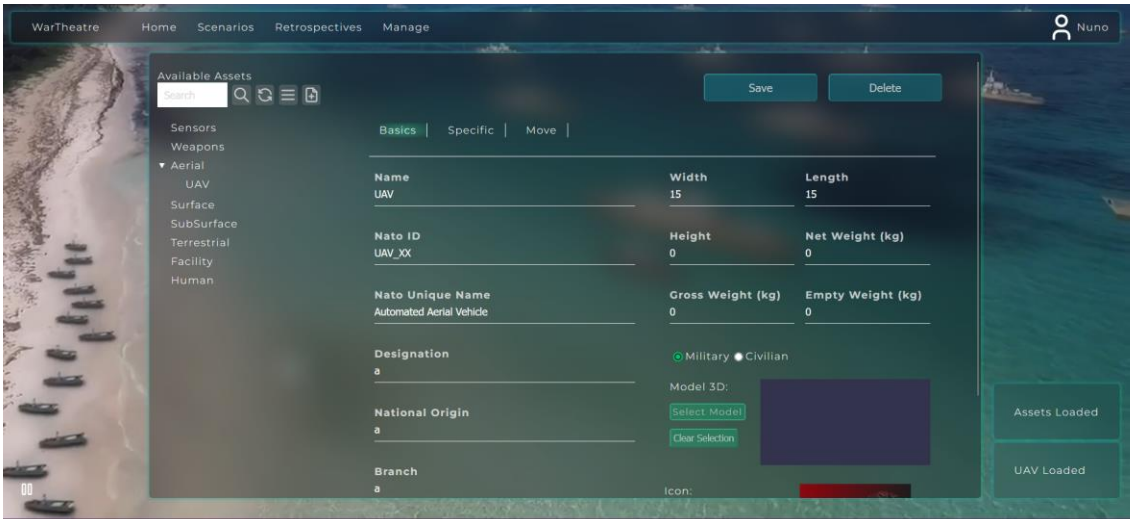

Figure 11 - Asset Management Screen

The creation of scenarios screen enables users to create new simulation scenarios from scratch. Users can define the play area, the scenario name, the number of teams, and the information about each team, which is composed of the maximum number of players, colour, and their "diplomacy" with other teams. This process is executed in a 3-step process, in which the first step is shown in Figure 12

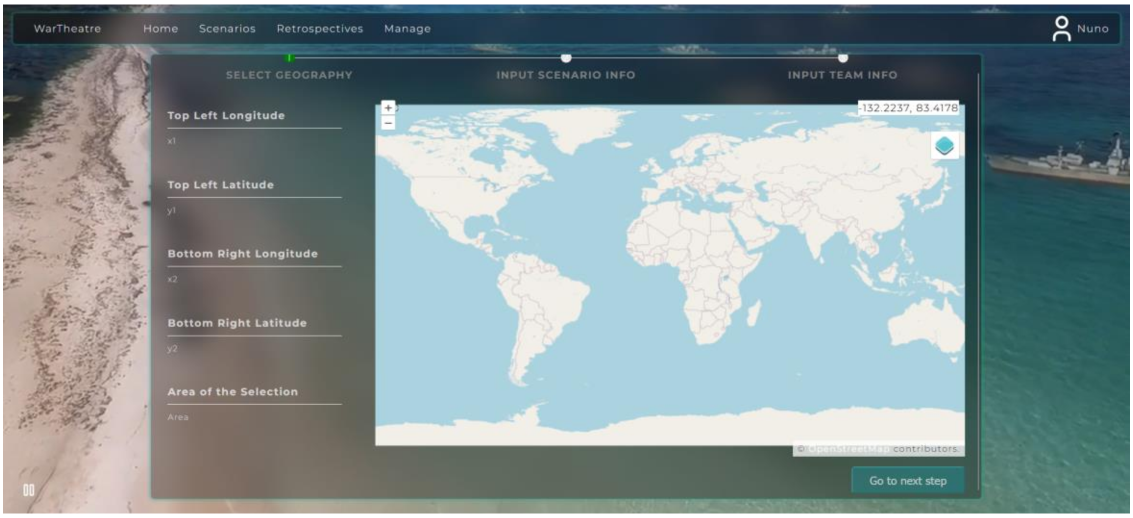

Figure 12 - 1st Step in the Creation of Scenarios Screen

The edition of scenarios screen allows users to modify existing simulation scenarios. Users can adjust the same parameters as in the previous subsection. Along with those alterations, the user can also place assets on the map and make scripts for each asset.

Figure 13 presents the first page of the editions, that will redirect to other pages. Figure 14 presents the screen where it is possible to place assets on the map and assign them to teams. Lastly, Figure 15, presents the screen that allows the scripting of each of the assets, where the list of assets placed on the map and available templates for scripts exist.

