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**Design and Development of the Virtual Museum of
Informatics and Telecommunications as an Immersive Virtual
Living Lab**

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ΔΙΠΛΩΜΑΤΙΚΗ ΕΡΓΑΣΙΑ

**Σχεδιασμός και Ανάπτυξη του Εικονικού Μουσείου
Πληροφορικής και Τηλεπικοινωνιών ως Εικονικό Ζωντανό
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ABSTRACT

The Museum of Informatics and Telecommunications (MI&T), founded in the fall of 2019, is the most recent addition to the cohort of museums of the National and Kapodistrian University of Athens. A team of museologists and architects have created plans for renovating and remodeling the Museum's current space. The plans are based on museological concepts aiming to mold it into a permanent exhibition area with the purpose of showcasing the history of informatics and telecommunications along with the concept of 'computational thinking' to the public, and at the same time acting as a 'living lab' for scientific research in multiple disciplines and at various (high school, pre- or post-graduate) levels.

This thesis presents the design and development of an immersive interactive virtual version of the MI&T, based on the notion of virtually reconstructing the physical Museum space as it is envisioned to become in the future. The virtual MI&T aspires to evolve as a tool that complements and augments the museum visit by adding a high level of immersion as well as a variety of interactions that would not be possible in the real world, thus leveraging the core attributes of Virtual Reality (VR) technology. To construct the virtual MI&T, an accurate 3D model of the new Museum was created based on the architectural designs. Then, multiple interactions were added to enhance the virtual experience through gamified processes and activities related to informatics and telecommunications. Moreover, to support the physical Museum's role as a 'living lab', its virtual rendition is designed in a modular way that allows the development of supplemental scenes that may serve as experiments or research projects. Three such scenes have been constructed to demonstrate the level of immersion, or 'presence', that the virtual environment is able to evoke. They are described in detail in this thesis as examples for future developers that may want to create immersive, interactive, multisensory experiences.

The virtual MI&T was evaluated in an exploratory study with 16 participants from different age groups and backgrounds. Each participant experienced the virtual environment using a mid-tier portable VR headset, the Oculus Quest 2, and then discussed their experience in a semi-structured interview conducted by the researcher. The findings revealed the engagement and educational potential of the virtual museum and its supporting environments (mini-games). However, they also highlighted the areas for improvement, primarily in terms of usability as well as in the enhancement of interactivity and interaction affordances. The 'open shell' approach adopted in the design and implementation of the virtual MI&T allows for future designers and developers to follow-up on these improvements and evolve the virtual museum into a dynamic experimental lab that will complement the real Museum.

SUBJECT AREA: Virtual Reality

KEYWORDS: virtual museum, cultural technology, immersion, interactivity, human-computer interaction, modular design, VR game, machine learning

ΠΕΡΙΛΗΨΗ

Το Μουσείο Πληροφορικής και Τηλεπικοινωνιών (ΜΠ&Τ), που ιδρύθηκε το φθινόπωρο του 2019, είναι η πιο πρόσφατη προσθήκη στα μουσεία του Εθνικού και Καποδιστριακού Πανεπιστημίου Αθηνών. Μια ομάδα μουσειολόγων και αρχιτεκτόνων έχει εκπονήσει τη μουσειολογική και αρχιτεκτονική μελέτη για την αναδιαμόρφωση του σημερινού χώρου του Μουσείου. Τα σχέδια βασίζονται σε μια σύγχρονη προσέγγιση που έχει ως στόχο να διαμορφώσουν το ΜΠ&Τ σε έναν μόνιμο εκθεσιακό χώρο με σκοπό την προβολή της ιστορίας της πληροφορικής και των τηλεπικοινωνιών μαζί με την έννοια της «υπολογιστικής σκέψης» στο κοινό και ταυτόχρονα σε «ζωντανό εργαστήριο» για την ανάδειξη και υποστήριξη της εκπαιδευτικής διαδικασίας και της επιστημονικής έρευνας.

Η παρούσα διπλωματική εργασία παρουσιάζει το σχεδιασμό και την ανάπτυξη μιας εμπυθιστικής διαδραστικής εικονικής έκδοσης του ΜΠ&Τ, βασισμένης στην ιδέα της εικονικής ανακατασκευής του φυσικού χώρου του Μουσείου όπως προβλέπεται να γίνει στο μέλλον. Το εικονικό ΜΠ&Τ φιλοδοξεί να εξελιχθεί σε εργαλείο που συμπληρώνει και επαυξάνει την επίσκεψη στο πραγματικό μουσείο προσθέτοντας ένα υψηλό επίπεδο εμπύθισης καθώς και μια ποικιλία αλληλεπιδράσεων που δεν θα ήταν δυνατές στον πραγματικό κόσμο, αξιοποιώντας έτσι τα βασικά χαρακτηριστικά της Εικονικής Πραγματικότητας. Για την κατασκευή του εικονικού ΜΠ&Τ, δημιουργήθηκε ένα ακριβές τρισδιάστατο μοντέλο του νέου Μουσείου με βάση τα αρχιτεκτονικά σχέδια. Στη συνέχεια, προστέθηκαν πολλαπλές αλληλεπιδράσεις για την ενίσχυση της εικονικής εμπειρίας μέσω παιχνιδιών και δραστηριοτήτων που σχετίζονται με την Πληροφορική και τις Τηλεπικοινωνίες. Επιπλέον, για να υποστηρίξει τον ρόλο του φυσικού Μουσείου ως «ζωντανού εργαστηρίου», η εικονική του απόδοση έχει σχεδιαστεί με αρθρωτό τρόπο που επιτρέπει την ανάπτυξη συμπληρωματικών σκηνών που μπορεί να χρησιμεύσουν ως πειράματα ή ερευνητικά έργα. Τρεις τέτοιες σκηνές έχουν κατασκευαστεί για να δείξουν το επίπεδο εμπύθισης, ή «παρουσίας», που μπορεί να προκαλέσει το εικονικό περιβάλλον. Περιγράφονται λεπτομερώς σε αυτή τη διπλωματική ως παραδείγματα για μελλοντικούς προγραμματιστές που μπορεί να θέλουν να δημιουργήσουν συναφείς διαδραστικές ή/και πολυαισθητηριακές εμπειρίες.

Το εικονικό ΜΠ&Τ αξιολογήθηκε σε μια διερευνητική μελέτη με 16 συμμετέχοντες από διαφορετικές ηλικιακές ομάδες και υπόβαθρα. Κάθε συμμετέχων βίωσε το εικονικό περιβάλλον χρησιμοποιώντας μια φορητή συσκευή VR, το Oculus Quest 2, και στη συνέχεια ακολούθησε συζήτηση για την εμπειρία με τη μορφή ημι-δομημένης συνέντευξης που διεξήγαγε ο ερευνητής. Τα ευρήματα αποκάλυψαν τα δυνητικά οφέλη και τις εκπαιδευτικές δυνατότητες του εικονικού μουσείου και των υποστηρικτικών του περιβαλλόντων (mini-games). Ωστόσο, τόνισαν επίσης τα πεδία βελτίωσης, κυρίως όσον αφορά τη χρηστικότητα καθώς και τη βελτίωση της διαδραστικότητας και των αντιληπτών δυνατοτήτων αλληλεπίδρασης. Η προσέγγιση «ανοικτού κελύφους» που υιοθετήθηκε στο σχεδιασμό και την υλοποίηση του εικονικού ΜΠ&Τ επιτρέπει στους μελλοντικούς σχεδιαστές και προγραμματιστές να εφαρμόσουν αυτές τις βελτιώσεις και να εξελίξουν το εικονικό μουσείο σε ένα δυναμικό πειραματικό εργαστήριο που θα συμπληρώνει το πραγματικό Μουσείο.

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ΛΕΞΕΙΣ ΚΛΕΙΔΙΑ: εικονικό μουσείο, πολιτισμική τεχνολογία, εμπύθιση, διαδραστικότητα, επικοινωνία ανθρώπου μηχανής, αρθρωτή σχεδίαση, παιχνίδι Εικονικής Πραγματικότητας, μηχανική μάθηση

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1. INTRODUCTION

The Museum of Informatics and Telecommunications (MI&T) is a newly established university museum located at the homonymous Department of Informatics and Telecommunications of the National and Kapodistrian University of Athens.

This thesis was conceptualized as a means of visualizing the new Museum of Informatics and Telecommunications based on the architectural designs created by the team of museologists planning the renovation of the MI&T. But until the museological plans can become a reality, the virtual Museum offers an opportunity to experience the future vision of the new Museum.

Currently, cultural institutes face some challenges, as stated by Dimitris Efraimoglou, the Managing Director at Foundation of the Hellenic World in his talk [1]. These include finding original ways to motivate people to visit, how to use new technologies in an educational context while remaining original, and the ability to provide, besides personal educational encounters, special experiences for small groups. He claims that by using Virtual Reality (VR) technology, they have a state-of-the-art visualization tool of historical information which can, furthermore, add engaged learning, immersion and social participation to a visit. Thus, the museum visit may become a premium, novel, highly immersive educational experience functioning as a motivator for attracting more and new visitors.

The virtual MI&T was designed based on these guidelines. The virtual environment will host several exhibits that will be complemented with numerous interactions aiming to assist the learning procedure by actively engaging the user. For example, in an old-fashioned museum, the visitor would see an exhibit with a label with some information next to it. VR provides creative freedom to the designer to devise anything imaginable and at the same time can immerse the user in a fantastical scenery. So, in our case, the user's VR avatar is able to interact with a timeline device by grabbing it with their virtual hands and pulling it sideways. As the device moves horizontally, its screen displays text, images and even videos from important time points of the history of information and communications technologies (ICT), making this a much more educational experience than the aforementioned.

Moreover, this thesis was inspired from the combination of the "Contemporary Technologies for Cultural Applications" course which is about technology use for Culture, and the "Interactive Systems" course where novel interactions between humans and computers are explored. Therefore, the software architecture was designed, from the beginning, in such a modular way, that it could serve as a 'shell' to future projects. These could be research projects, experiments, coursework or any other endeavors related to the MI&T, that are built as separate scenes which will be connected to the main Museum scene. Then the virtual Museum will become a platform for developers and scientists of numerous disciplines to meet and create projects targeted at various education levels. Currently, there are three demonstrative scenes which showcase important technological fields, such as multi user environments, intelligent computer agents, smart houses, and mixed reality devices. These can be modified, extended or used as a basis for other new ideas from future developers.

The result is a fully interactable immersive VR environment for the Museum. Currently, it is mostly fitted to work on the Oculus Quest 2 devices which are autonomous, cableless VR devices. The VR apparatuses will reside in the physical Museum space, loaded with the project, and allow the visitors to try it. Moreover, the project, as an open-source and interactive hub, will be able to play the role of a virtual university museum and living laboratory.

1.1 Aims and Motivation

Information and Communications Technologies have changed human society and civilization. It was natural for people to grow a fondness for devices related to these technologies and consequently new spaces were created with the purpose of storing and displaying them. One of these is the Museum of Informatics and Telecommunications [2] of the National and Kapodistrian University of Athens. It was founded in the fall of 2019 and is located in the ground floor of the Department of Informatics and Telecommunications (DI&T) building in Ilissia, Athens. The specific location is symbolic since it used to host the department's data center. It is one of the 21 museums hosted by the National and Kapodistrian University of Athens.

The MI&T is the focus of this thesis. A lot of exhibits, some functionable - some not, have been gathered from various laboratories, catalogued and stored in the Museum. Few are even from other departments or donated from private citizens. Besides the exhibits, there is also an archive of interviews with several retired professors of the Department. It aims to become a teaching medium for the significance of the informatics and telecommunications sciences in general, but also for their histories in Greece and internationally, as well as the history of the Department. By promoting the archive and the collections, the Museum tries to illustrate the evolution of computational thinking to the public.

The MI&T is being planned for renovation by a team of museologists and architects. The motivation behind the thesis is to create a virtual MI&T based on these renovation designs. Then, people will be able to virtually 'visit' the Museum, interact with the digital exhibits and learn about ICT and its history. Moreover, the virtual Museum can be viewed as the final outcome of its remodeling and thus serve as an evaluation and testing tool for the renovators, so they can change their designs accordingly, before construction begins.

By using VR technology, the virtual Museum can assist its physical counterpart with its goals. It can enhance its educational aspect by presenting the exhibits as three-dimensional (3D) models and by adding various immersive interactions, allowing the user to experience concepts and events, related to informatics and telecommunications, which are very challenging to happen in the real world. An example would be to demonstrate the involvement of computers in humankind's journey to space. Furthermore, it can support the role of the Museum as a center for scientific research, by being a platform for creating experiments and research projects associated with the Museum of Informatics and Telecommunications.

Overall, the goal of this work is to propose an immersive virtual museum, which will serve as a framework for developing and augmenting the physical, currently under development, MI&T space and promoting its living lab 'philosophy'.

1.2 Scope of the Thesis

The idea behind our project was to create a virtual reconstruction of the future Museum that will complement the physical. At this stage, the virtual form acts as a visualization of how the Museum will be transformed based on the architectural designs. At a later stage, it will be embellished with more 3D exhibitory objects and richer interactions. Moreover, it includes some additional scenes, reachable from the main Museum scene, which are thematically connected with the important time periods of the informatics and communications history. These scenes either serve as showcases of various new and old technologies or they can be mini-games that will teach significant historical bits through playing.

Furthermore, the virtual Museum can be uploaded online and reach a larger audience than the physical. This fact is especially crucial in the current day with all the covid-19 restrictions. Additionally, since it is an open-source project, after it is shared, it can be altered or upgraded with new interactive scenes. In this capacity, it can function as a breathing and dynamic hub for people from multiple disciplines to come together and conduct educational and scientific research programs at high school, pre- or post-graduate levels. It can be included in various lectures about museology, game design, human-computer interaction, programming or in respective workshops where the participants will learn corresponding skills through applied and practical approaches.

The physical university Museum can become an attraction for visitors of all ages. Especially the children, who are not familiar with many of the old artefacts, could take a tour in the Museum when they visit DI&T on the 'Open Day', for instance. The experience could be augmented by playing games in VR and may indirectly introduce new information about ICT and its history. A whimsical example would be the floppy disk which is almost always used as a 'Save' button image in applications, but younger people do not actually know where it derives from. A gratifying outcome would be for more young people to take an interest in ICT or in sciences generally. It could also motivate more students to apply for joining DI&T.

1.3 Contributions

The thesis aims to become a starting point for anyone who wishes to participate in the evolution and expansion of the project. As was stated in Section §1.2, it is an open-source project that may be edited and upgraded by multiple people. Therefore, this thesis serves as a document describing the architecture of the software application, so future developers can study it to adjust their design and development processes. Two main points are covered: a. the main Museum scene and b. the included three mini-games. The first is addressed to those that would like to work on the Museum scene, such as adding new interactions or information about the informatics and communications history and its time periods. An example could be the existing headphones objects, which are currently nonfunctional, to be able to play audio stories for the user. The second part is mostly directed to researchers that wish to create their own scenes and experiments related to the MI&T.

There is also a brief analysis of the used tools: 3D Studio Max, Unity Game Engine and the Oculus Quest VR Device. These can be helpful to fellow developers too. For instance, the UVW Unwrapping procedure in 3D Studio Max is explained in detail. Moreover, the VR Interaction Framework and its capabilities are revealed. It is very important because it provides the necessary functionalities to transform a default Unity project to a VR one. Lastly, Unity's ML-Agents Toolkit is investigated. The toolkit can construct intelligent

agents that are able to learn how to act ingame through Deep Reinforcement Learning and Imitation Learning techniques, devising a more compelling gameplay and a richer game experience as a result. It was used in one of the mini-games, Tron; and the described workflow can be replicated to create new games with Machine Learning affordances.

The virtual Museum is expected to become a living lab where people from multiple disciplines can assemble to organize and realize research projects targeted at various education levels. The common denominator is always the Museum of Informatics and Telecommunications and this thesis seeks to provide a framework and a tutorial for developing projects associated with it and its immersive virtual counterpart.

2. BACKGROUND AND RELATED WORK

In this chapter, the impact of digital technologies in the cultural space will be explored (§2.1), focusing mostly on VR technology and Virtual Museums, which are further analyzed in §2.2. The final section, §2.3, presents several examples of museum exhibitions and projects that employ immersive VR and have inspired the design and development of the virtual MI&T presented in this thesis.

2.1 Digital Technologies in the Cultural Space

Jahoda [3] claims that since social scientists have not succeeded in defining ‘Culture’ for more than a century, then he must agree with the conclusion of Lang [4] that: “attempts at defining ‘Culture’ in a definite way are futile”. Therefore, Jahoda’s stance is that it is “quite practicable and defensible simply to use the term without seeking to define it”. But if a formalization is indeed required, then culture should be defined in a specific context.

On the other hand, the history professors Findley & Rothney [5] have provided a generic interpretation of ‘Culture’: “understood as systems of symbols and meanings that even their creators contest, that lack fixed boundaries, that are constantly in flux, and that interact and compete with one another”, and cultural anthropologists [6] a more detailed one: “the universal human capacity and activities to classify, codify and communicate their experiences symbolically, through art (music, literature, lifestyle, painting and sculpture, theater and film), science, as well as moral systems”.

Then, we can perceive how the information and communications technologies have influenced the cultural space, just as they have done in multiple other aspects of life and society, by bringing newfound capabilities and possibilities to all the ways that ‘Culture’ shapes human civilization.

Burri [7] breaks down the actual steps of ICT’s engagement in the cultural space:

1. Digitization. The transformation of every type of content to binary digits which can be stored, processed and transferred. Audio, video, image, text files convert real-life information to a digital form.
2. Transfer. The digital files can be transferred at any point in the world at very fast speeds using the Internet: a public, global network of interconnected smaller networks. Entire movies can be downloaded in a few minutes or accessed online through streaming services. New protocols (IPv6) provide better performance and Quality of Service for multimedia [8].
3. Usage. On top of the aforementioned infrastructural transport layer sit the presentation and the application layers which provide access of the content to the user. The multimedia files can be used online or downloaded and used locally. They can be presented, interacted with, manipulated via countless apps.

Therefore, based on these affordances of the digital media, it is obvious how much ICT can influence the processes of cultural creation, expression and reciprocating. The content is now free of a tangible medium and can be shared, worldwide, cheaply and very fast. It can be stored, catalogued and organized in various repositories. Finally, it can also be copied and accessed by everyone.

Many digital technologies have been employed in the cultural sector. Some examples are: photogrammetry & 3D reconstruction of ancient artifacts, educational or serious games for enhancing learning through playing, mobile applications which can assist in

user personalization and corresponding dynamic storytelling events, multisensory interactions that can enrich a cultural experience by providing visual, aural, tactile or even olfactory stimuli to the visitor.

Out of all these, the VR technology, in particular, seems to stand out because of the feeling of 'being there' it is capable of evoking. This notion of 'presence' or 'place illusion' as it is called by Slater [9], allows the user to become immersed in a virtual environment, to lose one's sense of time and space, to mentally travel to other places and ages, creating, thusly, memorable multi sensorial experiences. This would be considered an ideal scenario for a virtual museum: to design and construct virtual environments which are able to generate such experiences that will allow a guest to engage with and learn about other cultures.

2.2 Virtual Museums

In simple terms, virtual museums are digital versions of their respective physical counterparts. The European Commission-funded V-Must project [10] defines the virtual museum as a digital entity with the characteristics of a physical museum that can complement and augment the visitor's experience by adding personalization and interactivity. Usually, virtual museums employ immersive VR technology to reconstruct a space. Hemminger et al. [11] describe some of the challenges that modern museums face, which motivate the development of virtual museums:

- The number of exhibits is always growing, while the storage capacity stays constant or is decreasing.
- Public Memory institutions are few and most of them store related data. Therefore, there are areas of knowledge and culture that are not covered at all. For example, there are many repositories about zoological data, but there are not many about the different kinds of dance.
- Visiting museums might be too expensive, because of travel and entrance fees, for some organizations such as schools from underprivileged districts.
- Some artifacts might be too delicate to be shipped to other museums.
- Some antiquities might be displaced, stolen or even destroyed.

Moreover, their proposed solution is to leverage the possibilities provided by various ICT, including digitization. Digitization, as analyzed in Section §2.1, records physical objects and spaces with a goal to provide access to everybody, always and from anywhere. Virtual museums utilize these technologies and have these advantages over physical ones:

- The digitized information can be stored and transferred through the Internet.
- The access is unlimited by the number of people, time, or place.
- Automated measurements, resulting in higher accuracy and easier recording.
- Artifacts can be compared based on their material or shape.
- Modelled objects can be viewed, analyzed and manipulated without harming the original.
- Antiquities can be placed in various virtual environments and under diverse visualizations.

The V-Must project [12] proposes a framework which uses digital technologies to transform a physical museum to a collaborative node of culture exchange. The framework includes instructions for the design and development of a virtual museum.

Charlotte Coates in her article [13] explains the increased appeal for virtual museums, especially since the pandemic and the lockdowns started. Virtual museums can immerse the user inside an experience, by creating interactable exhibits, customizable museum tours and even realistic, living environments. They are also more accessible, for example to people with mobility issues. Virtual museums can assist curators too. By offering a first-person viewpoint, they allow the curator to have a unique perspective of the exhibit and the surrounding space, enabling them to bring the exhibits and collections to life and create memorable experiences to the visitors. She closes by stating her belief that “VR exhibitions are not intended to replace the existing model, but to enhance and complement what is already there”.

Such an example is Uruguay’s Virtual Museum of Arts El Pais (MUVA) created by Alicia Haber [14], [15]. Developing a museum entirely on the web was the director’s solution to funding and lack of physical space issues. It is a 3D, digital building, designed by architects, that hosts virtual collections of Uruguayan modern and contemporary art. Its goal is to make the Uruguayan cultural heritage available worldwide and also to show art pieces that are kept in private collections and are unaccessible to the public. This concept of a fully virtual space was a major inspiration for our project. One screenshot of the virtual museum can be seen in Figure 1 (with permission from Ms. Haber):

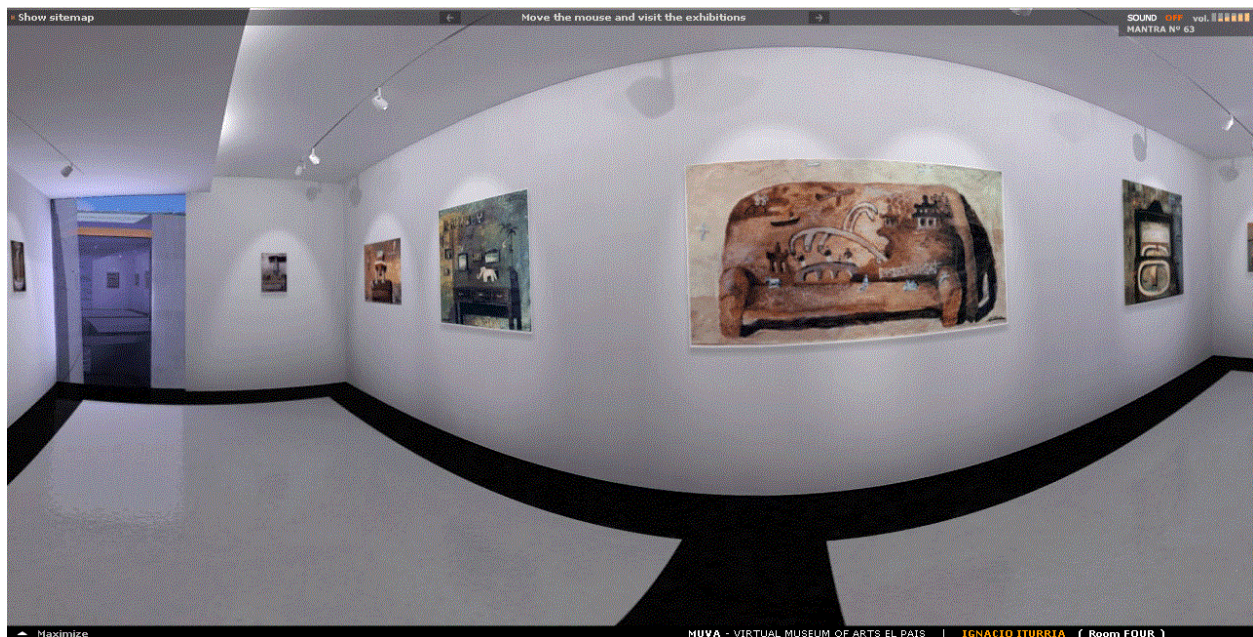


Figure 1: Virtual Museum of Arts El Pais

2.3 Examples of Immersive VR in Museums

This section will present examples of immersive VR technology used in virtual museum settings. These are usually VR applications that can be tried inside a museum and have been built around a specific collection.

The first is about the most famous painting in the world: “Mona Lisa: Beyond the Glass” [16] from the partnership of Musée du Louvre, HTC VIVE Arts and the VR studio Emissive.

The VR experience begins its virtual visit to the Louvre Museum with the iconic Pyramid and ends with the Grand Galerie showing all of the da Vinci paintings in the Louvre’s permanent collection. It combines animation, audio and interactive design to immerse the user in the world of da Vinci, where they travel through time to see how the painting was created and how it looks now, after 500 years and skillful restorations. The included narration explains facts and dispels myths about Mona Lisa. The application allows the user to participate in the creative storytelling and to inspect every detail, without worrying about queues or hurrying because of other people waiting. A screenshot of the application is reproduced from [17] (with permission from Emissive) in Figure 2.



Figure 2: Mona Lisa: Beyond the Glass

Another case is the “Modigliani VR: The Ochre Atelier” project [18]; a collaboration between the TATE Museum, the HTC and the PRELOADED companies, demonstrating, in VR, the unphotographed Parisian studio where Modigliani both lived and worked in his final months. Its intention is to illustrate the living conditions in which Modigliani painted some of his influential artworks, including the memorable “Self Portrait”, and to offer an insight into the artist’s state of mind in this period. It introduces more than 60 created 3D objects, materials and artworks. Figure 3 is a still screenshot, downloaded and reproduced after PRELOADED’s permission, which shows the studio:



Figure 3: Modigliani VR: The Ochre Atelier

This particular endeavor was designed around a persona which represents the average Modigliani visitor: a female, aged between 45-65, not familiar with the VR technology. Therefore, the overall VR experience was decided to be seated, so as visitors would not worry about cables or bump into something in the real space, and non-interactive, so that inexperienced users should not have to agonize over lack of controls knowledge and thus get distracted from the narration.

By recreating a place that cannot be visited in person, it attracted a weekly number of 3,500 visitors.

The following example is “The Glass Drawing Room Virtual Reality Experience” [19] of the Corning Museum of Glass, developed by Noho and makebelieve.

It is a VR in-gallery installation that allows the museum visitors to experience this specific room as it was in the 1770s decade. A small-scale model of the room that once existed was measured and photographed from all angles, leading to its VR reconstruction. The room’s objects, furniture and upholstery do not exist nowadays, so they were modelled after exhibits from the Corning and Victoria & Albert Museums and from the Duke of Northumberland and National Trust collections. The models were enriched with textured, reflective materials and the scene was lit from numerous candles in real-time. The result is an accurate virtual representation of the now-lost interior of the room which can be freely explored. The VR installation acts as a complementary experience to the museum tour, connecting the room from the 1770s to the present.

With makebelieve’s permission, a screenshot is presented in Figure 4:



Figure 4: The Glass Drawing Room Virtual Reality Experience

With the in-situ visits having been stopped, museums turned to ICT to reach their audiences. Digital experiences of cultural heritage have been developed and shared to people who would not have the opportunity otherwise. Projects have become more interactive, more user-focused; they now tell stories and narratives about characters and places and artifacts that induce memorable feelings, they use social media for user personalization and as a platform for culture sharing.

The EMOTIVE project [20], a H2020 EU funded research project, proposes a framework that can generate user-centered storytelling experiences designed to construct affective and interactive narratives for the cultural sector that will engage the visitor emotionally. It is based on these guidelines:

- The designed and created narrative should be centered around each user.
- The experience is interactive and should be based on stories and not on objects, allowing for social participation. If possible, the virtual and the real world could also blend, for example by using AR technology.
- The content and exhibits should enrich the experience and provide interaction opportunities.
- Use of personas, individual and group, that describe users in a concise way and may be employed to cater to their motivations.
- Take into factor the pre-, during and post-visit user experience.

The resulting output of the framework is shaping an old-fashioned museum tour to an interactive, emotional storytelling experience. Based on the proposed framework, the EMOTIVE partners have developed an example of a VR experience taking place in the UNESCO Neolithic site of Çatalhöyük. Two users can collaborate to perform various activities of this era, such as painting artifacts, repairing the house, and partaking in a burial process. The participants can customize their avatars, make choices, interact with each other, and follow a story driven narration. The experience is emotion-evoking and promotes learning through its exhibits and their interactions. Figure 5 is a screenshot of the VR experience reproduced with the permission of EMOTIVE's partner: "ATHENA" Research Center.



Figure 5: EMOTIVE - Neolithic Site of Çatalhöyük

Another project which brings a unique, highly immersive experience and has a theme relatable to museums is “Curious Alice: the VR experience” [21], a collaboration between Victoria and Albert Museum (V&A), HTC Vive Arts, the games studio PRELOADED and the illustrator Kristjana Williams. It was created as a part of V&A's 2021 exhibition “Alice: Curiouser and Curiouser”.

Curious Alice is a VR version of the “Alice in Wonderland” book. The user tumbles down the rabbit hole and enters Wonderland, explores a surreal landscape, communicates with characters from the tale and tries to complete multiple challenges similar to those in the book. The whole environment is drawn in a Victorian-esque style (see Figure 6 with permission from Kristjana Williams [22]), perfectly fitting Wonderland’s aesthetics, thus raising the level of player immersion. The project is fully interactive, taking advantage of the new capabilities of the VR technology. After the Alice story being an inspiration for movies, animated films and even games, this experience aims to bring an old fairy tale (1865) to life through the new VR dimension capturing the imagination of the visitors.

For those attending the “Alice: Curiouser and Curiouser” exhibition, there is a shorter version available, named “A Curious Game of Croquet”, which can be experienced by the VR devices in the gallery.



Figure 6: Curious Alice: the VR experience

American Museum of Natural History (AMNH), HTC VIVE Studios and Immersion have created an interactive, multiplayer, VR experience: “T. rex: The Ultimate Predator” [23].

It was inspired from the first T. rex skeleton which was discovered in 1902 and is now hosted in AMNH. The museum’s paleontologists and science visualization team have constructed the most scientifically precise, in perfect scale, 3D model of the iconic dinosaur to date. Besides the anatomy, its movement has also been modeled after extensive research.

The project lets a team of up to 3 visitors enter the AMNH’s Hall of Saurischian Dinosaurs, where they try together to assemble the dinosaur skeleton by placing its bones in the correct locations. At the end of the assembly, the users are “transported” to the location of Hells Creek Montana, 66 million years ago, where the dinosaur comes to life in front of them. This serious game has an educational aspect since during the assembly, information about the dinosaur is presented to the players.

With the permission of AMNH, Figure 7 shows a still screenshot of the dinosaur being created, and Figure 8 illustrates the dinosaur coming to life.



Figure 7: T. rex: The Ultimate Predator - Being Created



Figure 8: T. rex: The Ultimate Predator - Coming to Life

The project's architects claim that by using VR, they have succeeded in moving the visitors in a prehistoric environment where the exciting engagement with the exhibit creates a knowledge-enriching and memorable experience.

There is also a single player version for at-home use. Without having a pressure for time, it provides more historical facts, videos, animations and a guided tour.

3. THE MUSEUM OF INFORMATICS AND TELECOMMUNICATIONS

This chapter presents the physical Museum of Informatics and Telecommunications of the National and Kapodistrian University of Athens. In Section §3.1, the MI&T is described briefly and its current state is presented. At this time, the Museum hosts a collection of exhibits, but it is closed to the public. Section §3.2 concerns the renovated new MI&T. It includes the architectural designs that illustrate how the entire museum space will be remodelled. It also analyzes the museological concept that the Museum's renovation was based upon.

3.1 Museum - Current State

The MI&T [24] was founded in 2019 and occupies an area of 263 sq.m in the ground floor of the Department of Informatics and Telecommunications building. There is an autonomous entrance and it is planned to accommodate access to visitors with disabilities. Its main objective is to highlight the scientific fields of Informatics and Telecommunications and their respective domestic and worldwide histories. All of its archived exhibits complement the histories with short stories of their own, thus becoming an educational resource. They can also be used in research and educational activities of the Department, or even emphasize the importance of these sciences in modern society.

The Museum is currently an open space with the various related exhibits clustered in groups, for instance: laptops, personal computers, printers, transformers, storage devices, telecommunications equipment (network adapters, modems, routers), oscilloscopes, measuring instruments (multimeters, ampmeters, voltmeters, hygrometers, spectrometers, optometers), and educational simulation devices.

But the Museum is not open to the public presently. It is mostly used as a repository for the aforementioned exhibits. It serves as the focal point for graduate and undergraduate student courses and theses conducted at the Department of Informatics and Telecommunications, where teams gather information about their projects and present their work afterwards. Such projects could be utilized in the future version of the virtual Museum, telling new digital stories about old equipment. Figure 9 is a photograph of the Museum from September 2021. Additional images can be found in Appendix I.



Figure 9: Museum - Current State

3.2 The New MI&T

A team of museologists have planned the renovation of the existing Museum. They worked together with architects to envisage a new MI&T that will follow certain museological concepts to achieve its intended purposes:

- To become a permanent exhibitory space where the numerous exhibits and digital interactions will expose the important notion of ‘computational thinking’ to the public.
- To act as a breathing, dynamic laboratory for scientific research in multiple disciplines and at various (high school, pre- or post-graduate) levels.

As mentioned before, the project is expected to become a living lab where people from multiple disciplines can assemble to organize and realize research projects targeted at various education levels.

This yet-to-be-implemented plan was the motivation and the driving force behind this thesis: to create a virtual rendition of the current physical Museum and demonstrate how it will appear and function upon completion.

Section §3.2.1 shows the architectural designs of the new MI&T, along with the consequent 3D models. Section §3.2.2 describes the Museological Concept that this endeavor was based on.

3.2.1 Architectural Design

The architectural design’s top and orthographic 3D views are depicted in Figure 10:

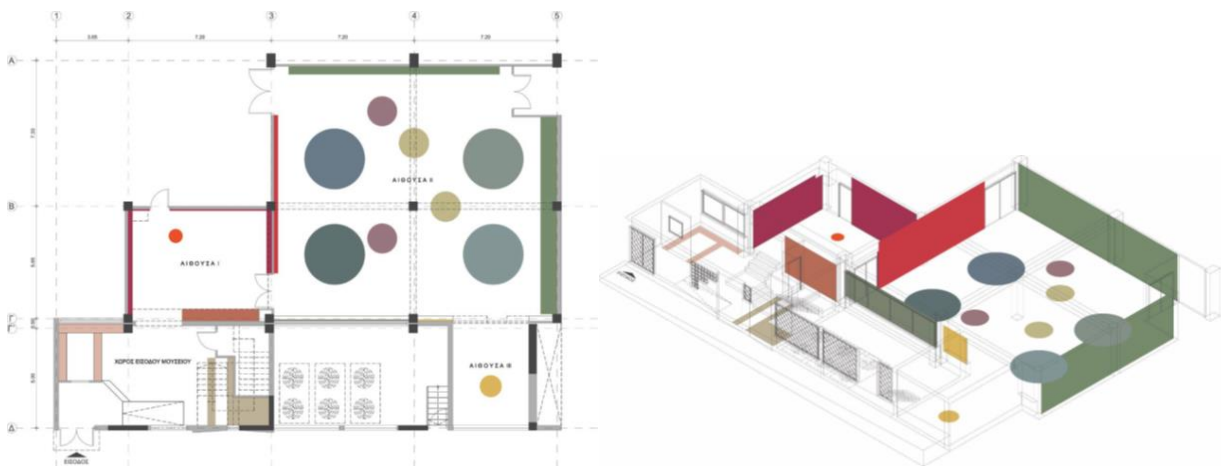


Figure 10: Architectural Design - Top and Orthographic 3D View

The main room’s architecture is characterized by letting the visitor free to walk around, explore and examine any of the existing six time periods sub-areas. The time periods are described in §3.2.2.

The corresponding visualization 3D model with and without the walls (for unhindered sight of the internal equipment and furniture) is portrayed in Figure 11:

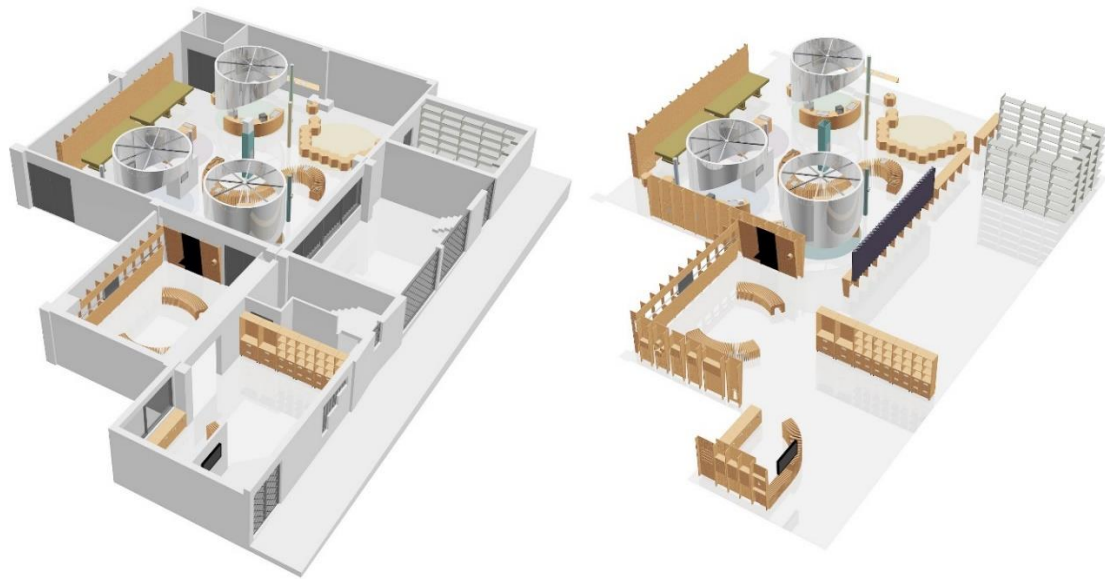


Figure 11: Architectural Design - 3D Model with & without Walls

3.2.2 Museological Concept - Themes

The design of the new Museum of Informatics and Telecommunications has been a challenging task. Its goal is twofold [25]:

- to present the history of Informatics and Telecommunications in general, but also the specific history of the Department and its role in influencing these sectors in Greece.
- to act as both an educational space, supporting coursework and research projects, and an autonomous exhibition place.

These factors led to a design of a permanent exhibition with dynamic content that can be enriched and updated by the academic and student communities. And this is the objective of this thesis. To provide an 'open shell' where other virtual environments can be created, added to and accessed by. Undergraduate and postgraduate students can make projects about the exhibits of the Museum's archive and collections, or about any other item that is related to ICT.

According to the basic principles of the modern museological approach, the visitor should be the center of a museum experience, where experiential learning will occur through various experiences and emotions. To facilitate this approach, the following means were devised:

- The visitor can become an active participant in the exhibition by interacting with some of the exhibits.
- New information can be discovered through enjoyable narrative methods, such as storytelling.
- Social interaction and participation in the exhibition's interpretation shall be encouraged and supported.

The various items are divided into sections associated with specific eras and people. These connections are highlighted in the exhibition, aiming to cultivate historical empathy

to the visitor through emotional engagement with the time, the people, the understanding of the era's historical contextualization and perspective-taking.

The architectural design was based on dividing the space in various sections where related information and exhibits will be presented to the visitor. These sections are [25]:

- Section 1: the Mathematical / Scientific Computer. This is from the 1940s up to the 1960s decade. The early computers appear here, with the ENIAC considered the first one. It is explained that these computers were constructed to be used in the military. They were operated by women operators who were called 'Computers'.
- Section 2: the Business Computer. In the 1970s, these were large processing machines, called 'mainframes', which also originated from military use. The first computer networks are discovered here, as well as the first software applications and programmers.
- Section 3: the Personal / Home Computer (1980s). The computer has become smaller in size, therefore making it possible for wider home use. People started using them for science and entertainment purposes. New opportunities arise, such as video games and scientific software.
- Section 4: the Networked Computer in the 1990s. This is the era of the computers as they are known today. The Internet and Social Media revolutionized everything, bringing people closer. The importance of data arose to new heights.
- Section 5: the Creative Computer. The computers in the new millenia (2000s) have been transformed from simple calculation devices to apparatuses used in every aspect of life, including the Arts. Examples of creative uses are: performance art, video art, animation, games, cultural heritage, digital music and many more.
- Section 6: the Ubiquitous Computer of the 4th industrial revolution. The representative and the main contributor of the modern digital era (2010s). ICT depend on the ubiquitous computer which appears in multiple sectors, such as: Artificial Intelligence, Big Data, Mixed Reality, Internet of Things and Smart Devices.