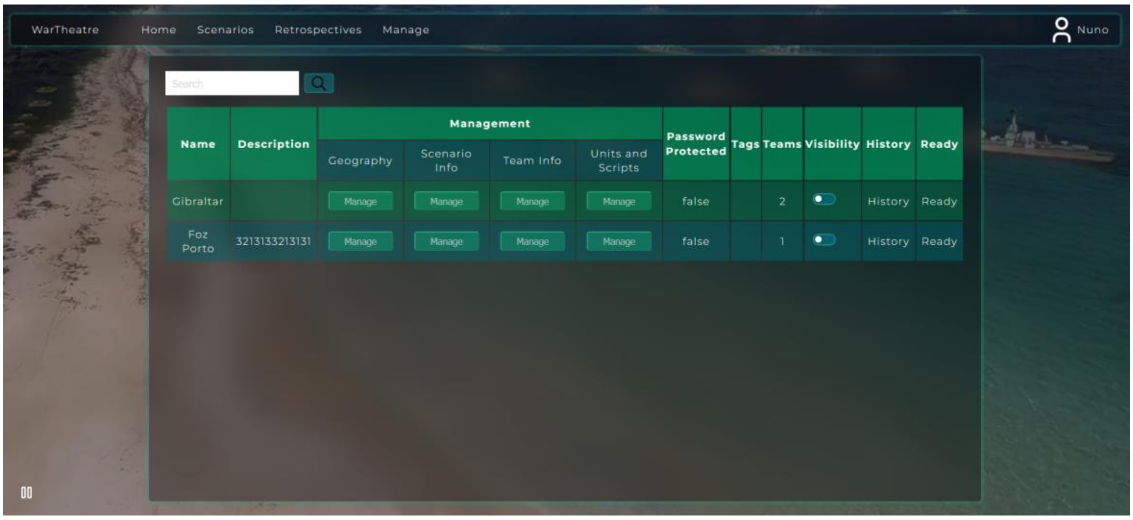

Figure 13 - Edition of Scenarios

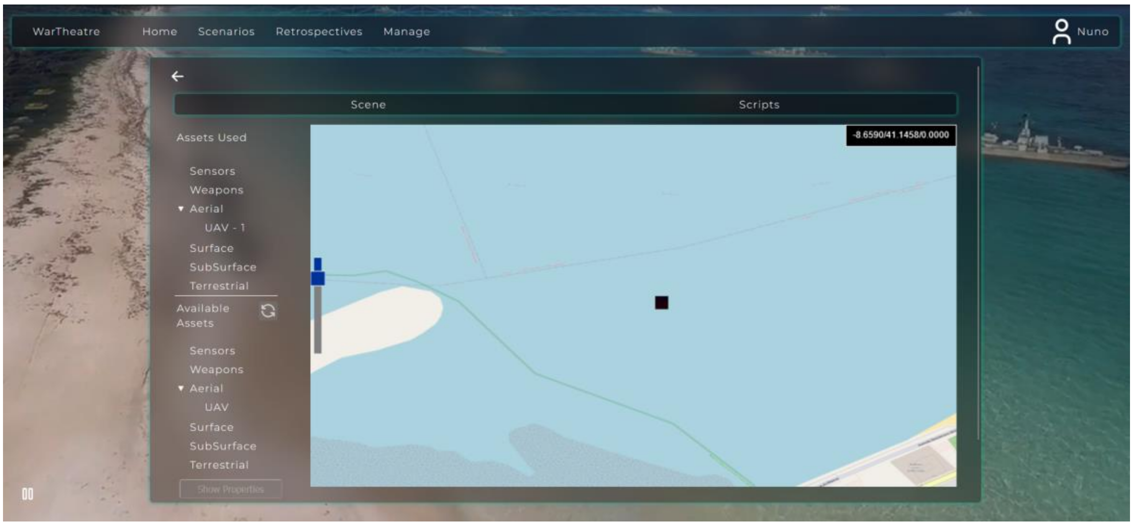

Figure 14 - Assignment of Assets Screen

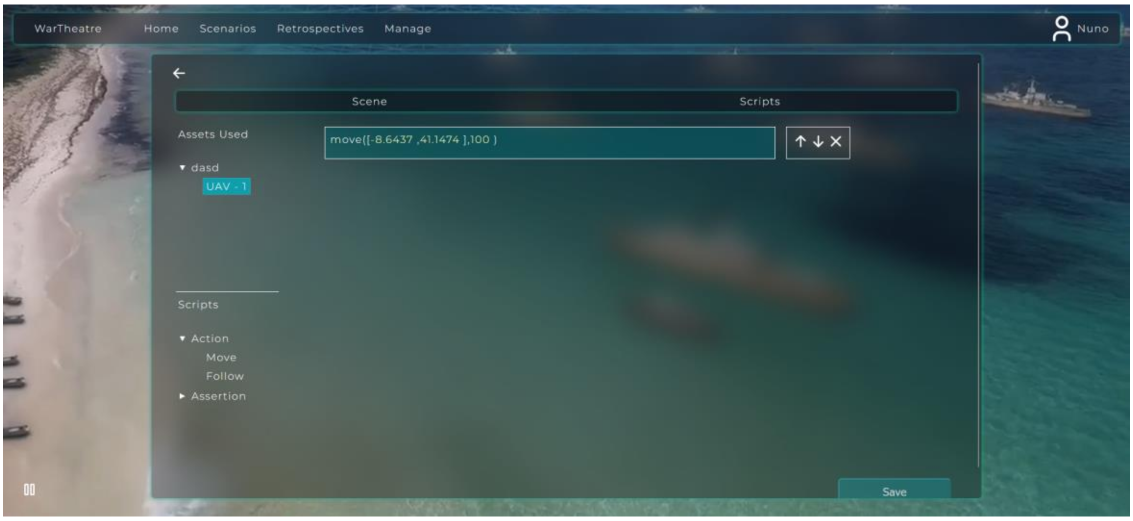

Figure 15 - Assignment of Scripts to Assets Screen

The lobby screen facilitates multiplayer interactions by allowing users to join or create virtual lobbies where they can gather and prepare for a game. It provides the ability to choose the scenario and team, as seen in Figure 16.

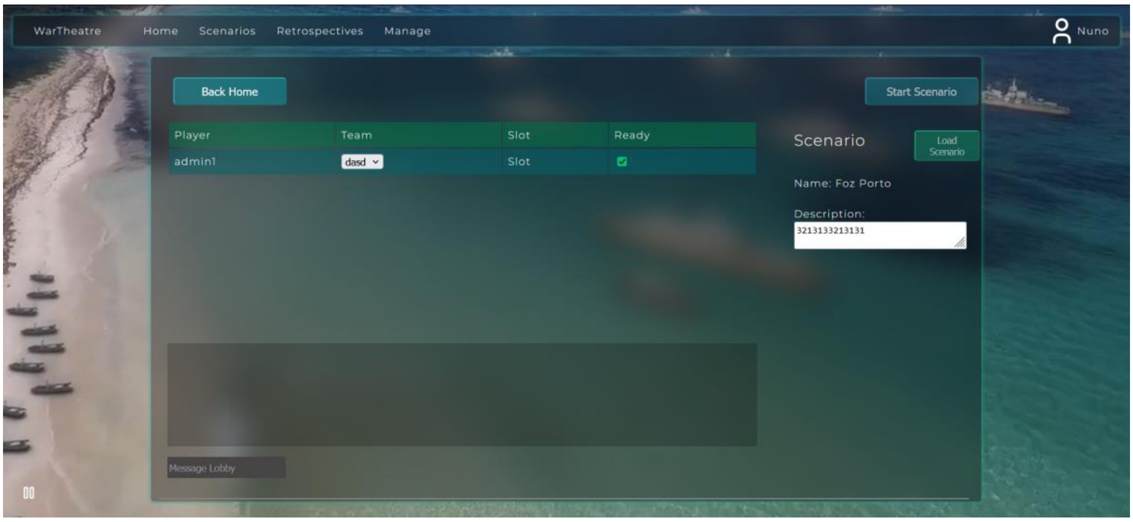

Figure 16 - Lobby Screen

The game screen is where the actual simulation takes place. It provides users with a visual representation of the simulated environment, including interactive elements and observing the scripts created in action, as seen in Figure 17.