Each section is associated with a unique color theme and demarcated in the museum space by circular ceiling structures.

The scenario of the exhibition is to present the History of Informatics and Telecommunications. The journey starts in the 1940s decade and reaches the current era. It will present the most important developments in the world of these two areas and how they affected society. Moreover, the interconnection between the fields will be displayed and how Informatics facilitated 'computational thinking'. In any case, the visitor is able to explore the Museum freely and without having to follow the order of the sections.

The six sections are in the second room of the Museum, which is the main room. It will also contain wall showcases with objects, digital tables, flexible digital interactive surfaces, headphones with audio stories of general interest (little stories) and technology stories (tech stories), a projector and the prisms with the three Computers images.

The first room is the Museum foyer. It will include an interactive timeline, wall prints and showcases with objects and constructions, a special showcase with the logarithmic rule, and digital tables. The timeline is the fundamental tool of presenting the History of ICT.

The Museum lobby is the place to welcome the visitors and to present some historical information through wall prints and digital touch screens.

4. THE VIRTUAL MI&T

In this chapter, the virtual MI&T will be presented. It was inspired by the MUVA example from §2.2. As described in the Introduction (§1.1), the concept of the project is to design and develop an interactive VR environment for the new Museum of Informatics and Telecommunications. At the core of this concept is the intention to provide an open-source project where more people could join in and further evolve it. Its main goal is twofold:

- A user can download it and install it in a VR device in their home. They could then experience a virtual version of the Museum and learn about the exhibits or the time periods (see §3.2.2) without leaving their houses. This can be very useful and accommodating in certain situations, such as in the covid-19 pandemic.
- A user could visit the actual Museum and then don a VR headset, provided in the premises, so they can play a serious game or a multiplayer mini-game that could enrich their visiting experience or enhance their learning procedure.

With these facts in mind, this chapter outlines the project's design decisions and modularity in §4.1, then the actual implementation of the virtual Museum in §4.2. Specifically, it describes the used tools, the produced MI&T 3D model and the utilized VR device. Finally, §4.3 presents the various scenes of the virtual Museum: the tutorial scene for teaching basic VR controls to the user, the main Museum scene that also serves as a 'shell' where more levels could be created and connected to, and the three interactive scenes which take the form of mini-games.

4.1 Design

In this section, the design decisions about the modularity of the software (§4.1.1), the Museum environment's structure (§4.1.2), and the user's navigation and interaction capabilities will be discussed (§4.1.3).

4.1.1 Modular Software Design

As it was stated previously, the project is designed in a modular way such that it can facilitate perpetual modification and growth. The main virtual Museum scene is the 'shell' where multiple other scenes, originating from the various time periods, can connect to through an implemented portal system. The application remembers from where the user entered a specific mini-game scene and returns them to that same position when they exit. The modular concept was inspired from Valve's "The Lab" [26] where multiple room-scale games are compiled together to offer different kinds of experiences to the player. These include games where someone can defend a castle equipped with a bow, repair a robot, use CT medical scans to learn about the human body, or even explore and travel in the vast solar system.

This design allows the project to be used in more ways than were mentioned in the previous section. The more probable one is as a learning tool for developing interactive applications. It can be a starting point and a tutorial project for courses of the undergraduate and postgraduate programme, such as:

- a. The graduate course in "Interactive Systems," which is focused on Human Computer Interaction and various modern environments of interactions, for instance Virtual and Augmented Reality and computer games. It deals with

interaction techniques & patterns and concepts like presence & immersion. The students are asked to design and complete a relevant team coursework.

- b. The graduate course “Contemporary Technologies for Cultural Applications” where technologies are taught to support the whole development cycle of applications for the cultural sector. Multimedia is digitized, processed and stored in repositories where they are managed and enhanced with metadata. Afterwards, the cultural content is presented through Virtual and Augmented Reality applications, digital storytelling and even holograms. Likewise, the students are tasked with designing and building a team project.

The virtual Museum can support such courses, since it encompasses most of the aforementioned functionalities. The github repository can be made available to the students to build new scenes which can connect to the main Museum scene through the portal system. Of course, the project could be utilized, also, in any related under-grad course.

4.1.2 3D Environmental Design

Designing the virtual Museum was initially based on the model derived from CAD software. This model required some adjustments before it could be used correctly inside the game engine. It had many sub objects that needed renaming and grouping. The windows were decided to not have a transparent material, so as there would be no extra modelling and rendering of an exterior environment. Because of the project's VR nature, two more decisions were made in order to minimize CPU and GPU cycles: a. to only use static (baked) lighting and not dynamic light sources and b. to not use real-time shadows of dynamic, movable objects.

The provided model was untextured and all the submeshes were using the same default material. Therefore, all the materials, textures, colors, and the lighting had to be selected in such a manner as to make the virtual model look as close as possible to the desired output depicted in Figure 11.

4.1.3 Navigation and Interaction Design

Concerning user navigation, the scene followed the museological approach from §3.2.2 that the user should be free to explore the space in any sequence they wish. For this reason, some of the wooden seats were deleted and the door leading to the main room was left open to offer a more effortless tour. Moreover, to facilitate an enjoyable navigation experience, it was determined to utilize a VR framework, analyzed in §4.2.3, which provides teleport and walking locomotion modes.

The VR framework also implements various interaction functionalities, such as grabbing, pushing, using UIs. Consequently, some interaction devices, for example the timeline, were designed to be added in the Museum space and take advantage of these capabilities in order to make the whole experience feel more immersive.

The general design decision was to have the Museum scene acting as a central hub from where other scenes would be initiated. Currently, three mini-games scenes have been developed, which are associated with the time periods of the ICT history. Future developers may create other mini-games, or interactive scenes, or museological experiments and then connect them to the main Museum scene. This modularity quality is supported by the designed portal system which remembers from where the user entered a side scene, and then returns them to that position when they exit from this scene.

4.2 Implementation of the Virtual Museum

The following chapter sections investigate the implementation of the virtual Museum. The used tools are analyzed in §4.2.1. Then the produced 3D Museum model is presented in §4.2.2. Finally, §4.2.3 describes the framework which provides VR interactions.

4.2.1 Tools

Multiple tools have been used during the project's implementation phase. Chronologically, the first software that was utilized was 3D Studio Max from the Autodesk company. There were two .max scene files (the Museum and its ceiling) that were imported there to be processed and then exported as .fbx files. Afterwards, these files were imported to the game engine Unity where the main development transpired. Eventually, the project was built and tested on the VR devices Oculus Quest 1 and 2.

4.2.1.1 3D Studio Max

3D Studio Max (Max for brevity) is a professional 3D modeling and rendering software for creating architectural visualizations and entire game worlds, for modeling single objects and animating characters [27]. A free educational license was provided for both the 2021 and the 2022 version.

The usual workflow is to create standard and extended primitives or other compound objects and then apply various modifiers and operations to their vertices, edges, faces, or polygons to reshape them as needed. Moreover, materials with textures can be created to alter the objects' appearance. Also, if these models have to be animated, they can be given an invisible skeleton (rigging) that can define its movement by corresponding animation clips.

As mentioned before, two .max scene files were produced from the architectural study. We can see them as well as Max's Graphical User Interface in Figure 12:

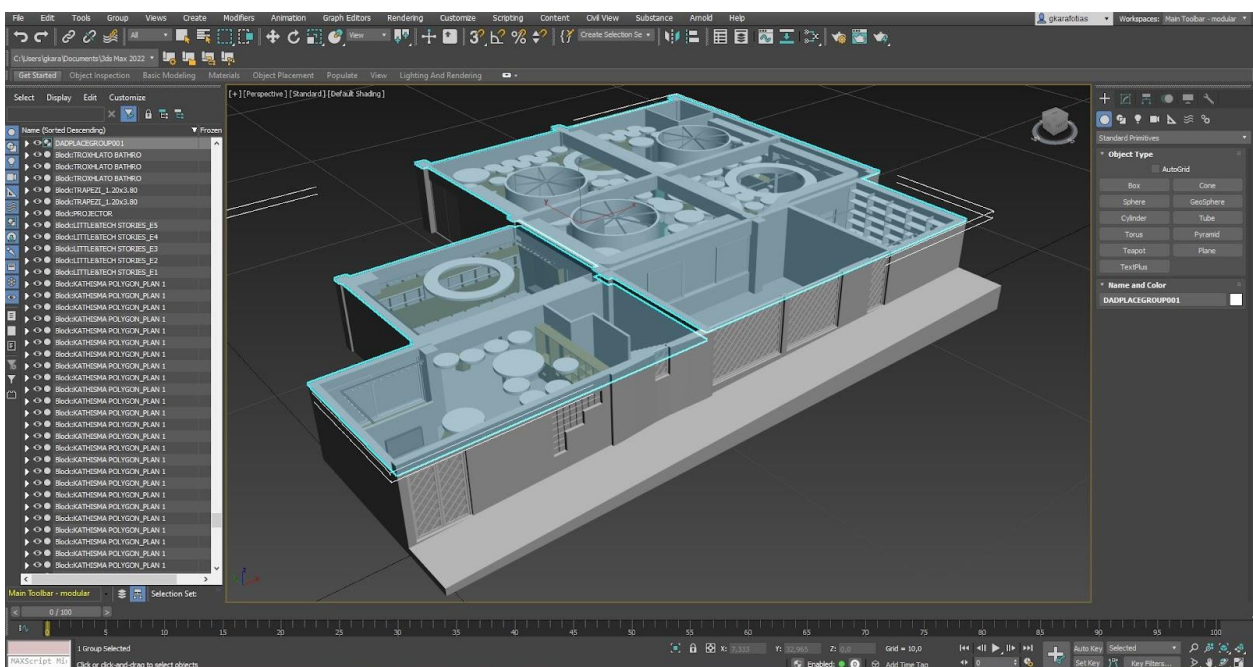


Figure 12: The Museum Models in 3D Studio Max

On the left side, there is a list of the models, sub-parts and groups of the scene. On the right side, there are buttons to create and transform objects. The middle window is where the scene is rendered. Two major models can be distinguished; the museum and the ceiling which is in transparent cyan color so the interior can be viewed underneath. The imported museum model did not have correct UV mappings, therefore these had to be created manually so the applied textures would look as they should. This UVW unwrapping procedure is further explained in Appendix II. After this, the models can be exported as .fbx files which is a type of file that includes information about the model's mesh and also about its material.

4.2.1.2 Unity Game Engine

The .fbx files were then imported to the Unity Game Engine [28] where the main development took place. Unity (for short) is a complete 3D rendering engine coupled with an Integrated Development Environment (IDE), the Unity Editor, which allows the user to create and edit 2D or 3D scenes. It is a product of the Unity Technologies company and was used under a Personal license. The project started in the 2019.4.13 version and was later continued in the 2020.3.11 version.

Figure 13 shows the untextured Museum and ceiling models inside Unity. These models will be the base of our VR scene and more functionalities will be built upon them, as it will be described in greater detail in §4.3.2.

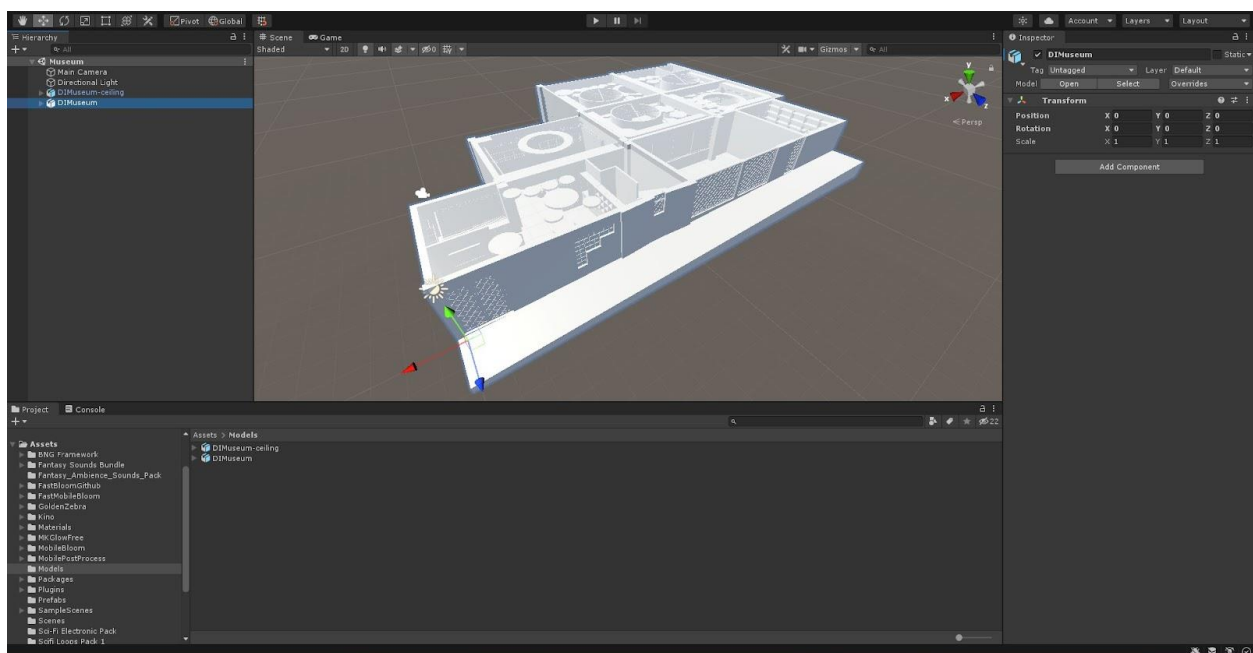


Figure 13: The Untextured Museum Models in Unity

We can also see Unity's default layout. It consists of four main windows:

- On the top left side, the Hierarchy. This is where the current scene and its contents are depicted.
- On the right side, the Inspector. The attributes of the selected object in the scene are shown here.

- On the bottom, the Project. All the files in the project are contained here. If a file is used in the current scene it will also show in the Hierarchy window.
- The central main window, the Scene. Here, every object in the Hierarchy is being rendered. We can manually change the scene objects' transformations (position, rotation, scale) and watch the changes in real time. When the Play button (on the top middle) is pressed, the Scene window is replaced by the Game window, where we can play and test our application.

Unity considers every object or entity as a GameObject that populates the scene. GameObjects follow the Component design pattern. This means that GameObjects have their behaviors defined through the use of independent and customizable pieces (called Components) which grant specific functionalities. Every GameObject has at least the necessary Transform Component, which is shown on the right side of Figure 12. There are two kinds of Components:

- Those that are embedded in the Unity Editor and offer generic capabilities, for example the Light Component which makes the GameObject function as a light source in the scene. Some common ones are: Mesh Renderers, Effects, Physics Rigidbodies, Colliders, Joints, AI related, Audio & Video related, Animation, User Interface (UI) related, Events, etc.
- And those which are created by the user and give original, custom functionalities. These are C# scripts that express the desired logic and are assigned to the corresponding GameObject.

The GameObjects follow a hierarchical order, which means that if a GameObject becomes a 'child' of another GameObject, then it will inherit its whole transformation. So, if the parent changes its position, rotation or scale attributes, these changes will also propagate to all of its children GameObjects.

The Unity Game Engine along with the Unreal Game Engine are considered to be the ones with the most features [29]. Unity's ease of use derives from the existence of multiple integrated systems that are ready to be added and utilized in any project. These include: Rendering System, Graphical User Interface, Input System, Physics System (PhysX), Collision System, NavMesh Navigation System, Terrain System, Lighting and Shadows, Effects System, Shader Graph, Animation System, Cinemachine and Timeline Systems, Audio and Video Systems, XR System, and others.

Finally, Unity is preferred because of its export capabilities. It can build a project to any of these platforms [30]:

- Mobile platforms: iOS, Android, (Android TV), tvOS.
- Desktop platforms: Windows (Universal Windows Platform), Mac, Linux.
- Web platform: WebGL.
- Console platforms: PlayStation (PS4, PS5), Xbox (Xbox One, Xbox Series X/S), Nintendo Switch, Stadia.
- Virtual/Extended reality platforms: Oculus, PlayStation VR, Google's ARCore, Apple's ARKit, Windows Mixed Reality (HoloLens), Magic Leap, Steam VR via Unity XR SDK, Google Cardboard.

4.2.1.3 VR Device - Oculus Quest

The project was tested on the Oculus Quest 1 and 2 devices [31]. The Oculus Quest headset was selected because it is the first VR headset with six-degrees-of-freedom (6DoF) inside tracking that also includes CPU and GPU chipsets; therefore, it works without any wires and does not need to connect to a computer. Its lithium-ion battery can deliver about two to three hours of gameplay, depending on the use. Its wireless nature makes it suitable for places like museums, where the visitors-users can walk around in specifically arranged spaces without any danger.

In our case, it would be very entertaining and educational to visit the Museum and see the various real exhibits, but also to be able to wear the VR head-mounted display (HMD) and experience virtual representations or models of any other computer or telecommunications device that could be hosted there, accompanied by intuitive interactions. The two headsets are shown in Figure 14:

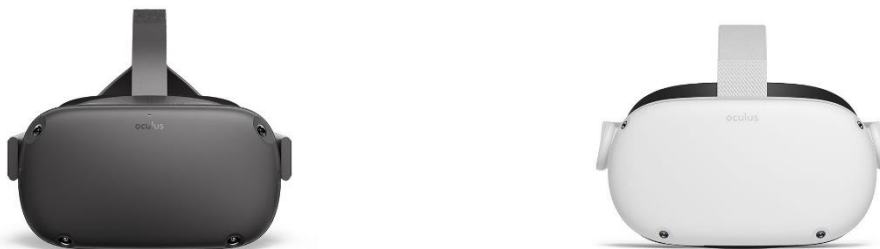


Figure 14: Oculus Quest 1 (left) and 2 (right)

Their hardware characteristics are compared in Table 1 (from [32] and choosing Quest 1 and Quest 2):

Table 1: Quest 1 and 2 Comparison

Oculus Quest 1	Oculus Quest 2
OLED Display	Fast-Switch LCD Display
1440 x 1600 Resolution Per Eye	1832 x 1920 Resolution Per Eye
72 Hz Refresh Rate	60, 72, 90 Hz Refresh Rate
Six Degrees of Freedom Tracking	Six Degrees of Freedom Tracking
3D positional audio	3D positional audio
Touch Controllers	Redesigned Touch Controllers
CPU: Qualcomm® Snapdragon 835	CPU: Qualcomm® Snapdragon XR2
GPU: Qualcomm® Adreno™ 540	GPU: Qualcomm® Adreno™ 650
Memory: 4GB total	Memory: 6GB total
Storage: 64GB, 128GB	Storage: 128GB, 256GB
Glasses Compatible	Glasses Compatible

Of course, the Virtual Reality Interaction Framework, which is detailed in §4.2.3, allows the use of other VR devices, namely the Oculus Rift-S, the Valve Index, the HTC Vive, the HP Windows Mixed Reality and the Pico VR.

4.2.2 MI&T 3D Model

The MI&T 3D model and its ceiling were exported from the architectural design (AutoCAD) and modeled in the 3D Studio Max software (Figure 11), using the tools described in Section §4.2.1. The main challenges encountered in this process include:

1. All the submeshes are unorganized, as it appears on the left side of Figure 11. Most meshes are named “Mass Element”, which does not help a designer manipulate them inside a game engine. Therefore, after importing the models in Unity and building prefabs out of them, some empty GameObjects were created to act as parents of similar sub meshes. These sub-meshes have been grouped together so as to provide easier collective manipulation. For example, the game designer can enable/disable all Panels with a single click. Or apply some kind of transformation to all related GameObjects, for instance, assign a new material to all Seats or make all CircularLights smaller. This helpful new hierarchy shows in Figure 15:

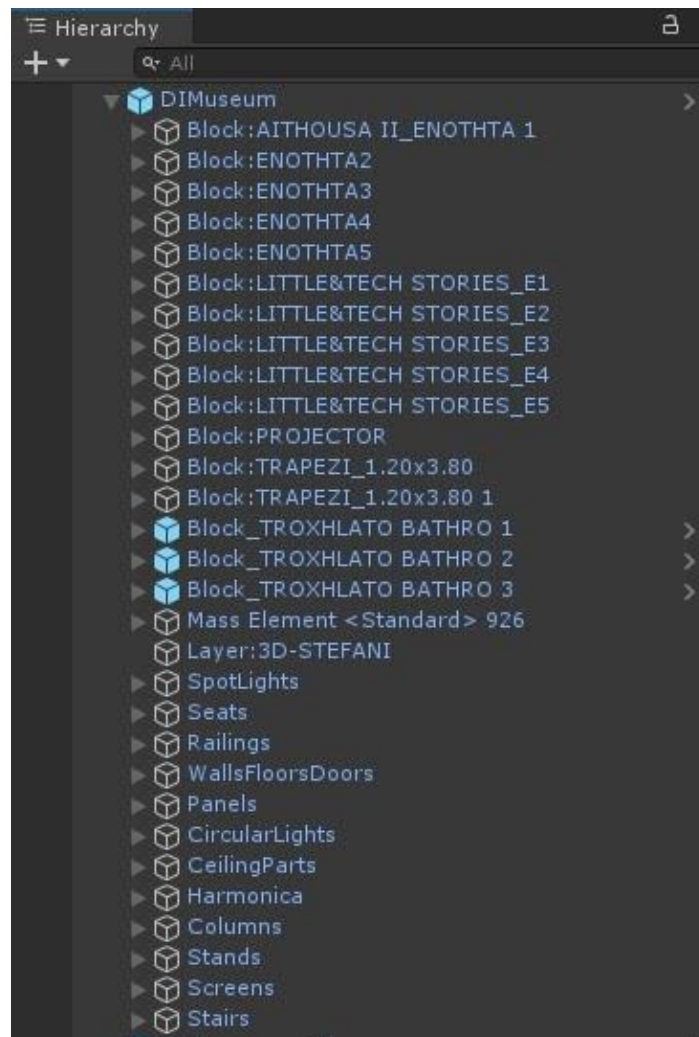


Figure 15: Museum 3D Model with Grouped GameObjects

2. The second important issue is that the various sub meshes do not have aligned UV coordinates. This means that the texture coordinates do not correspond with the geometry vertex information, so if a texture is applied to the mesh's material, the mesh's surface will not be textured correctly. The inaccurate texture mapping of the Timeline's bottom panel in 3D Studio Max shows in Figure 16, while the same panel with the corrected UVs in Unity is displayed in Figure 17:

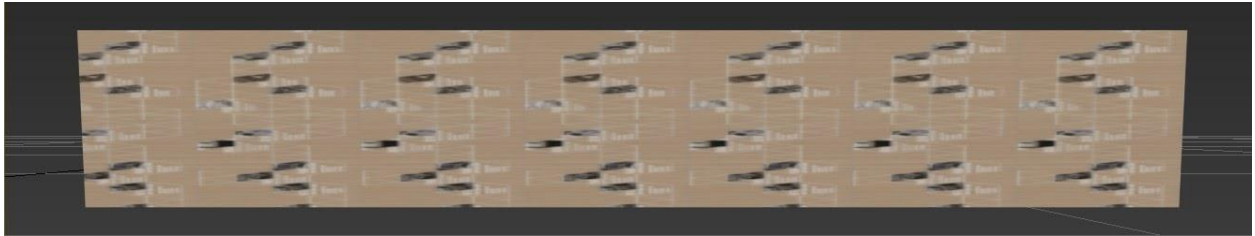


Figure 16: Panel with Incorrect UVs

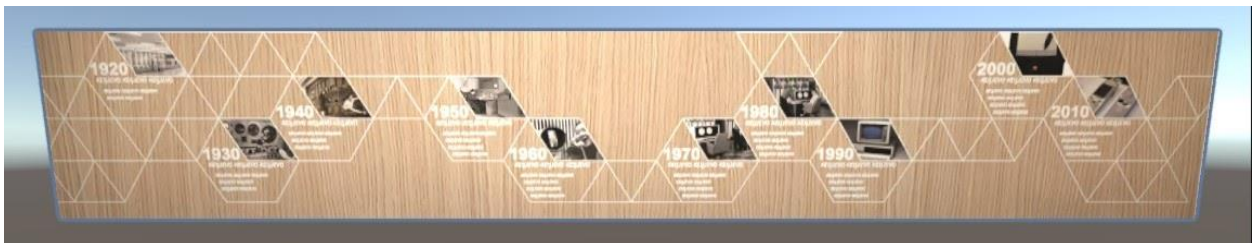


Figure 17: Panel with Correct UVs

Consequently, they had to be subjected in a UV remapping procedure which is reviewed in greater detail in Appendix II.

Then, after overcoming these two complications, the meshes are ready to be textured and lighted. As examples, these are some screenshots (Figure 18 - Figure 20) of the three main rooms with some models in them textured. The textures image files were suggested by the architectural team.



Figure 18: Lobby Partially Textured



Figure 19: First Room Partially Textured

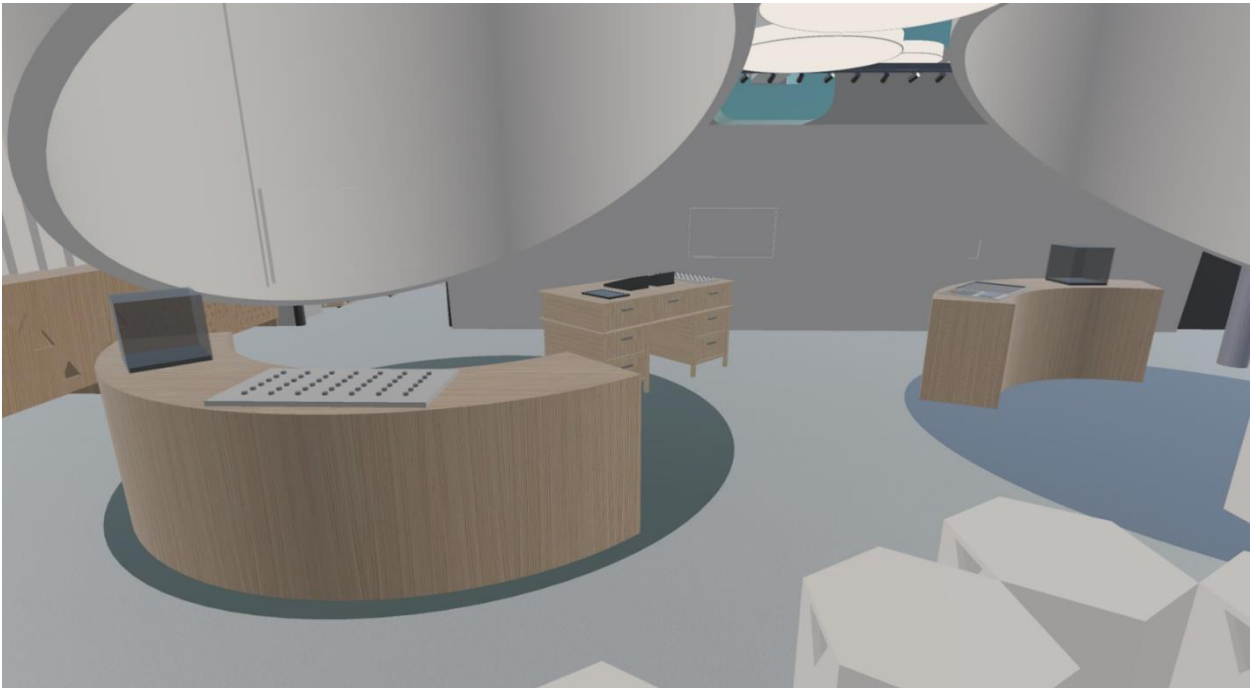


Figure 20: Main Room Partially Textured

We have also used Light Probes and Reflection Probes, which are special GameObjects that are placed in the scene and they gather lighting information offline, which they share with nearby objects. Then these objects are 'shaded' ingame, depending on this offline information and not on real time calculations. That way, we can use baked lights and not realtime, saving our processor cycles for other important computations in VR. In Figure 21, the faint purple lines connect the various light probes in the vicinity, creating a light probing network.



Figure 21: Example of Light Probes

Reflection probes follow the same logic; they are placed in some positions in the scene and they store reflection information which they apply to neighboring objects that have materials with non-zero metallic values (

Figure 22).



Figure 22: Example of a Reflection Probe

Another technique has also been used to help the renderer draw fewer elements: Occlusion Culling. This algorithm checks the viewport of the user's camera and culls those GameObjects that are not inside this frustum. So, for example, objects which are behind the user, are not rendered at all, since it is not possible to be seen. Figure 23 and Figure 24 showcase this approach:



Figure 23: Without Occlusion Culling

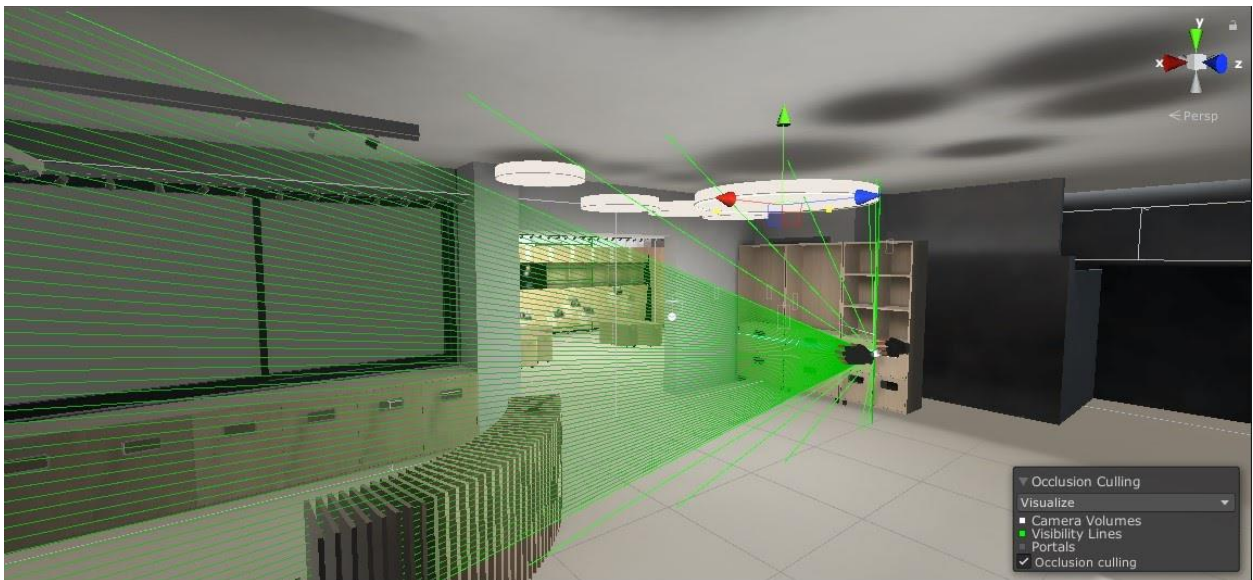


Figure 24: Occlusion Culling Hides Objects Out of Frustum

Finally, lights and shadows are ‘baked’, in the Unity Editor to special Lightmap image files. So, all the light and the shadows calculations are done once and saved in files. Then, at runtime, the rendering pipeline combines each lightmap with the materials’ textures of the affected GameObjects, saving processing power. An example of the main room is shown in Figure 25:



Figure 25: Baked Lights and Shadows

The final Museum models with accurate UVs and baked lighting, are displayed in Figure 26 (the ceiling has been disabled temporarily for a better view of the rest of the building). This outcome appears much more aesthetically pleasing and accurate to the architectural design than the untextured model from Figure 13.

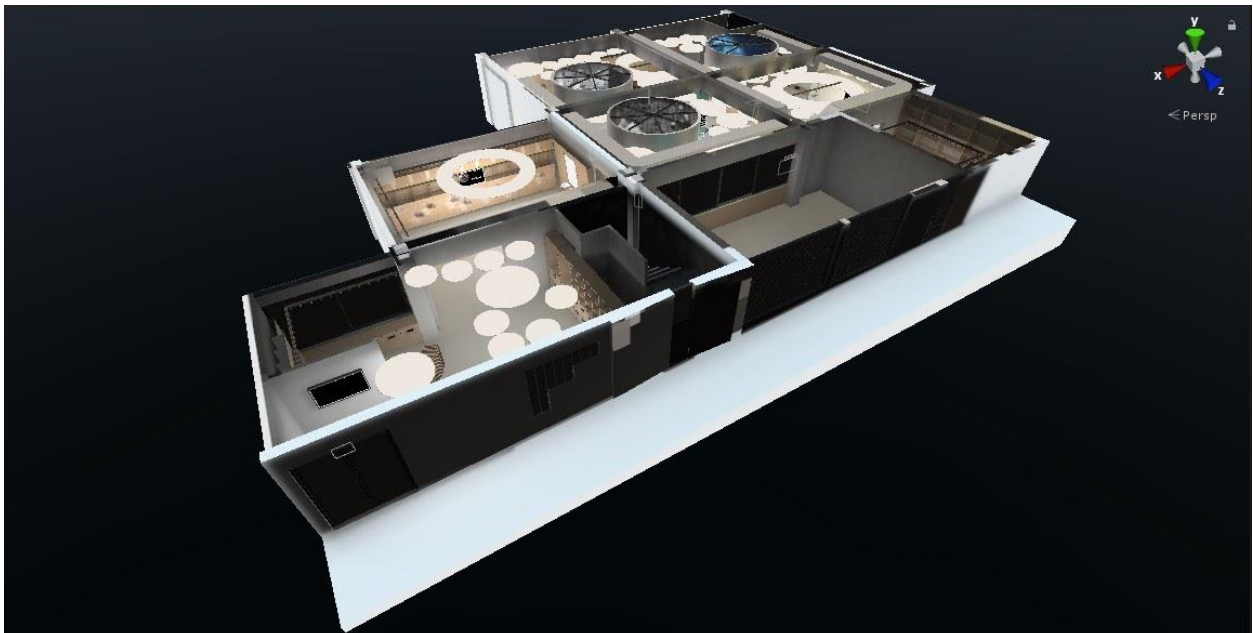


Figure 26: Museum Models with Correct UVs and Baked Lighting

4.2.3 VR Interaction Framework

The VR Interaction Framework [33] was purchased from the Unity Asset Store. This is an online store where developers sell assets like 3D models, textures, animations, audio files, game templates, entire game systems like networking frameworks, dedicated scripts, development tools and many others.

As noted in its page in the Store [34]: “The VR Interaction Framework makes it easy to create your own interactive objects and be productive quickly. This framework will give you the foundation you need to create polished VR experiences”. The framework supports most of the popular VR headsets, such as the Oculus Quest & Rift and the HTC Vive. It also includes prefabs, which are Unity’s special GameObjects packaged with specific capabilities and are ready to be deployed and used multiple times in a Unity scene. This was the reason the framework was selected, that many functionalities were provided and that they could be customized to fit our needs.

Some of the more important interactions offered from the framework are:

- A VR emulator which lets the developer test the project without using a HMD.
- A player rig that has VR cameras, smooth locomotion and teleport movement options.
- Grabbing hands with hand and fingers poses.
- Grabbable and throwable objects.
- Levers, buttons, knobs, doors and other objects that can be operated physically.
- Snap zones for equipping and placing objects.
- User Interfaces that interact with VR rays.
- Weapons (melee and missile) and destructible objects.

Figure 27 shows the player rig and its assisting colliders.

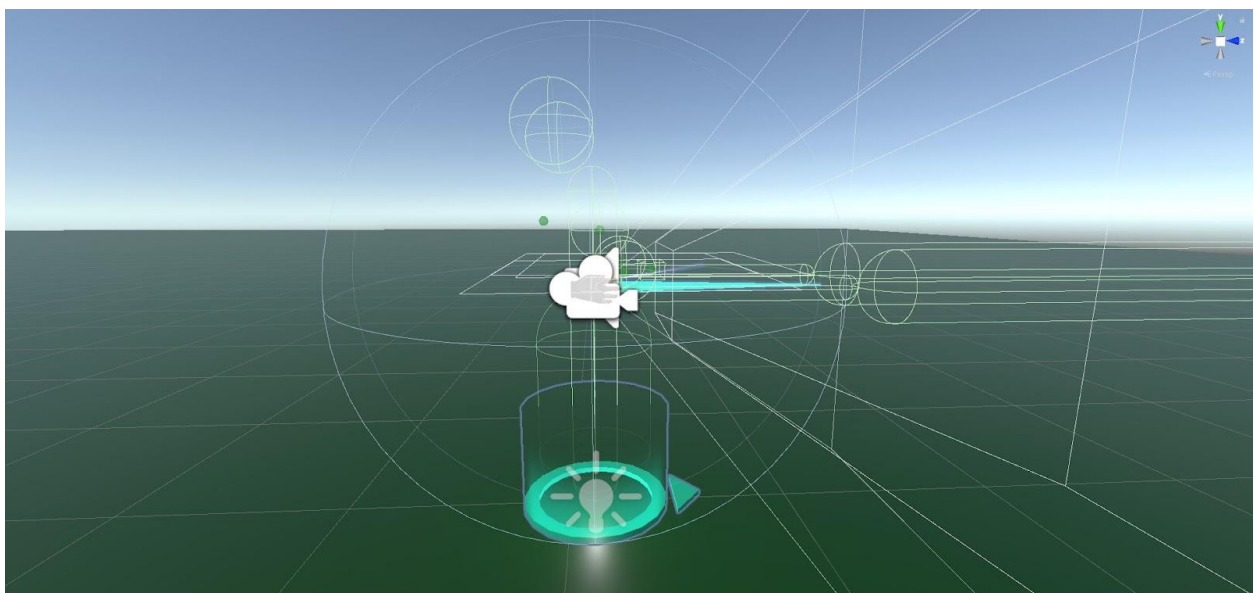


Figure 27: VR Interaction Framework’s Player Rig

4.3 Description of the Virtual MI&T Scenes

The following three sections describe the project's scenes: the tutorial, the main and the three interactive scenes respectively.

4.3.1 Tutorial Scene

After a preliminary round of testing, it was suggested that a tutorial scene should be added to the project, so that users who aren't familiar with the VR technology, can learn the controls and how to interact with the virtual environment.

This scene is essentially a corridor with few rooms, where different controls are explained in each one. The first room is depicted in Figure 28. Important interactions like grabbing objects and pointing & clicking on a User Interface window are shown. If the user is well-versed in the VR technology, they can skip the tutorial and promptly load the main Museum scene.

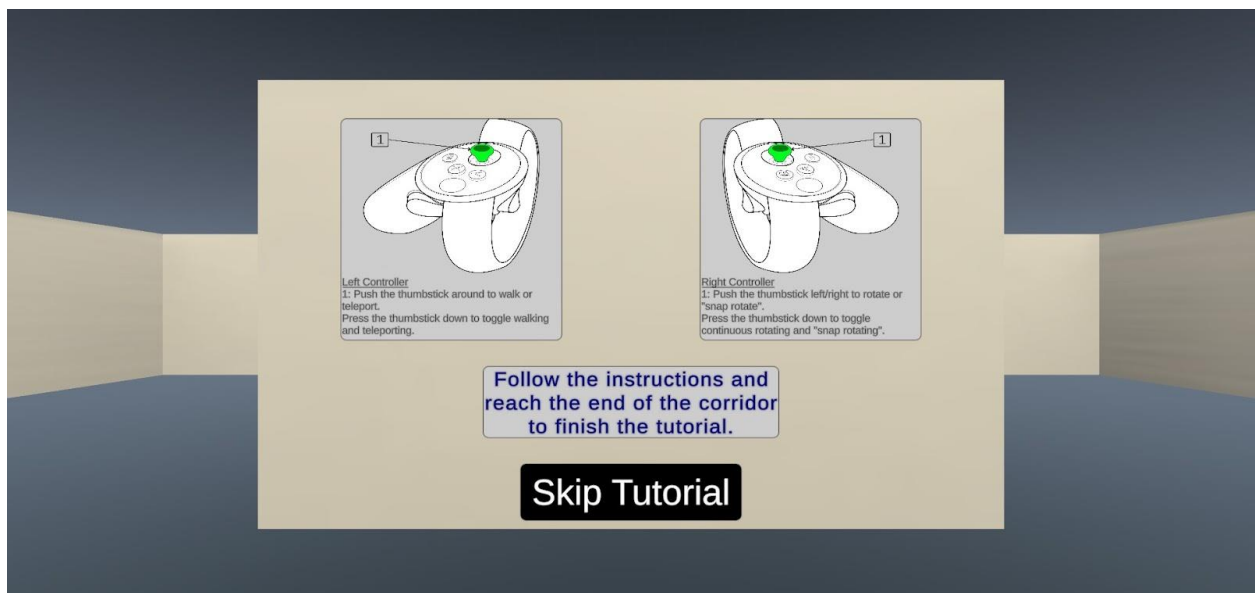


Figure 28: The Tutorial Scene

To further assist the player, the VR rig has been equipped with a tooltip, which can be toggled on and off with the left controller's Menu button, that shows all the controls and explains what is the goal of the current scene (Figure 29).