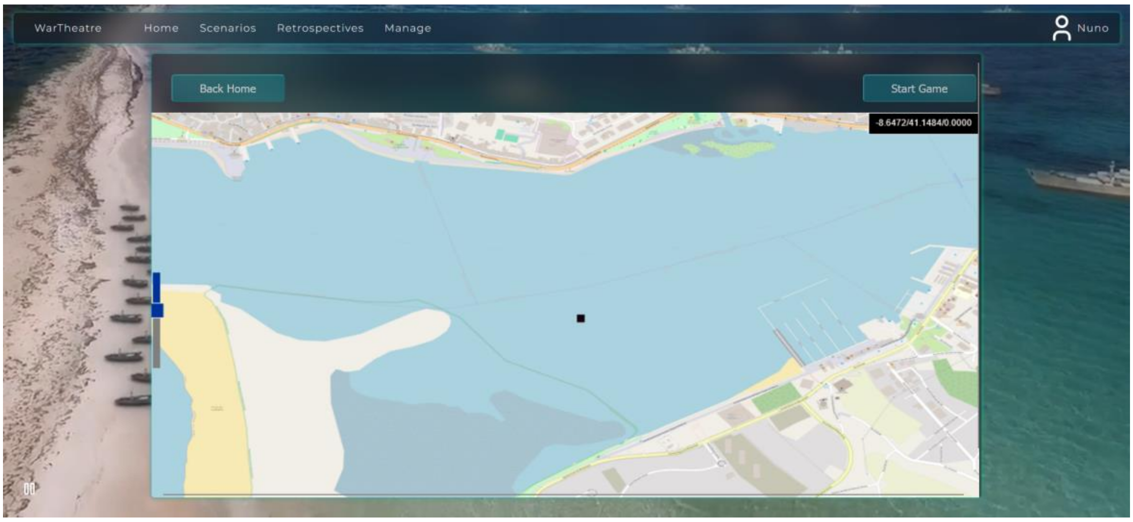

Figure 17 - Game Screen

Alongside the analysis of the pages, a workflow between them can be drawn, as presented in Figure 18.

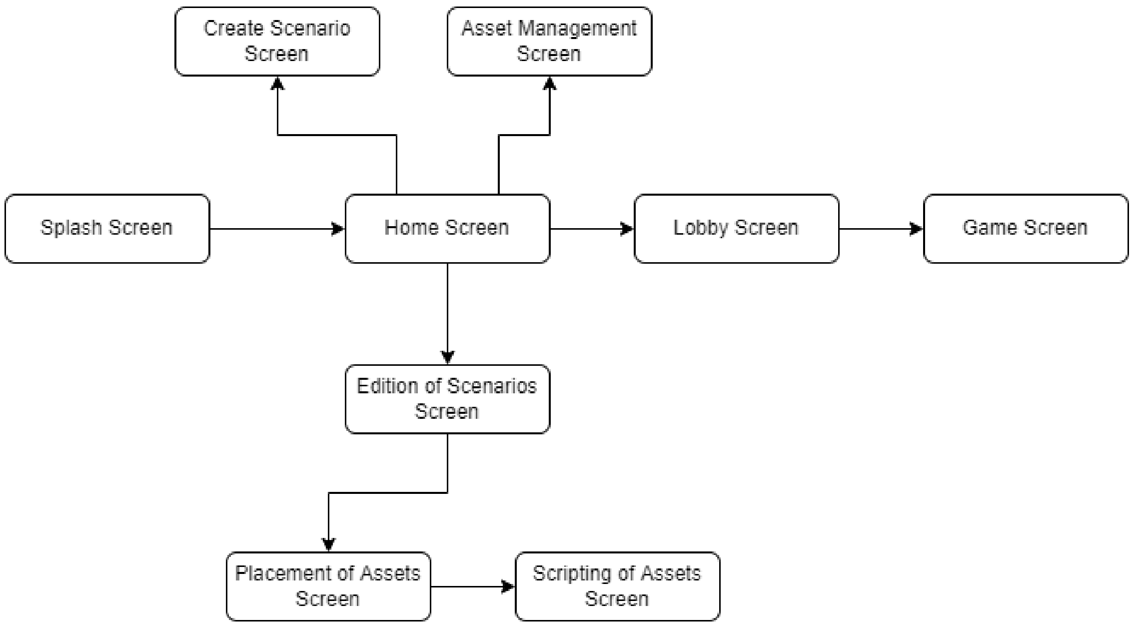

Figure 18 - Workflow of the application

3.2.2 Possible Alterations

With the knowledge of the workflow of the system, and the different screens existing, it is possible to determine the possible alterations.

Firstly, the Splash, Home and Creation of Scenarios screens are not planned to receive alterations. These screens have simple functions and are of singular usage, meaning that no other user can interact with them at the same time. Also, they possess no advantage in being augmented with AR technology. The remaining pages are intended to be improved.

Starting with Asset Management, Edition of Scenarios, Scripting of Assets and Lobbies Screen, these pages are intended for high usage and traffic. As previously stated, they have, among other responsibilities, the management and scripting of the assets, two of the main functionalities of the system. This means that the ability for multiple users to edit the characteristics of the assets at the same time is essential.

Regarding the remaining pages, namely the Placement of Assets and the Game Screen, the integration of collaborative tools is paramount. These pages require multiple users to place assets, configure them, along with viewing them during the gameplay. The utilization of AR technology drastically enhances the user experience and the quality of work done. By enabling them to visualize the assets within a 3D environment on the map, where they can manoeuvre and interact, the overall experience is greatly enhanced.

Table 9 presents a summary of the main existing functionalities and possible alterations.

Table 9 - Functionalities and possible alterations to the screens

Screen	Functionalities	Possible Alteration
Splash Screen	Login into system	N/A
Home Screen	View existing lobbies Change Nickname	N/A
Asset Management Screen	View existing assets Create new assets Manage assets	Addition of Y.js to be able to alter asset information simultaneously with other users
Creation of Scenarios Screen	Creation of new Scenarios	N/A
Edition of Scenarios Screen	View and manage existing scenarios	Addition of Y.js for simultaneous alterations to scenario information
Placement of Assets Screen	Place units on the scenario map and assign their allegiance	Addition of Y.js for simultaneous placement, of assets Addition of AR functions, for a better understanding position of assets in the map
Scripting of Assets Screen	Manage the script of each of the assets placed on the scenario	Addition of Y.js for simultaneous creation of scripts
Lobbies Screen	Select a scenario to play, and assign to each player a team	Addition of Y.js for implementation of chat and team preparation
Game Screen	Execute the simulation, and analyse the outcomes and decisions	Addition of Y.js for simultaneous simulation viewing Addition of AR functions

4 Solution Implementation

This chapter is dedicated to presenting details related to the alterations advocated in Chapter 3. It has been subdivided into three sections, in order to give a comprehensive perspective, not only of what was implemented but also of how it was verified. The last section regards the solution evaluation.

4.1 Implementation Description

As the development process could easily escalate in difficulty, it was decided to divide it into 3 phases for a systematic implementation. The first phase regards implementing collaborative work through the usage of Y.js. The second phase concerns the usage of WebXR in Babylon.js. The last phase, which was the implementation of ABE was not accomplished due to time constraints and will therefore be considered for future work.

4.1.1 Phase 1 – Collaborative Work

As previously stated, one of the main objectives of this thesis was the implementation of collaborative work into the simulator, which was achieved through the usage of Y.js. This was decided to be the first phase of development, as it was the less disruptive and easiest to implement.

Y.js in its essence, allows each user to have a local copy of the document, and changes are synchronized through a shared server. It employs conflict resolution algorithms to handle simultaneous edits, ensuring data consistency across all clients.

A few problems arose during the development. First was the way of how Y.js documents work. The contents of these documents are normally objects, meaning that they should be easily integrated with the existing schemas of the implemented software. However, due to the way the existing software was developed, there was a need to identify what type of asset the document was referring to.

Due to the large number of types of assets (Sensor, Weapon, Aerial, etc), for ease of usage in Typescript a master class was created, that being the “Asset”, as seen in Listing 1. Still, each type needed a function “properties” (Listing 2) to allow specification of their specific properties.

```
export class Asset {
  public asset: Sensor | Weapon | Aerial | SubSurface | Surface | Facility | Terrestrial | Human | undefined

  constructor() {
    this.asset = new Sensor();
    this.asset.id = "-1"
  }
}
```

Listing 1 - Asset Master class

```
properties(): Map<string, string> {
    return new Map([["type", this.weaponType.toString()], ["range", this.range.toString()], ["diameter", this.diameter.toString()], ["propulsion", this.propulsion.toString()], ["radiusOfEffect", this.radiusOfEffect.toString()], ["triggerRange", this.triggerRange.toString()]])
  }

  setProperties(values: string[]) {
    this.weaponType = values[0]
    this.range = Number.parseFloat(values[1]);
    this.diameter = Number.parseFloat(values[2]);
    this.propulsion = Number.parseFloat(values[3]);
    this.radiusOfEffect = Number.parseFloat(values[4]);
    this.triggerRange = Number.parseFloat(values[5]);
  }
```

Listing 2 - Properties Function

To solve this, one of the possible solutions, and determined to be the easiest, was to add in the object the type of the asset, and then use the constructor to transform the object into that class, as seen in Listing 3.

```
this.ymap.observeDeep(() => {
  var temp = this.ymap.get(0) as any
  switch (temp.Type) {
    case "Sensor":
      temp = new Sensor(temp);
       break;
```

Listing 3 - Solution implemented to the determination of the asset type

Although not the most ideal solution, as it adds a certain amount of technical debt, as it falls into the necessary work that would be needed if any new type of asset was added. Other solutions such as "eval" or "function" were deemed too insecure and uncontrolled. There was also an attempt to directly convert the variable to "Sensor | Weapon | Aerial | SubSurface | Surface | Facility | Terrestrial | Human" instead of using "any", however the variable would still be "Object" to the JavaScript compiler and as such, display an error.

Another issue arose due to how the different copies were transmitted between users. Among several possible technologies, the usage of "y-websocket"[7], a WebSocket provider was decided. This required the creation of a new server in the backend of the application, as well, as the connection with it through the frontend.

With the connections made between several users, discrepancies and overlaps of information started to occur, be it between two working users or work previously done and not saved still overlapping the existing information.

The first and easiest to resolve was the phantom work, that is, the work that was not saved but still overlapped. This correction was as simple as commenting a few lines regarding the persistence of data, as seen in Listing 4.

```
//before
if (doc.conns.size === 0 &&
persistence !== null) {

      persistence.writeState(doc.name,
doc).then(() => {
        doc.destroy()
      })
      docs.delete(doc.name)
    }
```

```
//after
if (doc.conns.size === 0) {

    doc.destroy()
}
```

Listing 4 - Changes made to the Websocket process (before/after)

It was decided to change the function, as when dealing with confidential information, there must be no way of leaving unintentional data exposed, meaning that if the user did not save the alterations, they must be discarded.

Regarding the discrepancies between users, when a new user joined an editing session, the object reverted to its last saved state, causing a loss of alterations. As such, it was decided to prioritize edited objects. This means that when a new user starts editing, the system must load two times, the first being the original object, while the second is the altered object.

[7] https://github.com/yjs/y-websocket

4.1.2 Phase 2 – AR Implementation

Having the first phase completed and tested, the second phase could begin. This phase regards the second major objective of the thesis, the implementation of AR technology. As previously asserted, the existing application already uses Babylon.js which possesses the ability to easily add VR and AR functionalities.

The first major roadblock of this phase was how to test the AR experience since the availability of such capable equipment was scarce. Several ideas were tough off, with the two most promising being:

1. The use of a smartphone, for the most ideal and realistic;
2. The use of Google Chrome's extension "Immersive Web Emulator"[8], for an easier time debugging.

With that objective in mind, a whole process of trial and error began, which started with the first idea.

Since the development of this thesis was in a developer branch not deployed in the company's servers, the necessity of the smartphone to connect to the computer running the software was paramount. To achieve this, Internet Information Services[9] (IIS) was used, as it allowed to host a local web server, granting smartphones and other devices access to the software through the local IP of the hosting server. After allowing other devices to access the program, development with XR started, with an immediate problem, WebXR only works with https.

A solution for this was to create a local Secure Sockets Layer (SSL) certificate and run the backend as an HTTPS server instead of HTTP. This also implied that the web sockets previously used in y-websocket were now WebSocket Secure (WSS).

Although WebXR now worked on other devices connected, all the collaborative functions previously developed would not work, no matter how many different solutions and fixes were tried, due to the inability to connect with WSS. As such, it was decided to abandon the idea of using other devices, and the devolvement continued with the Immersive Web Emulator extension.

Having now a more stable development and debugging platform, the real implementation of WebXR started to gain momentum. For easier management of time and effort, smaller objectives were defined, namely:

1. Allow users to enter the AR environment, view the map and move around;
2. Allow users to see the assets placed on the map;
3. Allow the assets to be represented by 3D models on the map.

[8] https://chromewebstore.google.com/detail/immersive-web-emulator/cgffilbpcibhmcfbgggfhfolhkfbhmik
[9] https://www.iis.net/

Starting with the first objective, originally the maps were scaled with a fixed value, allowing for them to have a closer size to their real counterparts, in which their coordinates correspond to the ones in the real world. This brought a major problem, as when a user enters the AR environment, he is always located at the coordinate (0,0,0), and the map would be outside of the play area.