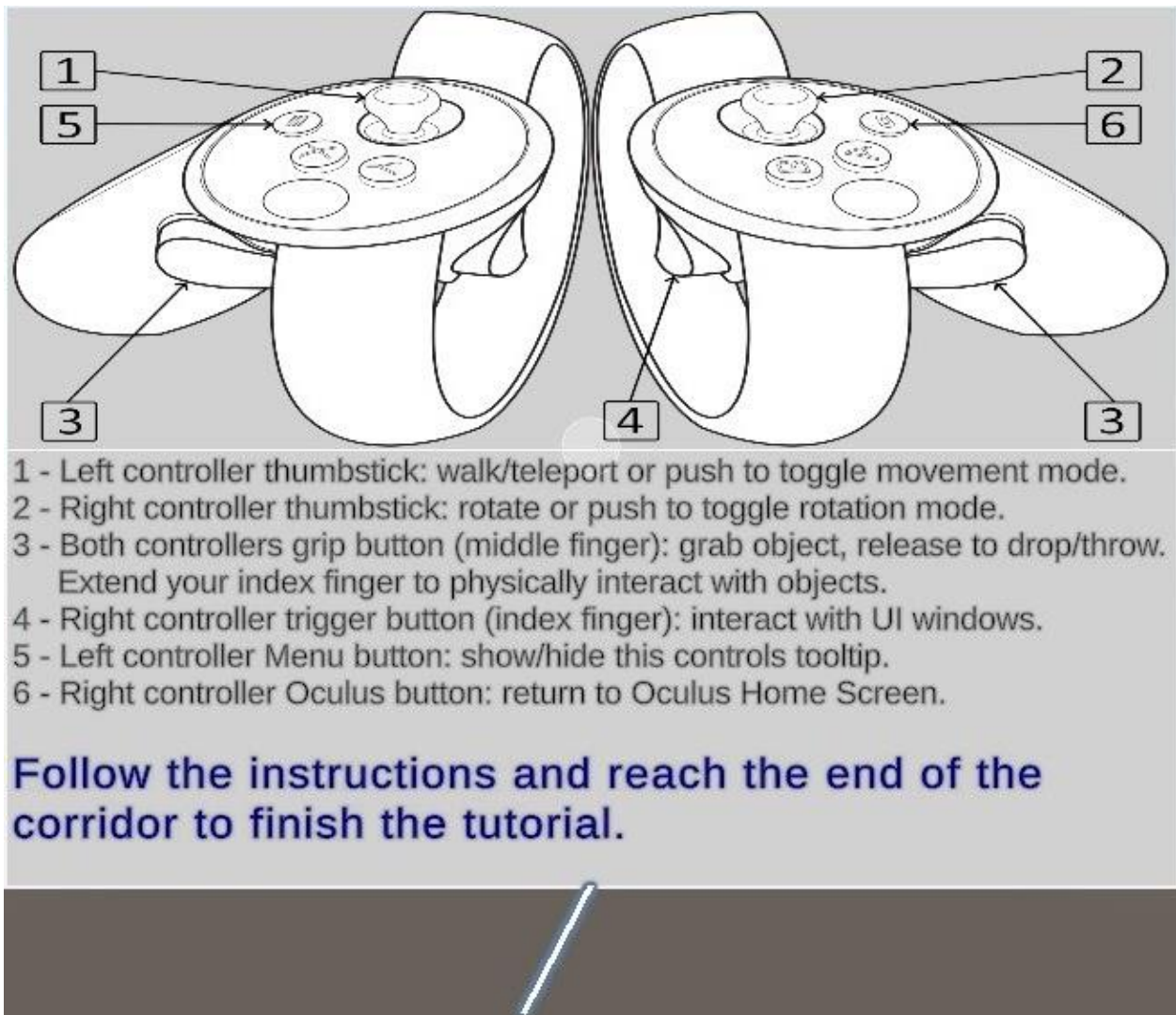


Figure 29: The Tooltip with the Controls and the Scene Goal

When the user reaches the end of the corridor, they should have learnt the controls and should be familiar with the interaction techniques.

In the final room, there is a button to load the main Museum scene which is detailed in §4.3.2.

4.3.2 Museum Main Scene

The Museum main scene is the 'shell' of the project. It acts as the central hub for all the rest scenes that are associated with the time periods of the ICT history. The scene is the VR manifestation and realization of the architectural design that was described in §3.2.1 (shown in Figure 9) and the textured models from §4.2.2.

As outlined previously (§3.2.2), the Museum comprises three separate areas: the lobby, the first and the second chamber. The second is the main room where dedicated spaces, for each of the six time periods, exist. All these, along with the surrounding furniture and devices, were replicated in the Museum's VR environment as 3D models, textured and illuminated.

Figure 30 shows the lobby of the Museum and Figure 31 the first room with its movable timeline device in the center. Figure 32 - Figure 34 are about Room 2's auxiliary areas: the computers prisms, the wall of historical Informatics & Telecommunications time points and the storage room, respectively. Figure 35 through and including Figure 40, illustrate the six important time periods: the Scientific Computer of the 1940s - 1960s, the Business Computer of the 1970s, the Personal Computer of the 1980s, the Networked Computer of the 1990s, the Creative Computer of the 2000s and the Ubiquitous Computer of the 2010s.



Figure 30: Lobby



Figure 31: Room 1 and its Movable Timeline Device

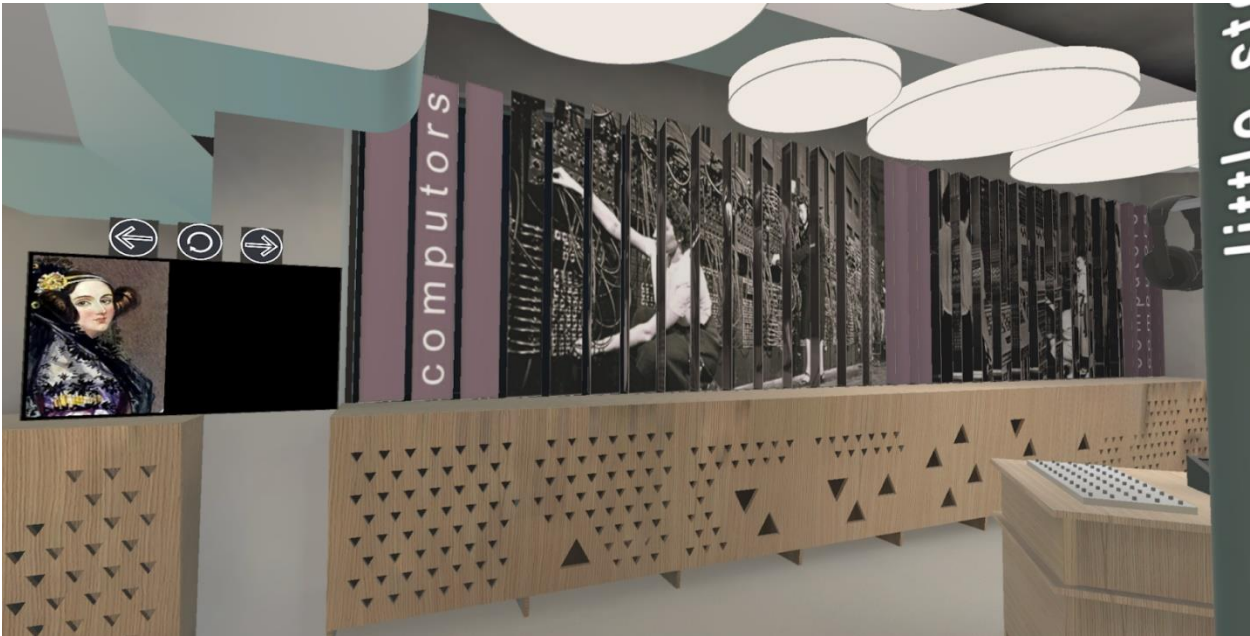


Figure 32: Room 2 – Computers



Figure 33: Room 2 - Wall of Important Time Points for Informatics & Telecommunications



Figure 34: Room 2 - Storage Room



Figure 35: Room 2 - Time Period 1, the Scientific Computer



Figure 36: Room 2 - Time Period 2, the Business Computer



Figure 37: Room 2 - Time Period 3, the Personal Computer



Figure 38: Room 2 - Time Period 4, the Networked Computer

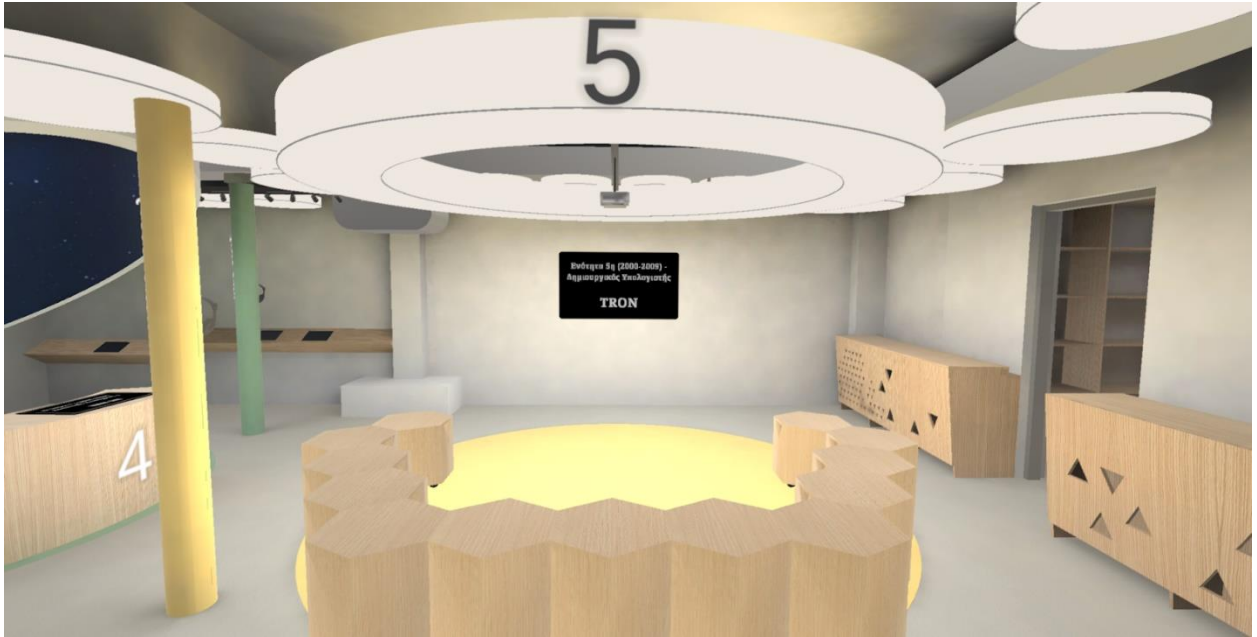


Figure 39: Room 2 - Time Period 5, the Creative Computer



Figure 40: Room 2 - Time Period 6, the Ubiquitous Computer

Four interactive devices have been developed.

- a. The first one is the grabbable timeline device. The user can grab the device with one or both hands and pull it to the left or right. When the device reaches certain positions, then the screen on top of it shows the available information. In Figure 41 we can see that the device's cyan marker, on its top right, rests on the yellow marker of the year 1973. So, the screen finds the corresponding Scriptable Object (Unity's persistent data object), consumes and presents the details which are stored there. The green markers are usually in the first year of the decades - time periods and they also indicate that a video is available and will be shown on the timeline's screen. The timeline can be pulled up to the boundaries shown in Figure 30. The data was retrieved from the coursework of a student team [35].



Figure 41: Interactable Timeline

- b. The second device is a whiteboard along with a marker pen. The player can grab the pen and write or draw on the whiteboard. Its use is fairly intuitive, so there are not any extra instructions. The only exception in the existing interaction patterns, is that the user does not need to hold the grip button continuously; in this particular instance, the button acts a toggle which sets the pen free or grabbed by the hand. That was implemented this way in order to not make the player tired of pressing a button whilst writing / drawing and a tooltip was created ingame as a reminder. Figure 42 depicts the whiteboard, the marker pen, and the buttons which change the pen's settings. The button on the top left erases the whiteboard. The top right button returns the pen in its original position, if, for example, it drops to the ground. The three buttons in the middle row change the marker's tip size. The bottom three buttons change the marker's writing color. The hand that grips the pen is turned invisible, so as not to hinder the visibility of the whiteboard's surface.

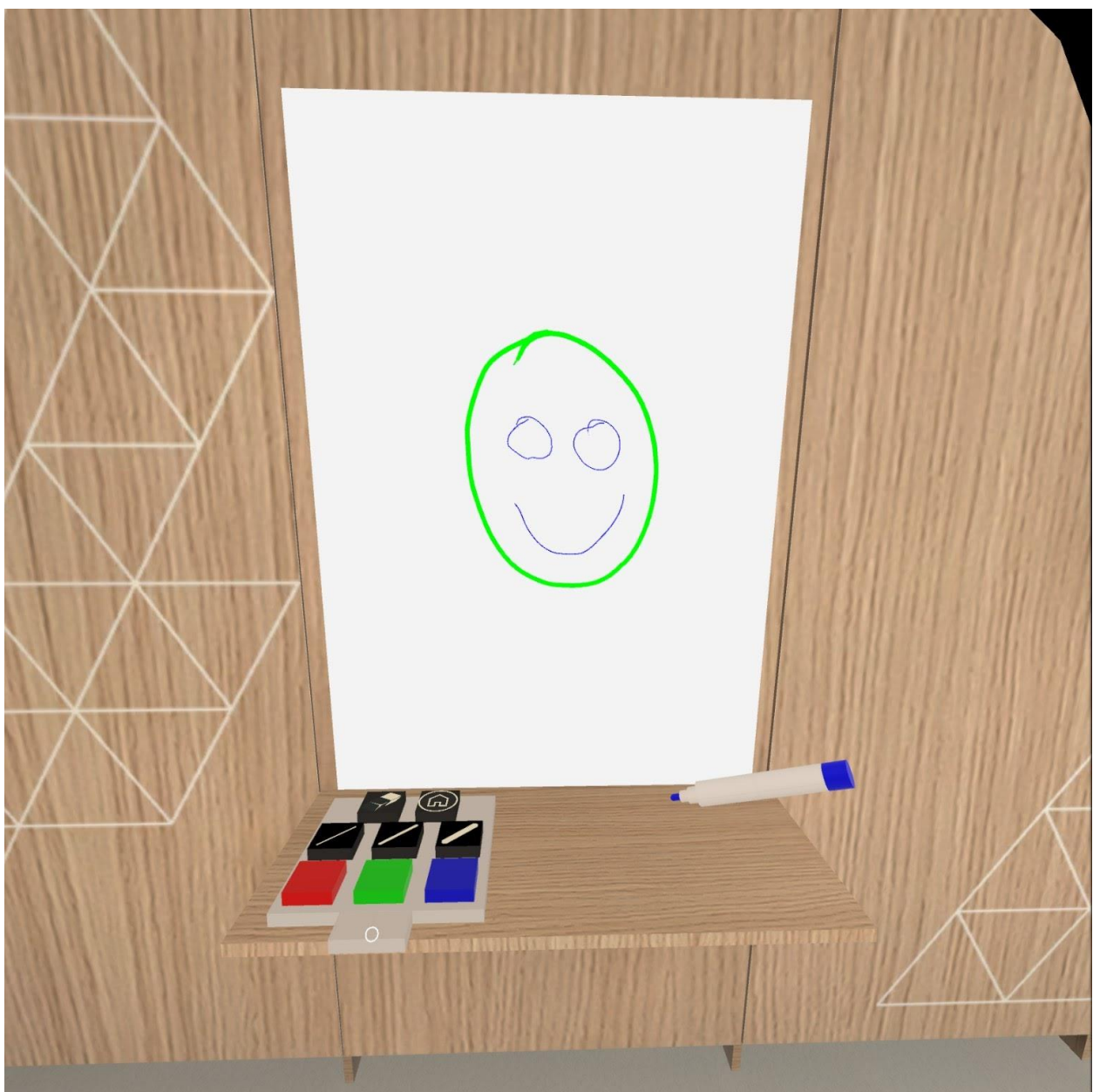


Figure 42: Marker Pen

- c. The last 2 apparatuses are both about the Computers. One is a screen that provides information about them and the other is a series of prisms. The Computers were women that programmed the early computers in the 1940s [36]. Both can be seen in Figure 43. The screen shows data about the first Computers. When the arrow buttons are pressed, the screen loads and displays the information for the next or previous Computer from a corresponding Scriptable Object. The middle button starts a video about the Computers. The data and the video were coursework from the student team [37]. The other device is a series of rotatable prisms which three different sides. For each prism, one side is textured from the top row, one side from the middle row and the last side from the bottom row (see image atlas in Figure 44). The rule is that for the same prism, all sides get the textures parts from the same column. The game is that the user tries to rotate all the prisms in such a manner that the same sides of all the the prisms are faced to them and thus show one image in its entirety.

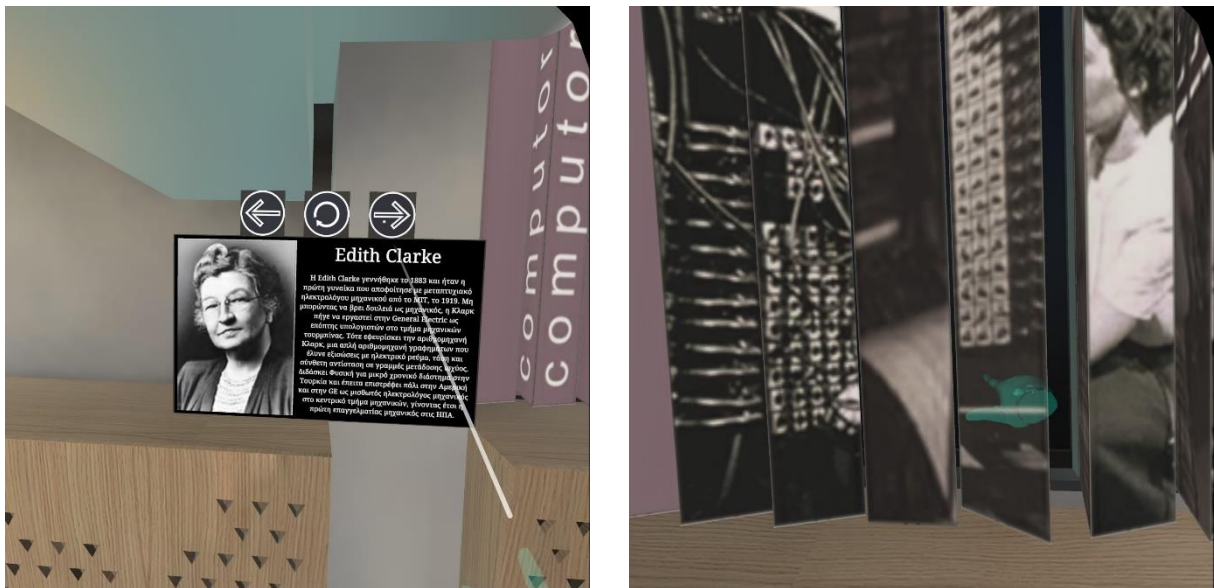


Figure 43: Screen and Prisms About the Computers



Figure 44: Computers Image Atlas

Responsible for correctly positioning the player when they move between scenes, is the Portal Manager GameObject. This manager saves, in the Unity's player prefs, which scene the user visited last. So, when the player does return back to the main Museum scene, this last location is loaded from Unity's player prefs and the Portal Manager moves them in the assigned position. One of these portal positions is demonstrated in Figure 45. The cyan box is where the player VR rig will be positioned and the perpendicular line is the orientation (its forward vector) of the rig. Therefore, in this particular example, when the user clicks on the button to load the "Mixed Reality" scene, this portal location is saved. Afterwards, when the user returns to the Museum scene, the portal location is loaded and the Portal Manager positions them in the location shown in the figure.



Figure 45: Section 6 Portal

Currently, there are also three available mini-games which can be accessed by UI buttons in the appropriate areas. These UIs can be discerned in Figure 38 (of time period 4), Figure 39 (of time period 5) and Figure 40 (of time period 6). Clicking on these buttons will load the corresponding scenes, which are described in the next chapter sections.

4.3.3 Interactive Scenes

These scenes were developed to:

- a. Showcase various technologies, interactions and gameplay elements.
- b. Act as tutorials or starting points for other developers to create new additional scenes, for example students doing a team coursework.