To resolve this, it was decided to remake the creation of the map, which involved working out the new map mesh sizes, scaling values and positioning, as seen in Listing 5. This alteration also involved creating new converters from the real-world coordinates to coordinates in the Babylon.js environment and vice versa, as depicted in Listing 6 and Listing 7.

```
  giveMapSize(map: string[][]) {
    let upperLatitude = +map[0][1];
    let upperLongitude = +map[0][0];
    let lowerLatitude = +map[1][1];
    let lowerLongitude = +map[1][0];

    // Calculate center point
    const centerX = (upperLongitude + lowerLongitude) / 2;
    const centerY = (upperLatitude + lowerLatitude) / 2;

    // Adjust all coordinates to center mesh at (0, 0)
    const minX = (+upperLongitude - centerX) / this.meterToPixelRatio;
    const minZ = (+lowerLatitude - centerY) / this.meterToPixelRatio;
    const maxX = (+lowerLongitude - centerX) / this.meterToPixelRatio;
    const maxZ = (+upperLatitude - centerY) / this.meterToPixelRatio;

    // Calculate scaling factor
    const scaleFactor = this.desiredMeshSize / Math.max(Math.abs(minX), Math.abs(minZ), Math.abs(maxX), Math.abs(maxZ));

    // Apply scaling factor to coordinates
    const scaledMinX = minX * scaleFactor;
    const scaledMinZ = minZ * scaleFactor;
    const scaledMaxX = maxX * scaleFactor;
    const scaledMaxZ = maxZ * scaleFactor;

    return [scaledMinX, scaledMinZ, scaledMaxX, scaledMaxZ, centerX, centerY, scaleFactor];
  }
```

Listing 5 - Method to calculate the map size

```
function convertWorldCoordsToSceneCoords(position: string,
meterToPixelRatio: number, centerXPixel: number, centerYPixel:
number, scaleFactor: number): Vector3 {
    let aux = position.split("/");

    const originalX = +aux[0];
    const originalZ = +aux[1];
    const originalY = +aux[2];

    const translatedX = ((originalX - centerXPixel) /
meterToPixelRatio) * scaleFactor;
    const translatedZ = ((originalZ - centerYPixel)  /
meterToPixelRatio ) * scaleFactor;

    return new Vector3(translatedX, originalY, translatedZ);
}
```

Listing 6 - Method to convert coordinates of the real world to the game scene

```
function convertSceneCoordsToWorldCoords(xPosition: number,
zPosition: number, yPosition: number, meterToPixelRatio: number,
centerX: number, centerY: number, scaleFactor: number): string {
    let latitude = xPosition / scaleFactor;
    let longitude = zPosition / scaleFactor;

    longitude = (longitude * meterToPixelRatio) + centerY
    latitude = (latitude * meterToPixelRatio) + centerX

    let altitude = yPosition.toFixed(4).toString();

    return latitude.toFixed(4).toString() + "/" +
longitude.toFixed(4).toString() + "/" + altitude;
}
```

Listing 7 - Method to convert coordinates of the game scene to the real-world

The next major blockade was the usage of the 3D objects in the game. Currently, in the Asset Management screen, the assets have a slot to add a 3D model, however changing it, does not change the appearance of the asset in the map viewing. The assets are represented by a cube sized with the dimensions assigned to the asset, with the image and colour of the team to which they are assigned.

The first problem that appeared was the orientation of the loaded models. Due to how an asset is represented by several meshes, it was decided to use the original representing cube as the parent to the models. This allowed all the several meshes to stay together with the caveat that the orientation of the asset could be incorrect depending on the model used, as seen in Figure 19.

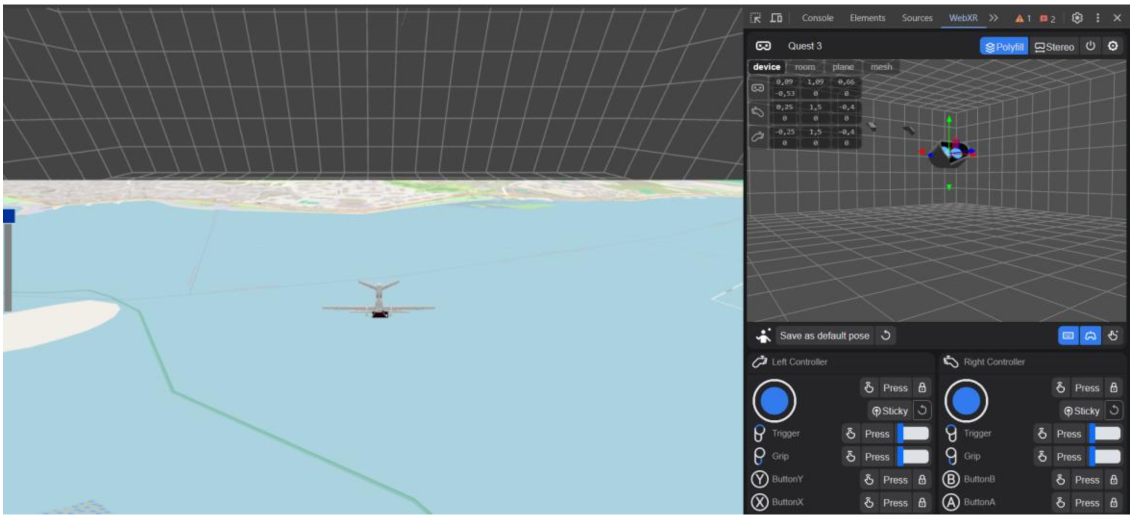

Figure 19 - Wrong orientation of the loaded model

Another issue encountered was the scaling of each asset. In a fully fledge simulator, all the assets would be checked beforehand, for them to all be scaled correctly.

As this project is a proof of concept, several different open-source assets were used, making so that assets would not correctly correlate. This was corrected by obtaining the biggest bounding box of the meshes and scaling it in relation to it allowing for more uniform scaling. This solution can be seen in Listing 8.

```
(newMeshes) => {
    var combinedBoundingBox = new BABYLON.BoundingBox(new BABYLON.Vector3(Number.MAX_VALUE, Number.MAX_VALUE, Number.MAX_VALUE), new BABYLON.Vector3(Number.MIN_VALUE, Number.MIN_VALUE, Number.MIN_VALUE));

    newMeshes.forEach(mesh => {
       mesh.computeWorldMatrix(true);
       var boundingBox = mesh.getBoundingInfo().boundingBox;
       combinedBoundingBox.reConstruct(boundingBox.minimumWorld, boundingBox.maximumWorld);
    });

    var maxDimension = Math.max(combinedBoundingBox.extendSizeWorld.x, combinedBoundingBox.extendSizeWorld.y, combinedBoundingBox.extendSizeWorld.z);

    var desiredSize = 0.05;
    var scalingFactor = desiredSize / maxDimension;

    newMeshes.forEach(element => {
       element.scaling = new BABYLON.Vector3(scalingFactor, scalingFactor, scalingFactor);

       element.parent = entity;
    });
});
```

Listing 8 - Scaling model resolution

4.2 Testing and Validation

In this section, the two testing procedures that are essential to the software development process and that were used during the solution development process will be discussed, namely performance and acceptance tests.