The three mini-games were designed to relate to their corresponding time periods. Therefore, for the 4th time period (the Networked Computer - §4.3.3.1) a multiplayer game, for two or more players, was built using a networking library. For the 5th time period (the Creative Computer - §4.3.3.2), a game about the movie “Tron” was developed. It utilizes modern Machine Learning (ML) techniques, instead of traditional programming. Lastly, for the 6th time period (the Ubiquitous Computer - §4.3.3.3), the created scene includes interactions with state-of-the-art Mixed Reality technologies, trying to showcase their usage in a smart house environment.

As it was mentioned in §4.1.1, the modular design of the project facilitates the creation of countless more scenes, related to the Museum or not, that can be connected to and accessed by the main Museum scene. These scenes could serve as team projects for multiple courses, theses, or even as research projects.

The three, already developed, scenes are analyzed in the succeeding paragraphs.

4.3.3.1 Section 4 - Networked Computer: Bandu

The 4th section / time period is about the Networked Computer. For this reason, the scene about this section is a multiplayer game where several players can join the same room and play together. The game was inspired from the board game “Bandu” [38].

The game’s objective is to stack game pieces on top of the white base on the table, without any of those dropping outside of the base. The players take turns pulling random pieces from the purple magic bag. Each time a player pulls a piece, this is selected randomly from a list of not already pulled pieces. If a piece drops from the white base and touches the table, an error sound will be played and the players should restart the game by clicking on the reset buttons on the table’s corners. In Figure 46, a screenshot of the game can be viewed.



Figure 46: Multiplayer Game - Bandu

The game was developed using the free edition of the Photon Unity Networking (PUN) library [39]. It is preferred by many developers because it offers readily available functionalities for networking GameObjects in the same scene. It also provides hosting servers with private or public lobbies and game rooms. It takes care of disconnecting, reconnecting, latency and scaling issues. Its principal elements are:

- The Photon View. This Component is required to be placed on any GameObject that is to be networked. It assigns a unique View ID, which is an integer number that the network will use to recognize this specific GameObject.
- The Photon Transform View. This Component is designated to a GameObject that its transform (any combination of its position, rotation and scale) must be tracked and synchronized by the network and updated in every client's game scene. So, this is useful for objects that move and rotate and these adjustments need to show in every client. On the other hand, static scene objects may skip this Component since they are loaded when the scene starts and do not have to be updated.

Let's emphasize the last three Components in Figure 47. The Networked Grabbable is a script that inherits from the class Grabbable and the interface IPunObservable. It is collapsed in the screenshot because it is too long. The Grabbable class is from the VR Interaction Framework (§4.2.3) and it makes an object grabbable and interactable through certain functionalities. The IPunObservable interface 'demands' the implementation of the OnPhotonSerializeView function which is called by the PhotonView script to synchronize the object in the network. The Photon View is the essential script of the PUN library, as defined above. It was automatically assigned the View ID 59 which increases when new objects with this Component are added to the scene. The last script, BanduPiece, is a MonoBehaviour which has two main functions, one to teleport the object to the magic bag (when it is randomly selected) and the other to reset it back to its starting position and rotation when the user presses the Reset buttons on top of the table.

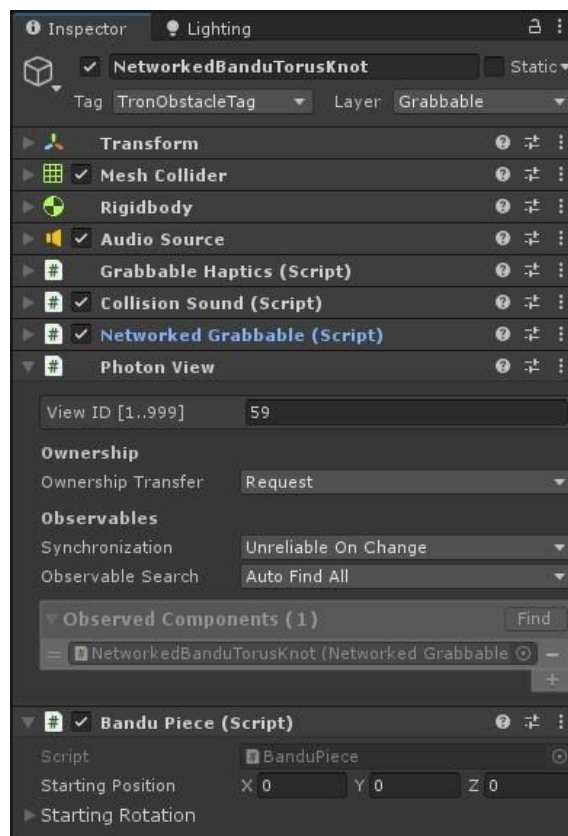


Figure 47: Components of a Bandu GameObject

Figure 48 shows the game pieces that are currently available to be randomly drawn from the magic bag. These are equipped with either primitive Box and Capsule Colliders or with Mesh Colliders for more precise collision detection.

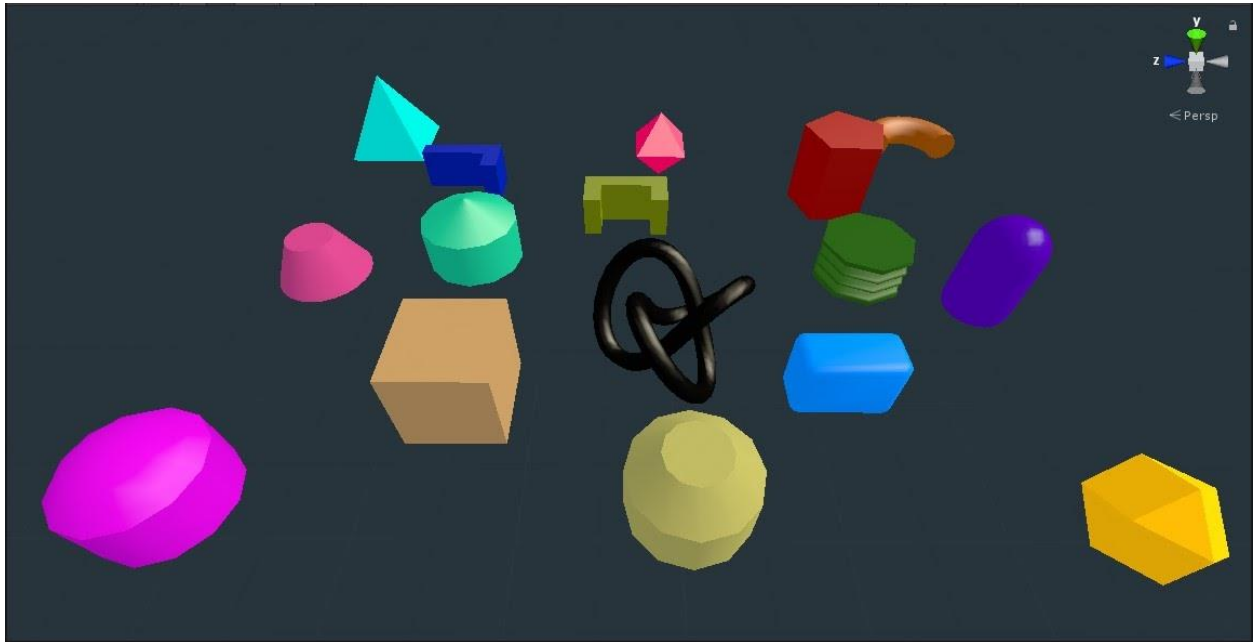


Figure 48: Bandu's Game Pieces

PUN also supports Remote Procedure Calls (RPCs). These are method-calls on other clients in the same room. The caller decides which clients (for example all the clients) will execute this particular function.

4.3.3.2 Section 5 - Creative Computer: Tron

The decade 2000 to 2010 was characterized by the emergence of the Creative Computer. Many industries, related to the Arts, have grown to incorporate and encompass computers in multiple creative ways. Examples are: 3D models in architecture, digital oil painting, computer animated films, computer-aided design (CAD), 3D printer sculpting, painting in 3D space with VR, and more. The inspiration for this mini-game was the movie “Tron” from 1982 which, in like manner, was influenced from the video game “Pong”. This film was selected as a theme for the game because it was one of the first films that made extensive use of computer animation [40].

The developed game has the player compete against three (green, red, purple) non player characters (NPCs), which will be called as agents thereafter. Every agent is riding a Tron bike which leaves a solid trail, of identical color, behind it. All bikes are moving at the same speed and the driver can only perform a 90-degree turn to their left or right. The objective of the game is to be the last rider alive. The player and the agents ‘die’ when they crash to any other solid object such as the level boundaries, the red obstacles, the trails from the other bikes, or even to the other bikes themselves. Therefore, the human player should try to both evade the enemy bikes & trails and at the same time try to cleverly use their trail to entrap the opponents leading them to crash. If the player ‘dies’, then they are asked if they want to start over. The gameplay is comparable to the game “Snake” [41]. A screenshot of the game can be seen in Figure 49:

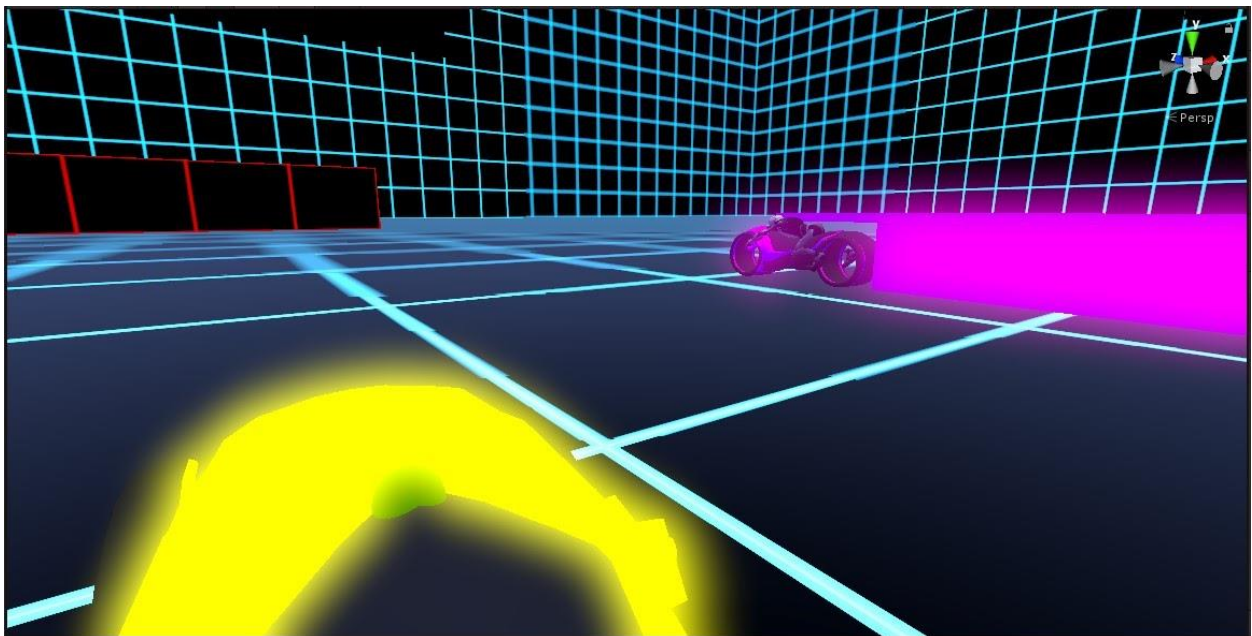


Figure 49: Tron Gameplay (Editor View)

In this Figure, we can distinguish the yellow bike which is always the human player. There is a small green sphere on top of the bike, which acts as a visual cue for informing the player if they can turn or not. When it is green, the player may turn, otherwise when it is red, no turning is possible. The rule is that the minimum time between two consecutive turns is 0.5 seconds. This rule is obeyed by all three computer-controlled agents too. The red obstacles are also discerned in the image, which are randomly positioned and scaled every time the mini-game restarts. Finally, we can identify one computer agent (the purple one), as well as the trail that it leaves behind it as it drives along.

Figure 50 is a screenshot taken from playing in a VR device.

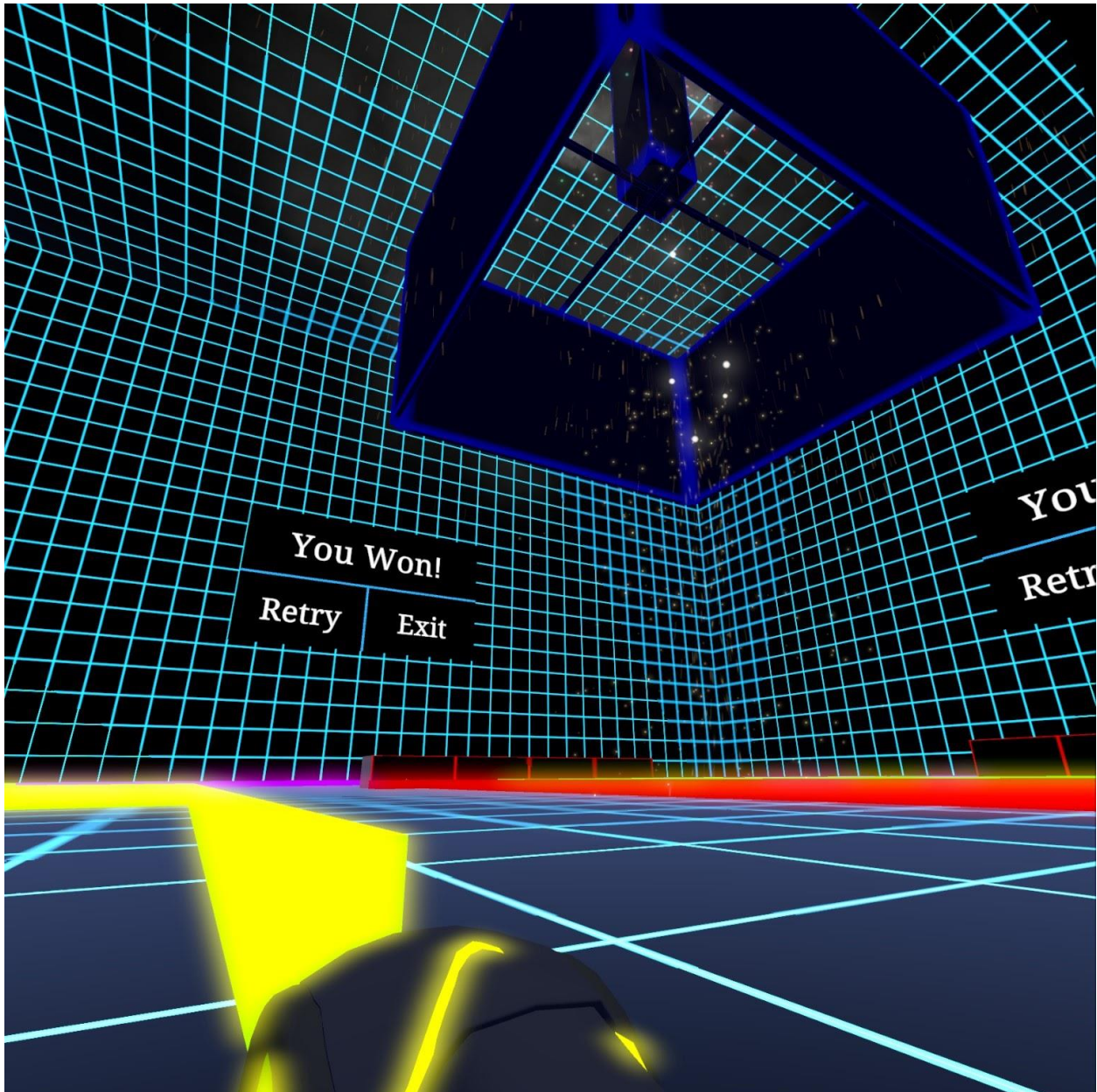


Figure 50: Player Wins (Ingame VR View)

Experiencing it in VR is more exciting since the user can rotate their head and watch the entire level for incoming enemies. This is also assisted by the fact that the agents have an Audio Source Component which plays a 3D spatial humming sound, imitating the sound of the bike's engine, thereby warning the player when they get close. In Figure 49, the user has won and fireworks have been set off in the center of the arena. The UI screens on all four walls let the player decide to play again or exit.

But the most important thing in this game is how the computer agents are driving. A traditional Artificial Intelligence (AI) approach would be to set human-designed driving rules, for example, the agent should check the distance to the closest wall and then decide to turn to avoid colliding there. Instead, we decided to use a more modern and sophisticated technique that lets the agents learn how to drive: Machine Learning and specifically Reinforcement Learning.

4.3.3.2.1 ML-Agents and Reinforcement Learning

Unity released the first beta version of its Machine Learning package, ML-Agents, on 19 September 2017: [42] and [43]. This is an open project that provides a Python API which uses several ML methods, such as reinforcement learning, imitation learning, neuroevolution, to train intelligent agents to behave and make decisions inside a Unity created environment. Several algorithms are provided for these methods. The current (September 2021) stable release version is “Release 18”. The steps to install and use the package are detailed in Appendix III.

Machine Learning is considered, in general, the scientific study of algorithms and statistical models that help us build computers that perform a particular task by learning from its environment and without being explicitly programmed by humans [44].

In our case, we have used Reinforcement Learning (RL) [45] which uses a reward function that rewards the correct actions or punishes the wrong ones of the agents. An agent, besides a set of allowed actions, also has a set of defined states. The possible states are mapped to possible actions through a policy. Finally, a model is the environment’s representation and based on it, a Neural Network (NN) will be created and trained that will be responsible for making the decisions in runtime. So, an agent will use RL to learn, by observing the environment and getting rewards for certain behaviors, how to update its NN in ways so as to get the maximum rewards. ML-Agents use the Proximal Policy Optimization (PPO) algorithm [46] which optimizes the agent’s decision so they earn the highest cumulative reward over time.

In summary, these are the steps of using ML-Agents:

1. Initialization phase: define target behavior and task. Its building blocks are:
 1. Observations from the environment.
 2. Actions, what is the agent allowed to do.
 3. Reward signals, positive or negative rewards for specific events ingame.
2. Training phase: train the agents to complete the target task by using the optimal actions to maximize the reward. A model, or brain as it is called in Unity's ML-Agents, will be created.
3. Inference phase: the agent uses the trained brain and its corresponding learned policy to complete the task and play the game in Unity.

These steps are illustrated very elegantly in this diagram (Figure 51), borrowed from [47]:

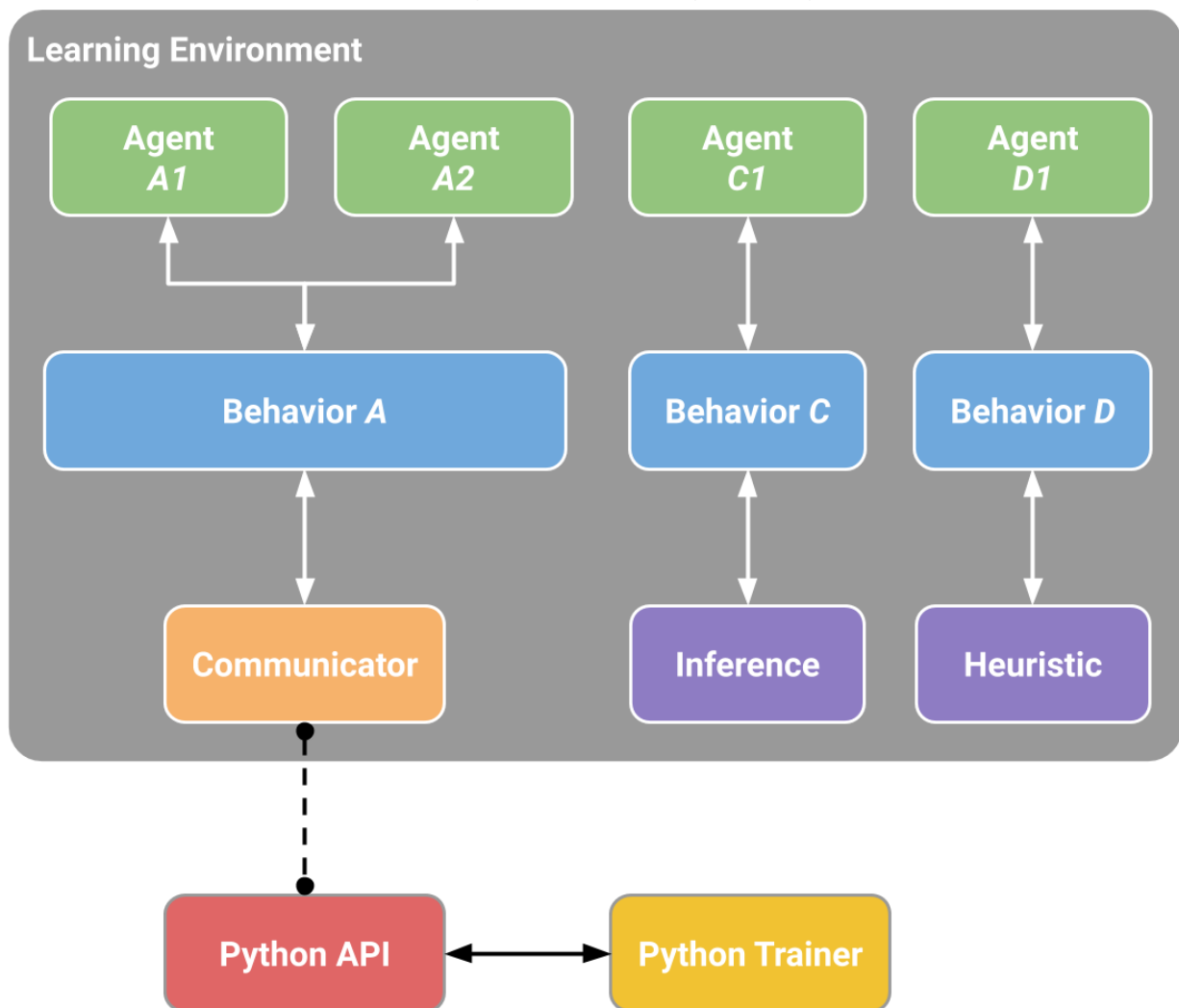


Figure 51: ML-Agents Learning Environment

Agents A1 and A2 are currently training, whilst agent C1 uses a trained brain to behave, and agent D1 is controlled by the user with a heuristic function (it is detailed in the end of this section).