Through meetings between the organization responsible and the author of this report, a proposal for validating the solution was defined. This proposal encompasses the implementation of performance and acceptance tests, ensuring sound testing methods and valid results.

4.2.1 Performance and Stress Tests

Performance tests aim to evaluate the efficiency and responsiveness of a system by measuring its ability to handle varying workloads and stress levels. They are tools used to indicate how well the system satisfies the needs of its stakeholders (*Isabel Azevedo, 2023*).

To be able to test the system, the tool Apache JMeter[10] was used. JMeter is an open-source software designed to perform load testing, performance testing, and functional testing of web applications. It does this by simulating variable loads to measure and analyse their performance under different conditions.

With this tool, it was possible to compare the capabilities of the WebSockets with the HTTP posts. This was important as the ability of the real-time collaborative work was dependent on them.

The endpoint "/WarTheatreAPI/api/asset/byId", was chosen as the comparator between the two protocols, as it is the major endpoint used in the page Asset Management screen due to being how a user could see the changes done to an asset. A priori, it was expected that the WebSocket implementation would be a major improvement due to how the HTTP works and to confirm this theory, the following configurations were used:

- Configuration 1:
  - Number of Threads (users): 100
  - Ramp-Up Time: 50 seconds
  - Test Duration: 60 seconds
- Configuration 2:
  - Number of Threads (users): 400
  - Ramp-Up Time: 100 seconds
  - Test Duration: 60 seconds

With these configurations, in total there were 4 group threads, the first 2 threads are configured to simulate 100 users and the last 2 threads are configured to simulate 500 users, with each run being done three times and the average being presented, as seen in Figure 20.

[10] https://jmeter.apache.org

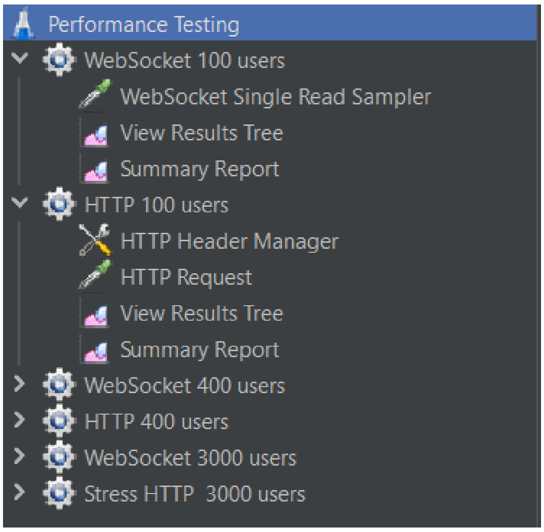

Figure 20 - Jmeter Performance Tests

Annex A exhibits the results of the test and as expected the WebSocket implementation is more efficient and has better performance than the HTTP implementation. This comes down to various factors, such as the size of the packages, the time needed to access the database, and the overall latency of the communication.

A stress test group was also implemented, with the objective of knowing how many threads the system could handle until having a ~10% error, which results are presented in Annex B. It was concluded that the HTTP implementation with a 3000 set of samples obtained a 16.77% error rate while the WebSockets obtained a with a 3000 set of samples an 85.73% error rate.

4.2.2 Acceptance Tests

Alongside the performance tests, acceptance tests have the objective of verifying the results obtained in the development of a solution are according to the requisites established in the solution analysis, in which, exists the involvement of the interested party in the solution (client, product owner, etc) (*ARQSI, 2021*).

The acceptance tests were done through the usage of the application and included having a sample of 10 collaborators, in pairs of 2, use the application at the same time, especially with editing assets and scenarios functionalities. This allowed for a more realistic approach and enabled a more comprehensive validation of the collaborative features. In the end, they were asked to fill out two questionaries, a System Usability Scale (SUS) and an Interface Validation.

The SUS (*Brooke, 1996*) questionnaire, as seen in Annex C, is a simple ten-item scale giving a global view of subjective assessments of usability. This scale is generally used after the respondent has had an opportunity to use the system being evaluated, but before any debriefing or discussion takes place. Respondents should be asked to record their immediate response to each item, rather than thinking about items for a long time. All items should be checked. If a respondent feels that they cannot respond to a particular item, they should mark the centre point of the scale.

Before statistical analysis, the validity of questionnaires was checked, and the total scores were computed. To obtain the final score, it is necessary to invert the negative-oriented questions, questions 2, 4, 6, 8 and 10, and then sum up all the scores. As the max possible value is 40, it is then multiplied by 2.5, to get a value between 0 and 100. Following this, descriptive statistics were conducted, normality evaluated, with statistical significance established for $\alpha = 0.05$, and outliers removed. With the final scores ranging between 0-100, the descriptive statistics and distribution plots of participants' SUS scores are represented in the following Table 10, Figure 21 and Figure 22.

Table 10 - Descriptive statistics of participants' SUS scores

Valid	10
Missing	0
Mean	71,25
Std. Deviation	6,04669331
Shapiro-Wik	0,8072
P-value of Shapiro-Wik	0,02142
Minimum	60,00
Maximum	77,50
25th percentile	68
50th percentile	72,5
75th percentile	75

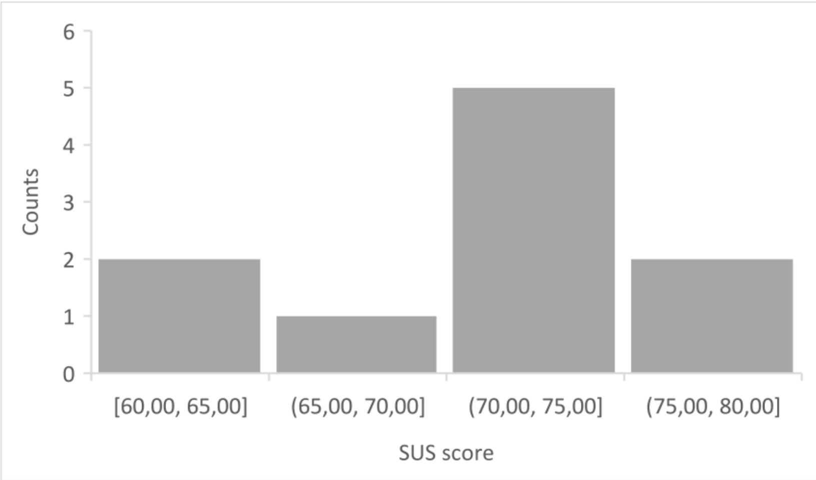

Figure 21 - Distribution Plot

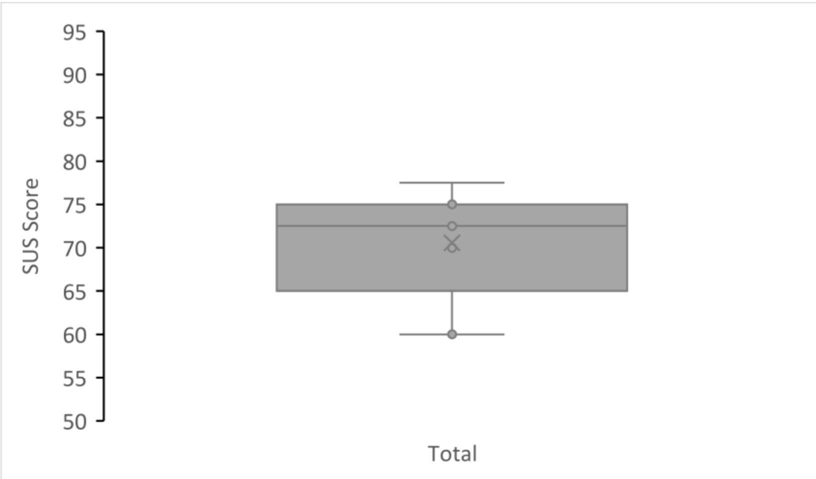

Figure 22 - Boxplot

The mean score of 71,25 was considered the indicator of the application's usability. This score is directly convertible to a percentile rank of 70%, with the SUS score interpreted as a grade of a B (*Brooke, 2013*), corresponding to the level Good of the System Usability Scale (*Brooke, 2009*).

The second questionnaire, an Interface Validation present in Annex D, was composed of 13 questions with the categorical variables of the Likert scale coded considering Strongly Disagree=0, Disagree=1, Neutral=2, Agree=3, and Strongly Agree=4, with a statistical significance established as $\alpha = 0.05$.

The various answers were then computed by considering the average value obtained when considering simultaneously the 4 validation scenarios. When considering each observation as a single entry, as seen in Table 12 for descriptive statistics and Figure 23 for the sample distribution, it was verified that the mean accuracy of user's intention detection is 3,544 which corresponds to a scaling accuracy of 88.6%.

Table 11 - Users' answers for different validation scenarios

	D1	D2	D3	D4
Valid	10	10	10	10
Missing	0	0	0	0
Mean	3,53333333	3,575	3,733333333	3,333333333
Std. Deviation	0,30550505	0,296858552	0,290593263	0,394405319
Shapiro-Wik	0,9044	0,871	0,7497	0,8737
P-value of Shapiro-Wik	0,2496	0,1053	0,005746	0,1129
Minimum	2	3	3	2
Maximum	4	4	4	4

Table 12 - Overview of Users' answers to the Interface Validation Questionnaire

Valid	40
Missing	0
Mean	3,544
Std. Deviation	0,354528
Shapiro-Wik	0,9044
P-value of Shapiro-Wik	0,2496
Minimum	2
Maximum	4

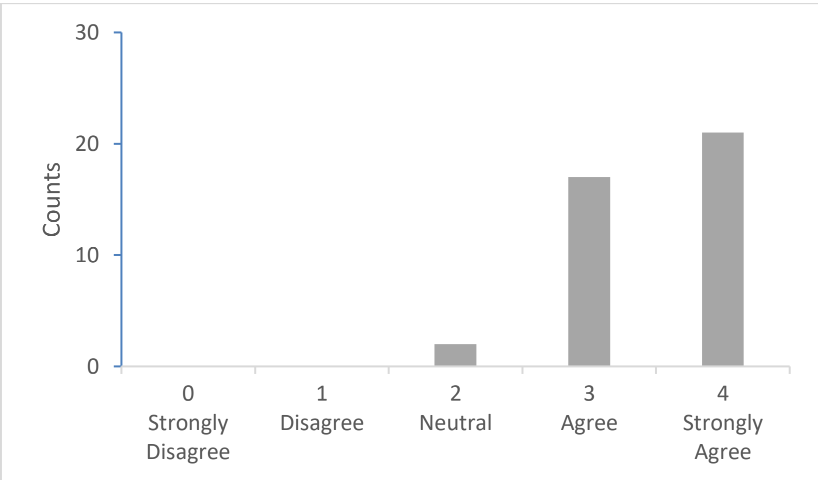

Figure 23 - Overall accuracy of Users' intention

4.3 Solution Evaluation

In terms of evaluating the solution, as shown through the performance and acceptance tests, the system is quite well formulated and functional, corresponding greatly to the expectations of the company owners and project managers.

Although still a prototype, and with only some knowledge in the area, the results indicate a promising direction for specification and further development. The different approaches taken and experimented with throughout the course of this project facilitated the identification of potential issues related to the usage of concurrent editing, synchronization, and data consistency.

Regarding the not implementation of the ABE, although it was due to time constraints, the author of this report was not satisfied for not being able to even delimitate a plan of approach for this technology.

Even so, taking into account the testing of the functionalities highlighted in section 4.2, which ensures the integrity of the system, it is possible to conclude that the alterations done to the software were a success.

5 Conclusions

This chapter aims to conclude the work developed throughout the thesis and project, highlighting the results obtained and verifying if these results are in accordance with the pre-established objectives, emphasising limitations that proved to be obstacles to the development process, future work, and final appreciation of the project.

5.1 Objectives Achieved

As mentioned previously in this document, namely in section 1.1, modern military training environments are very expensive, be it in personnel or equipment cost, and as such, the usage of virtual simulators is rising. With it, the need for an easier approach to the creation and editing of scenarios and assets, and a more immersive experience is increasing, and companies need to adapt to those new needs. For this reason, SisTrade intended to explore and acquire knowledge on the costs and time needed to implement such functionalities in its software.

In short, it can be assumed that the solution has a positive and innovative contribution, mainly in terms of the knowledge gained relating to the use of collaborative tools and the usage of augmented reality. This new knowledge can now be studied on how it can improve the existing software of the company, an Enterprise Resource Planning that includes a management information system and a manufacturing execution system.