So, in our Tron mini-game, first, we set up the agent with a Ray Perception Sensor 3D Component (see Figure 52) which casts rays 70 degrees to the left and to the right of its forward vector. These sensor rays will assist the agent interact with the environment, for example it will know that an obstacle (if tagged that way) is in front of it.

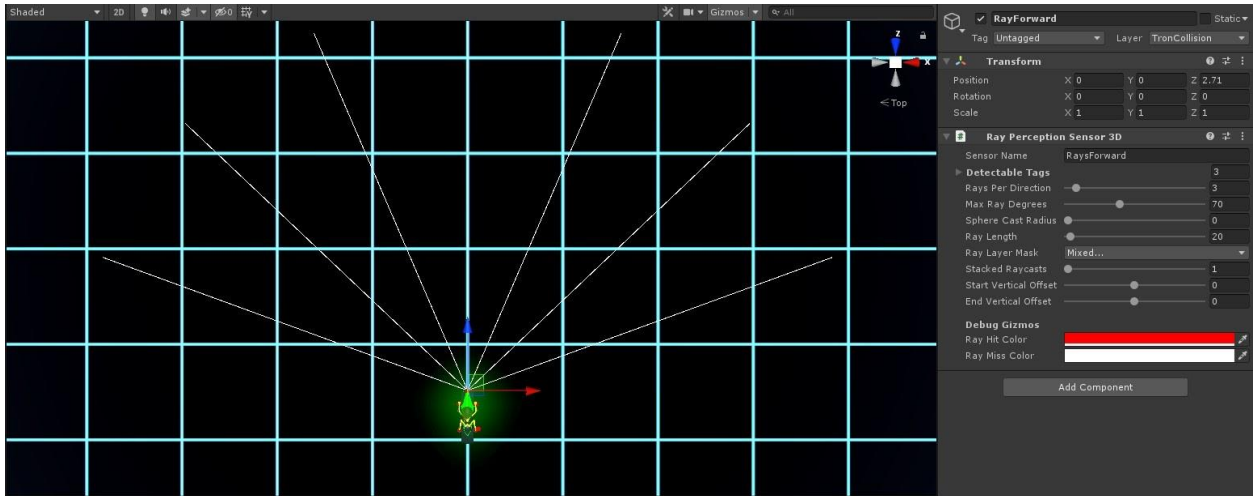


Figure 52: Agent’s Ray Perception Sensor 3D Component

The red agent, specifically, uses another mode of perception: the Grid Sensor (Figure 53) which provides information about the environment captured from the grey grid that moves along the agent.

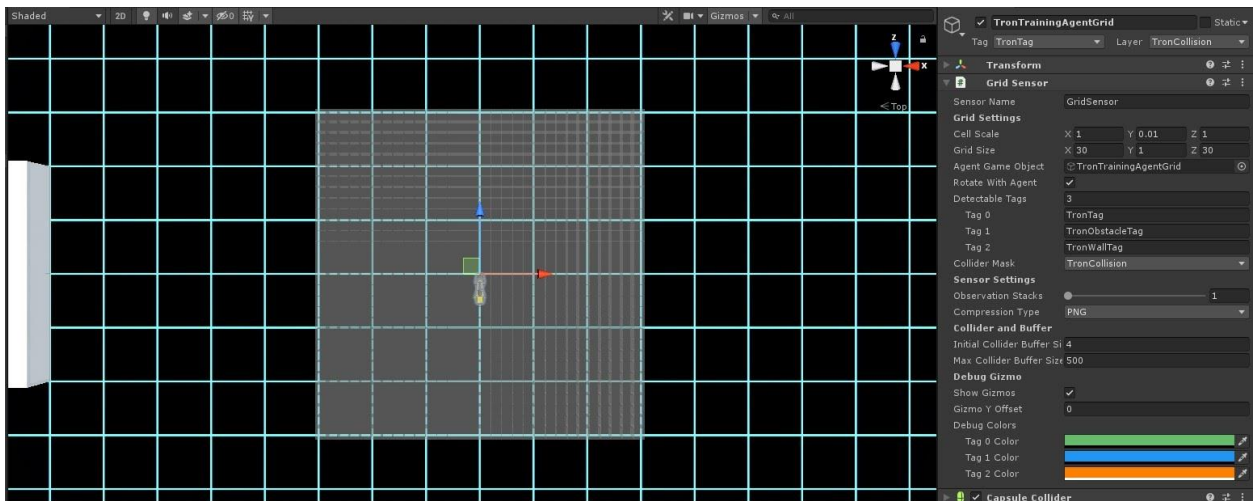


Figure 53: Agent’s Grid Sensor Component

The agents are also equipped with the following Components: Behavior Parameters, Decision Requester and Tron Single Player (Figure 54).

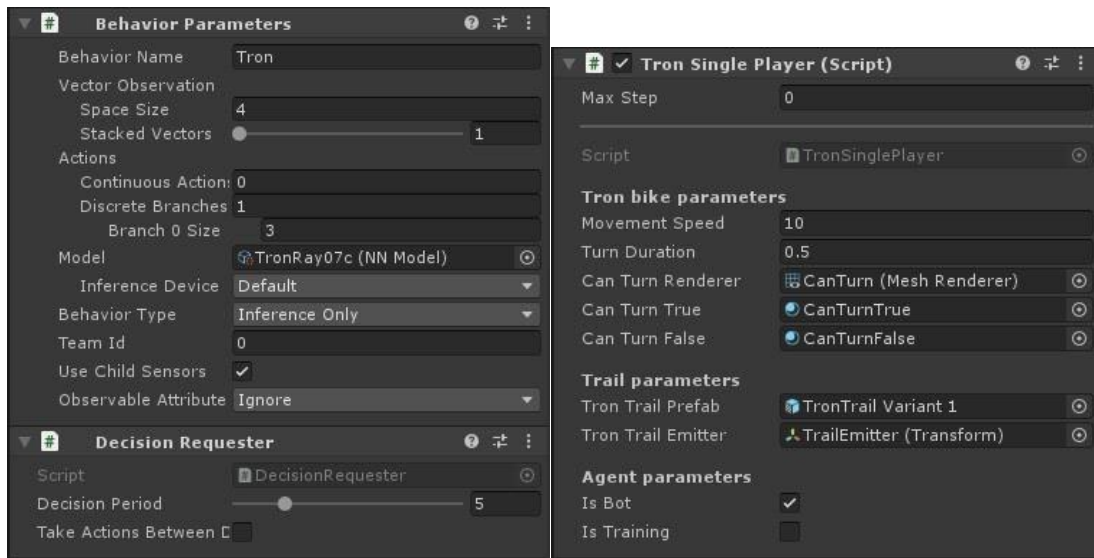


Figure 54: BehaviorParameters, DecisionRequester and TronSinglePlayer Components

The Behavior Parameters assigns a model / brain to an agent. This is the trained Neural Network that will make the decisions in the runtime. The behavior type is if the agent is in training or inference mode. The Observation Vector defines how many observations should the agent keep and update; it is 4 because it needs 1 float for the agent's rotation around the y axis value (which is its heading), and 3 floats for its Vector3(x,y,z) position. The Actions is an array of 3 discrete integers, which will be further explained after the reward rules.

The Decision Requester asks from the NN Brain of the Behavior Parameters to make decisions every 5 Academy Steps.

The Tron Single Player is our own script. It inherits from the base class Agent, the principal class of the ML-Agents package. Its Max Step is 0, because it is currently set in inference mode. If it were in training mode, then the Max Step could be 5000 which means that this particular agent would make 5000 steps before restarting the training episode. The Movement Speed is the bike's continuous speed. The Turn Duration (0.5 seconds) is the minimum time between two consecutives turns. Therefore, the player and the agents cannot make two turns in a time less than this. The Can Turn Renderer and the two materials are for the green / red sphere on the Tron bike that visualizes this rule. Then there are the parameters for the trail, the prefab instantiated and the emitting position in the back of the bike. Finally, there are two boolean parameters defining if the agent is a bot or a player, and if it is training or not. This script is using:

1. information from the environment (Ray Perception or Grid Sensor Component),
2. agent self-observations: heading and position (Behavior Parameters),
3. the 3 discrete actions from the NN Model (Behavior Parameters)

to perform an ingame action, such as turning to the left, and also to add a positive or negative reward (if training). So, in the beginning, the agent will start taking random actions, while always collecting observations from the environment and itself. To facilitate

the agent's learning procedure, we have set these rules (given that: i.1 action it taken every 5 steps and ii. 1 training step happens every 1 Unity's fixed timestep which, generally and at this project, is 20 milliseconds):

- a. If it moves forwards, it should get a positive reward of: 0.1.
- b. If it turns to the left, it should get a positive reward of: 0.001.
- c. If it turns to the right, it should get a positive reward of: 0.001.
- d. If it collides with the arena's boundaries, it should get a negative reward of: -0.9.
- e. If it collides with the arena's red obstacles, it should get a negative reward of: -0.9.
- f. If it collides with another Tron bike, it should get a negative reward of: -1.0.
- g. If it collides with its own trail, it should get a negative reward of: -0.7.
- h. If it collides with another agent's trail, it should get a negative reward of: -0.8 and give to this agent a positive reward of: 0.5.

The reward values are inside the [-1,1] range, as advised by the ML-Agents package's creators.

If all the agents collide or the Max Step value (for example 5000 training steps) is reached, then a new training episode will begin. Therefore, after the initial random actions, the agent will slowly begin to learn that going straight gives it more positive reward than turning; this was set that way to imitate human behavior where most of the time people follow a straight path and only turn to evade an obstacle. Moreover, it will also learn that it should prefer to turn (a small positive reward) than collide with anything (since a collision is always a negative reward). It should try to never hit another bike (because both will lose) and the level's boundaries and red obstacles. The smallest negative reward is suicide (hitting its own trail) which should be preferred than hitting an enemy's trail because in this case the other agent will also get a positive reward.

The NN Model does not understand notions as turn left or go straight. It only understands the values in its Actions array (with discrete values in our case). So, it learns that the action with the integer value of 0 gives it the biggest positive reward (going straight) and that the actions with values of 1 (turn -90 degrees) and 2 (turn 90 degrees) give it the same amount of positive reward, which is smaller than the amount from 0, but is preferable than crashing into something (negative reward). So, it learns how to optimize these available actions in order to maximize the yielded reward. At the same time, these actions are translated to ingame actions, such as turn 90 degrees. A last note, the Tron Single Player script provides a Heuristic function, that is used when the agent's Behavior Type is set to "Heuristic Only" mode, and will then take over the control of the agent (for example with input from the keyboard) instead of the NN.

4.3.3.2.2 Machine Learning Training Project

The AI agents, described in §4.3.3.2.1, are driving themselves using a NN which was trained in a separate project. The training did not transpire in our original Museum project because of these two reasons:

- The Model of the NN is just one .onnx file. It does not seem good practice to pollute our original project with hundreds of files and megabytes for just one output file.
- It was easier to clone the ML-Agents project from the github and then use it as a base for our specific needs, since it contains many examples for both mini-games and training configuration .yaml files.

So, we created a new scene and started experimenting with the examples. We tried the following types of learning which were not a good match for our needs:

- a. Imitation Learning (IL). This area of Machine Learning is used when a human user demonstrates how the agent should play the game. Then the NN learns based on this behavior and not on a reward-giving policy as in Reinforcement Learning. The downside of this method is that it needs a lot of human-involved time, whereas our RL game was left alone training for up to 6 hours per training session. IL can also take advantage of multiple humans teaching the NN, which could be an excellent team coursework project in the future.
- b. Curriculum Learning (CL). Here, a task is learned gradually, starting from a low level of task difficulty and raising it to keep the model optimally challenged always. It needs some kind of parameters that can change value and thus modify the difficulty. There are not such parameters in our case, so this method was not pursued further. But it could work, if some gameplay elements would change, for example, the moving speed of the Tron bike, the minimum duration between two consecutive turns, the number of the agents or the number of the red obstacles in the scene and-so-forth.
- c. The GridWorld example of ML-Agents. Its Behavior Parameters include a Visual Observation of the scene from a camera's top-down view, which is used to identify the goal and the obstacle. This method of operation cannot work in our enormous scene, because if the camera was positioned high enough to capture the entire space, then no details would be visible for recognition, as shown in Figure 55 (top view) and Figure 56 (side view):

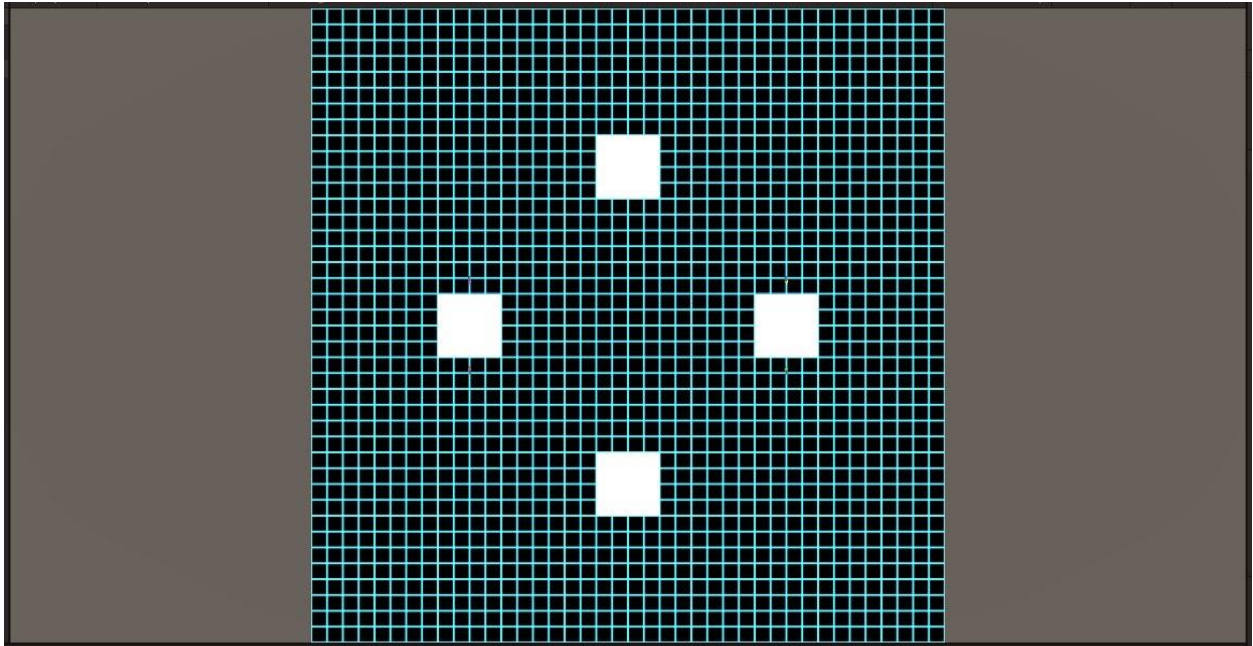


Figure 55: Top View from Orthographic Camera; No Trails / Bikes Are Visible

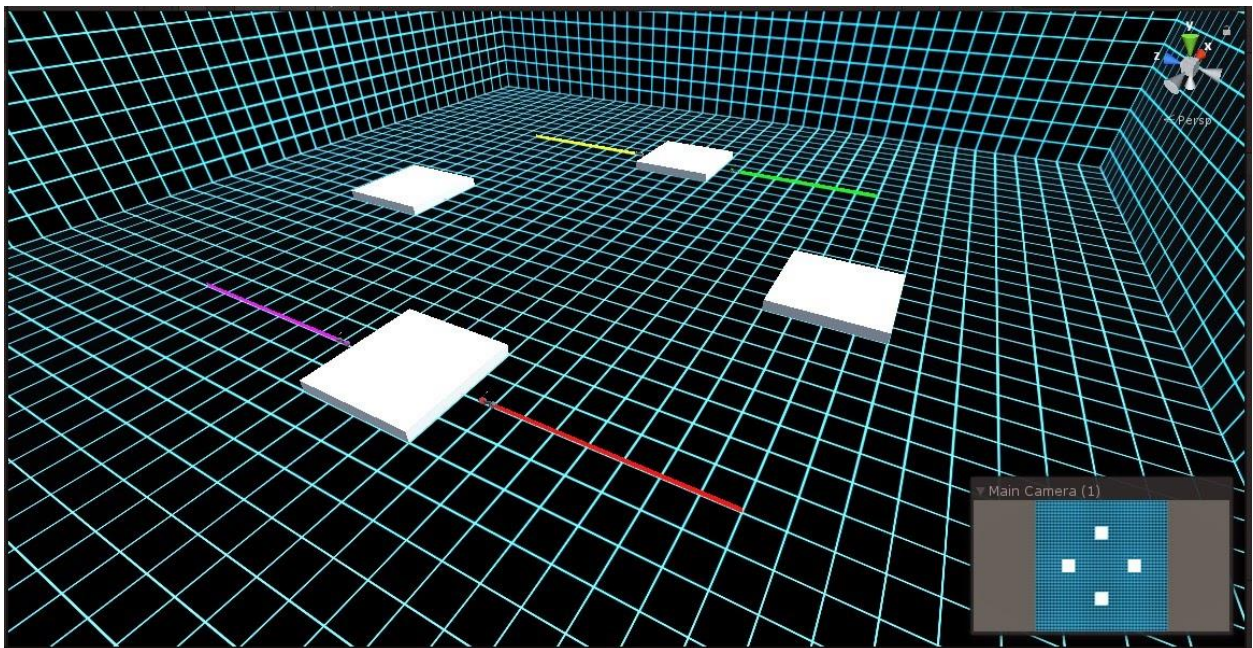


Figure 56: Side View from Perspective Editor Camera; Trails Are Visible

Therefore, our conclusion was to use Reinforcement Learning with two different types of environment perception: with a Ray (Figure 52) and a Grid (Figure 53). The red agent uses the Grid while the other two use the Ray.

We started with just a single agent using the Ray Sensor and afterwards we were adding extra features, watching the agents' training every time. The first training scheme was one agent without a trail. It learned how to avoid the obstacles and the bounds (Figure 57). We use nine training environments (only six show up in the figures), to speed up the training procedure, due to parallelization.

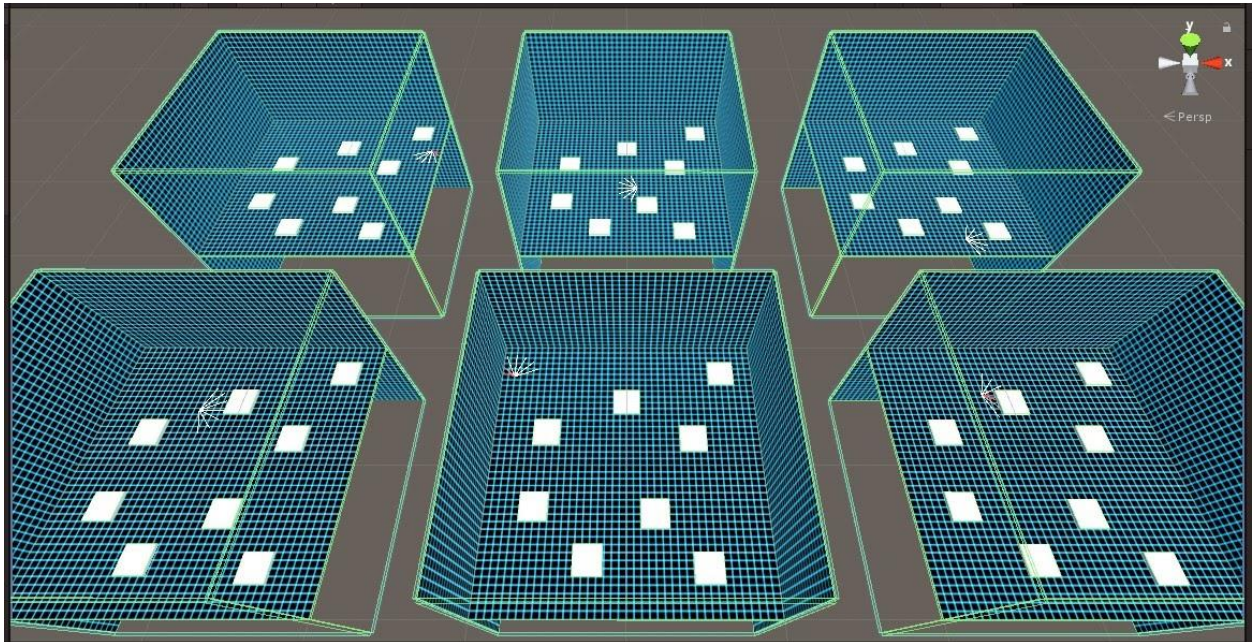


Figure 57: Training of Single Agent, No Trail, Ray Perception, Static Obstacles

Afterwards, we made the obstacles randomly change position and size to help against ML's overfitting problem (Figure 58):

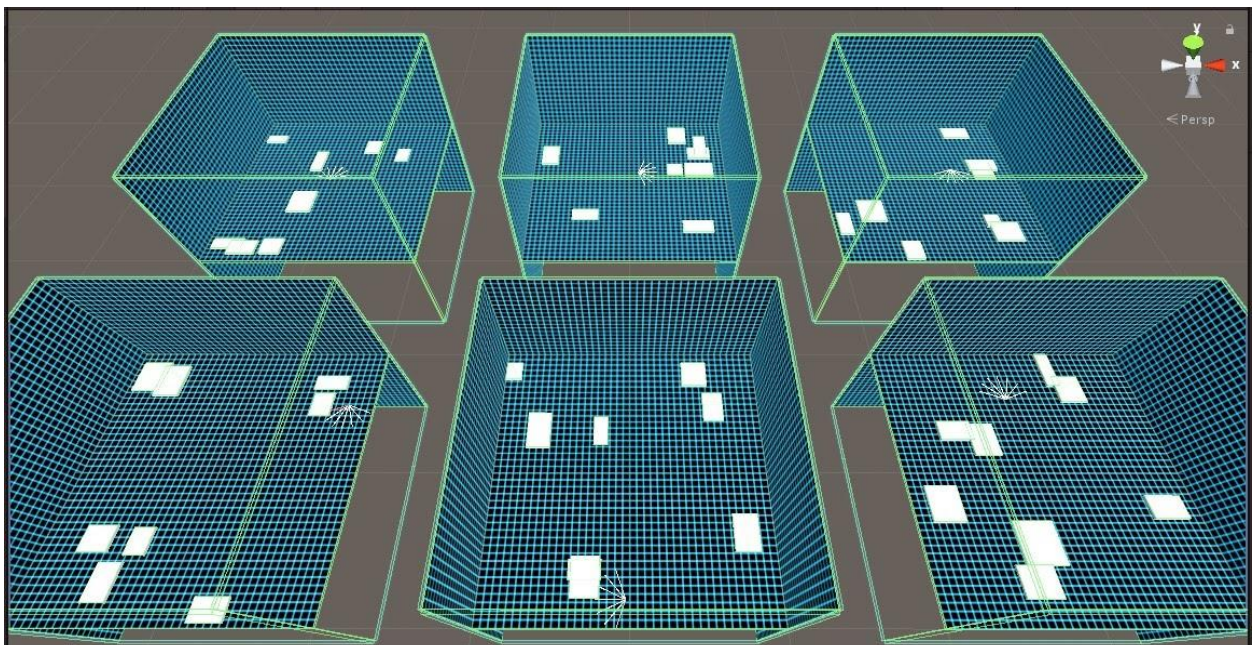


Figure 58: Training of Single Agent, No Trail, Ray Perception, Randomized Obstacles

Then we added a trail behind the Tron bike, which the agent should also circumvent (Figure 59):

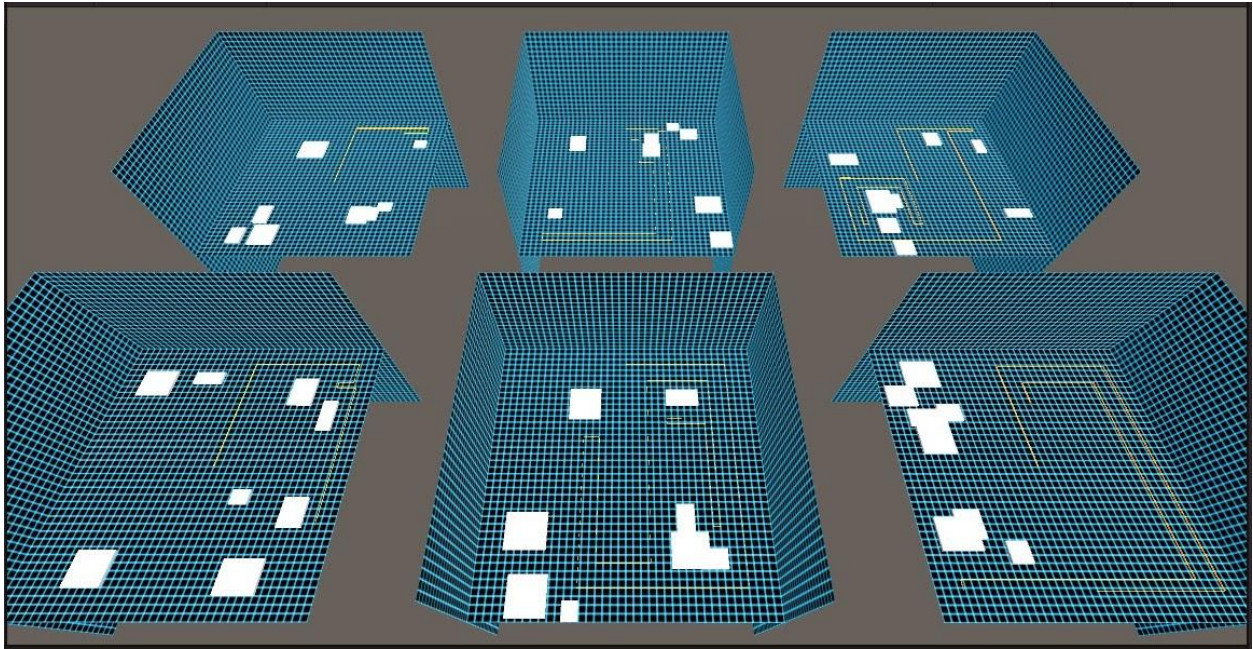


Figure 59: Training of Single Agent, with Trail, Ray Perception, Randomized Obstacles

Subsequently, the number of agents was increased to four: a yellow, a green, a purple and a red. This was the finalized setup (Figure 60), in which, thereafter, we only changed some configuration parameters values (Appendix IV), trying to find the optimal behavior.

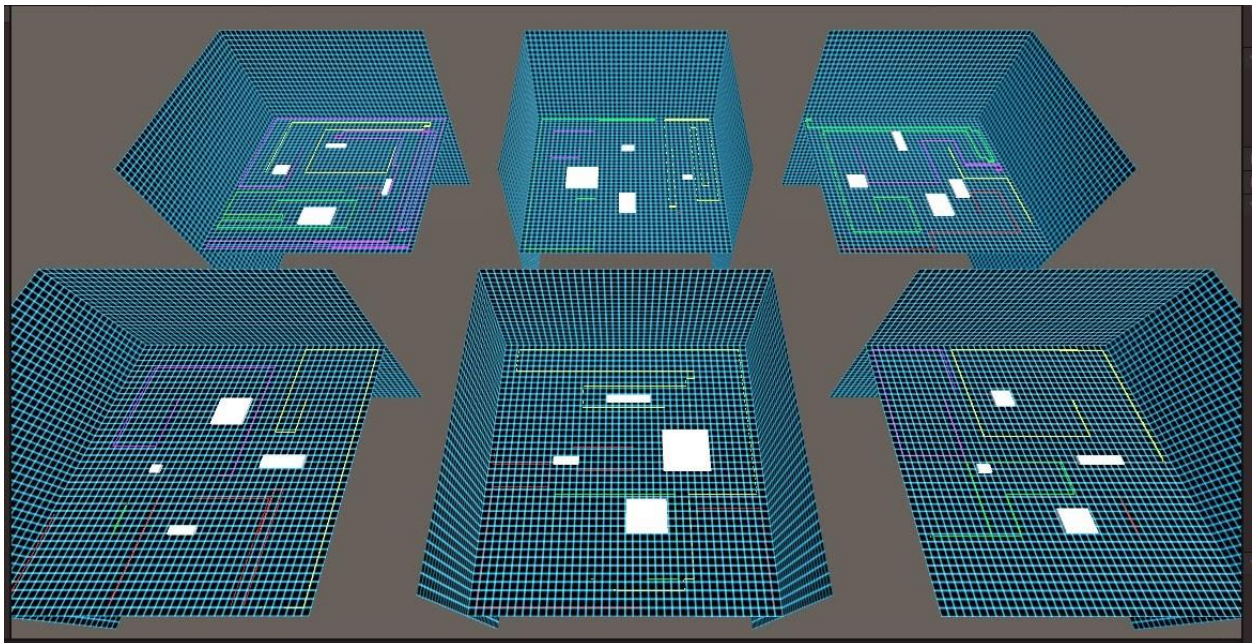


Figure 60: Training of Four Agents, with Trail, Ray Perception, Randomized Obstacles

Let us also show Figure 61, where the agents learned to hit their own trail (it's more obvious in the top right environment), because of a mistake in our reward policy, where a positive reward was assigned in the suicide case, instead of a negative one.

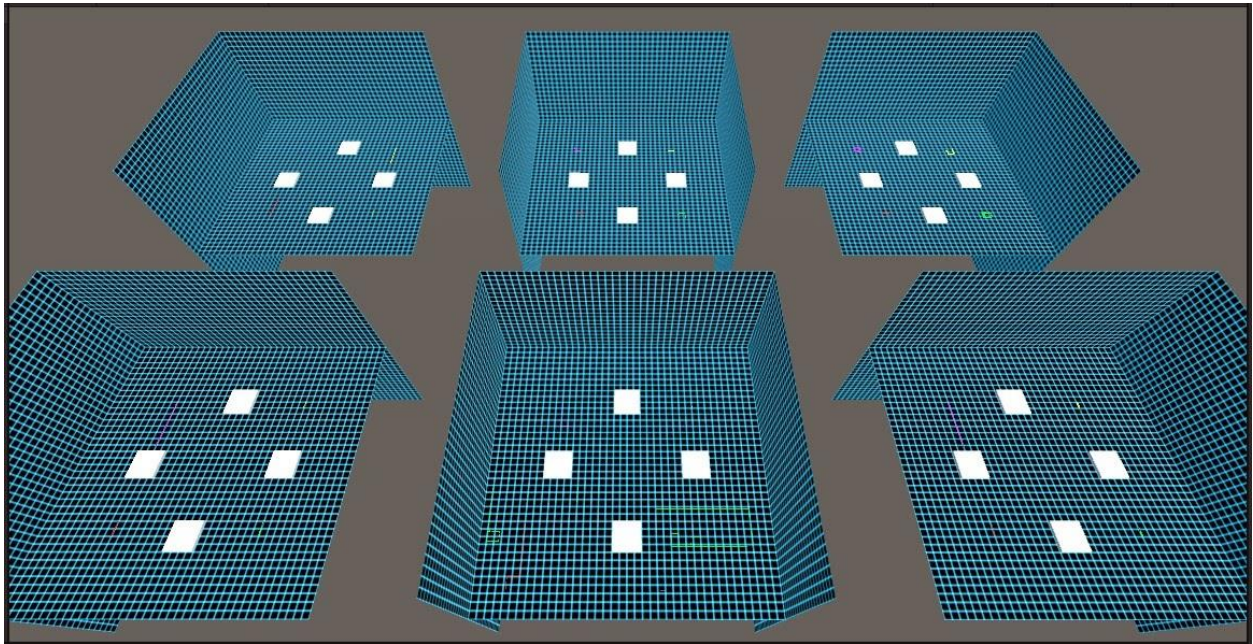


Figure 61: Wrong Training of Four Agents Hitting Their Own Trails

The same training procedure was followed for agents with the Grid Sensor. The only difference is that because the grid is more processor intensive than the rays, the training scene includes four parallel training environments, see Figure 62:

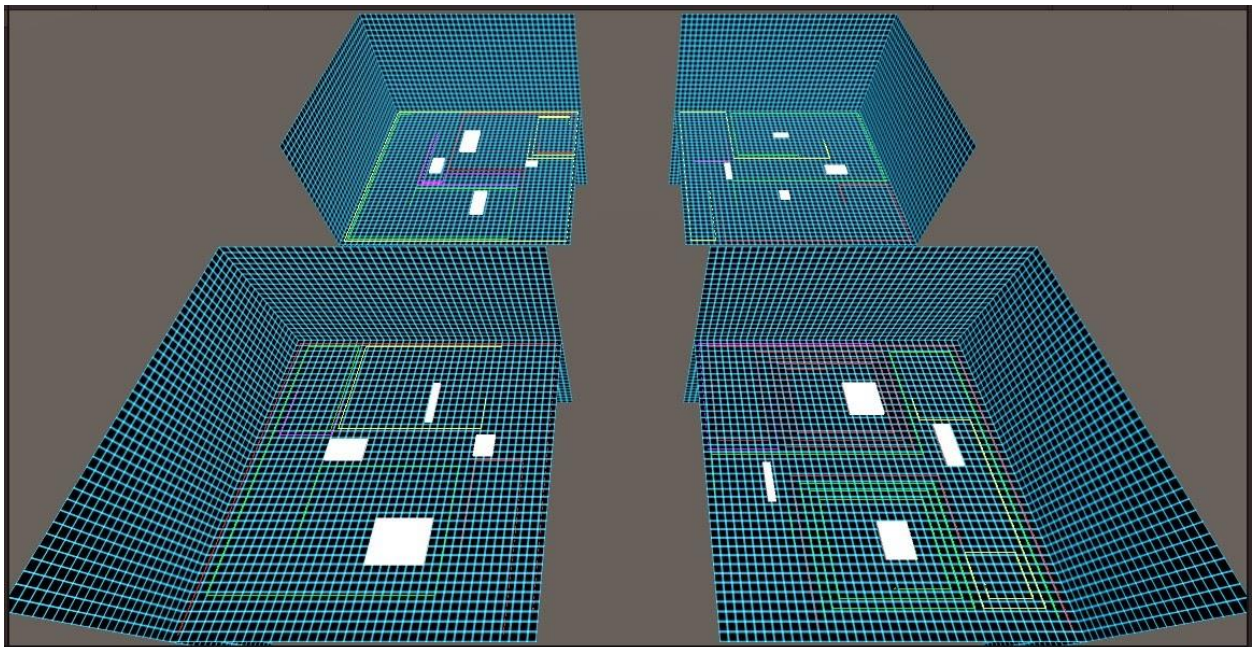


Figure 62: Training of Four Agents, with Trail, Grid Perception, Randomized Obstacles

This is a screenshot (Figure 63) of the console for an ongoing training session. The output is every 50.000 steps.

```
Administrator: Anaconda Prompt (Anaconda3) - conda install pytorch torchvision torchaudio cpuonly -c pytorch
[INFO] Tron. Step: 50000. Time Elapsed: 114.264 s. Mean Reward: 18.799. Std of Reward: 16.574. Training.
[INFO] Tron. Step: 100000. Time Elapsed: 223.020 s. Mean Reward: 34.576. Std of Reward: 14.534. Training.
[INFO] Tron. Step: 150000. Time Elapsed: 335.167 s. Mean Reward: 36.780. Std of Reward: 13.288. Training.
[INFO] Tron. Step: 200000. Time Elapsed: 444.598 s. Mean Reward: 41.081. Std of Reward: 10.633. Training.
[INFO] Tron. Step: 250000. Time Elapsed: 555.100 s. Mean Reward: 43.864. Std of Reward: 5.764. Training.
[INFO] Tron. Step: 300000. Time Elapsed: 664.385 s. Mean Reward: 40.297. Std of Reward: 11.699. Training.
[INFO] Tron. Step: 350000. Time Elapsed: 774.529 s. Mean Reward: 42.120. Std of Reward: 8.982. Training.
[INFO] Tron. Step: 400000. Time Elapsed: 884.369 s. Mean Reward: 41.726. Std of Reward: 9.625. Training.
[INFO] Tron. Step: 450000. Time Elapsed: 992.838 s. Mean Reward: 43.204. Std of Reward: 8.607. Training.
[INFO] Tron. Step: 500000. Time Elapsed: 1102.250 s. Mean Reward: 41.670. Std of Reward: 10.153. Training.
[INFO] Exported results\Tron14\Tron\Tron-499973.onnx
[INFO] Tron. Step: 550000. Time Elapsed: 1212.577 s. Mean Reward: 44.106. Std of Reward: 5.893. Training.
[INFO] Tron. Step: 600000. Time Elapsed: 1322.734 s. Mean Reward: 43.646. Std of Reward: 5.367. Training.
[INFO] Tron. Step: 650000. Time Elapsed: 1431.837 s. Mean Reward: 42.567. Std of Reward: 9.044. Training.
[INFO] Tron. Step: 700000. Time Elapsed: 1539.399 s. Mean Reward: 43.542. Std of Reward: 6.252. Training.
[INFO] Tron. Step: 750000. Time Elapsed: 1649.448 s. Mean Reward: 44.259. Std of Reward: 5.454. Training.
[INFO] Tron. Step: 800000. Time Elapsed: 1765.223 s. Mean Reward: 44.172. Std of Reward: 5.722. Training.
[INFO] Tron. Step: 850000. Time Elapsed: 1886.077 s. Mean Reward: 44.414. Std of Reward: 4.085. Training.
[INFO] Tron. Step: 900000. Time Elapsed: 1998.504 s. Mean Reward: 44.165. Std of Reward: 5.477. Training.
[INFO] Tron. Step: 950000. Time Elapsed: 2109.931 s. Mean Reward: 44.024. Std of Reward: 5.713. Training.
[INFO] Tron. Step: 1000000. Time Elapsed: 2220.296 s. Mean Reward: 43.334. Std of Reward: 7.977. Training.
[INFO] Exported results\Tron14\Tron\Tron-999938.onnx
[INFO] Tron. Step: 1050000. Time Elapsed: 2332.358 s. Mean Reward: 43.122. Std of Reward: 8.746. Training.
[INFO] Tron. Step: 1100000. Time Elapsed: 2443.506 s. Mean Reward: 43.763. Std of Reward: 6.161. Training.
[INFO] Tron. Step: 1150000. Time Elapsed: 2550.487 s. Mean Reward: 43.339. Std of Reward: 7.801. Training.
[INFO] Tron. Step: 1200000. Time Elapsed: 2658.639 s. Mean Reward: 44.077. Std of Reward: 6.308. Training.
[INFO] Tron. Step: 1250000. Time Elapsed: 2766.741 s. Mean Reward: 44.368. Std of Reward: 5.778. Training.
[INFO] Tron. Step: 1300000. Time Elapsed: 2873.924 s. Mean Reward: 43.802. Std of Reward: 7.639. Training.
[INFO] Tron. Step: 1350000. Time Elapsed: 2981.196 s. Mean Reward: 44.772. Std of Reward: 4.148. Training.
[INFO] Tron. Step: 1400000. Time Elapsed: 3087.770 s. Mean Reward: 42.471. Std of Reward: 8.561. Training.
[INFO] Tron. Step: 1450000. Time Elapsed: 3193.147 s. Mean Reward: 43.921. Std of Reward: 7.041. Training.
```

Figure 63: Console of a Training Session

Regarding the training configuration file (see Appendix IV), we experimented with changing mostly these values:

- batch_size
- buffer_size
- beta
- num_layers
- max_steps
- summary_freq

From the Tensorboard, we get these graphs for different configurations and for various parameters values (Chart 1):