Another contribution is the acquisition of experience with prerequisites and the requisites of working in the Defence industry, a diverse and very closed world. Moreover, the multiple personnel that SisTrade delegated to accompany the project, and who have served as guides during the whole period of the acceptance of the functionalities developed, were very satisfied with the results obtained.

Table 13 sets out the realization of the objectives proposed in section 1.2.1, defined in the project's initial phase. The objectives are subdivided into several, for a more thorough evaluation of them. The value given to them is a combination of the writer's opinion and the supervisor in SisTrade.

A level 5 of realization is an objective which satisfies or even overcomes the initial expectations, on the other, a 0, is an objective that did not fulfil the minimum requirements.

Table 13 - Realization of the objectives

Objectives	Outcome	Level of realization (0-5)
Integrate new graphic and collaborative technologies to develop a multi-user and collaborative interface	With Success	4
Addition of Y.js for simultaneous:	With Success	4
Edition of assets	With Success	5
Placement of assets	With Success	5
Script editing	With Success	4
Addition of AR functions for:	With Success	4
A better understanding of the positions of assets in the map	With Success	4
A better viewing of a scenario running	With Success	5
Using Attribute-based encryption to control access to information	Not Implemented	0

Only a portion of the proposed objectives were achieved, primarily because of time constraints imposed by the project's timeline and complications encountered during development. Additionally, it should also be noted that the degree of achievement was not the maximum value for all of them, due to key limitations that arose during the development process, which will be addressed in the next section.

5.2 Limitations, Threats and Future Work

Firstly, it should be noted that this project was developed on top of an already existing solution, which may represent threats to the validation of the developed work. Threats such as incorrectly implemented foundations, which were seen during the development of this thesis, and the testing scenarios used to validate the solution may not cover the full range of real-world conditions under which the system will operate.

Additionally, as with all acceptance tests, the results are subjective from respondent to respondent, and as such they should be taken with a grain of salt. In addition, when the product is finished, the sample pool for the acceptance tests must be larger and with a bigger spectrum of respondents' professions.

Another limitation of the project is its need to be able to deal with any kind of asset, adding a lot of complexity to the functionalities and needs of the system. This makes it so that the development process can become very cloudy. Furthermore, the fact the application is 100% web-based, limits the kind of functionalities and developments that can be done due to the hardware available for potential users, and how heavy a web package can be on a computer.

This project is not a final solution, only an improvement of a proof of concept and a way to acquire knowledge. There are several possible improvements such as:

- Implementation of the attribute-based encryption model
    - Research and selection of a model
    - Implementation and testing of that model
- More functionalities for the augmented reality
    - Ability to place assets in AR
    - Ability to change the size and proximity of the user to the map

    Adding height to the maps
- Possible transformation from augmented reality to virtual reality
- Alterations of the visuals and styles of the software.
- Several improvements to the code, regarding the code and performance.

5.3 Final Assessment

With a project as ambitious as this, due to the knowledge in the area being very reserved in the military circles, and a lack of it within the members of the company, it was a risk to take it. However, almost all objectives were achieved with satisfaction.

This project presents a new reinforcement of SisTrade's presence in the military sector, with potential application in other domains, especially in its already existing market. It also represents a small step regarding the future MIRICLE 2 project, in which SisTrade will also participate. Moreover, it serves as an example of the necessary steps and setbacks included in the enhancing of a simulator platform.

Finally, for the writer of this report, this challenge proved to be of a higher difficulty, having felt a certain uncertainty if it was possible to achieve all the objectives. This project allowed the acquisition of knowledge, be it in the military sector, and on how to be fully responsible for the development of a project.

In conclusion, the work developed was a success at all levels: personal, academic and professional.

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Annex A. Performance Test Results

Technology	Configuration	Samples	Average	Min	Max	Std. Dev.	Error (%)	Throughput (sec)	Received (KB/sec)	Sent (KB/sec)	Avg. Bytes
WebSocket	1	100	83	69	300	24.66	0.000%	2.01723	0.26	0.36	131.0
HTTP	1	300	116	99	378	21.01	0.000%	6.02192	7928.95	2.15	1348282.0
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WebSocket	2	400	79	60	315	26.75	0.000%	4.00778	0.51	0.71	131.0
HTTP	2	400	278	104	6811	695.12	0.000%	4.00541	5273.85	1.43	1348282.0

Annex B. Stress Test Results

Technology	Samples	Average	Min	Max	Error (%)	Throughput (sec)	Received (KB/sec)	Sent (KB/sec)	Avg. Bytes
WebSocket	3000	5891.99	390	6102	85.73%	52.66	0.51	0.71	131.0
HTTP	3000	7946.52	1309	101365	16.77 %	24.55	26909.59	8.75	1348282.0

Annex C. System Usability Scale

	Strongly Disagree 1	2	3	4	Strongly Agree 5
1. I think that I would like to 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 awkward 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					

Annex D. Interface Validation Plan

Please use the following credentials to login:

- User A
  - Email : testUserA@gmail.com
  - Password: userAPassword
- User B
  - Email : testUserB@gmail.com
  - Password: userBPassword

Validation Scenario 1 – Edit Asset

For this scenario, got to the option "Assets > Edit Assets>" and start by viewing an asset and editing it. Another user may then also start editing the asset simultaneously.

Asset chosen: ____

The system was able to transition between single-user to multiple-user collaborations.

Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree

The transaction between the types of collaborations was seamless.

Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree

The system was able to display and save the alterations been done.

Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree

Validation Scenario 2 – Placement of Assets

For this scenario, go to the option "Scenarios > Edit Scenarios> Manage Units and Assets" and view the available assets to a scenario, place them around the map and edit their properties.

Scenario chosen: ____

The system was able to transition between single-user to multiple-user collaborations.

Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree

The transaction between the types of collaborations was seamless.

Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree

The system was able to display the positions and characteristics of the assets.

Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree

The system was able to show the scenario in Augmented Reality.

Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree

Validation Scenario 3 – Edit Asset Scripts

For this scenario, go to the option “Scenarios > Edit Scenarios> Manage Units and Assets > Scripts” and, view the existing scripts and make new ones.

Scenario chosen: ____

Asset chosen: ____

The system was able to transition between single-user to multiple-user collaborations.

Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree

The transaction between the types of collaborations was seamless.

Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree

The system was able to display and save the alterations made.

Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree

Validation Scenario 4 – Run a Scenario

For this scenario, create, or join, a lobby and run through a scenario.

Scenario chosen: ____

The system was able to support lobbies with an active chat.

Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree

The system was able to execute the scenario.

Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree

The system was able to show the scenario in Augmented Reality.

Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree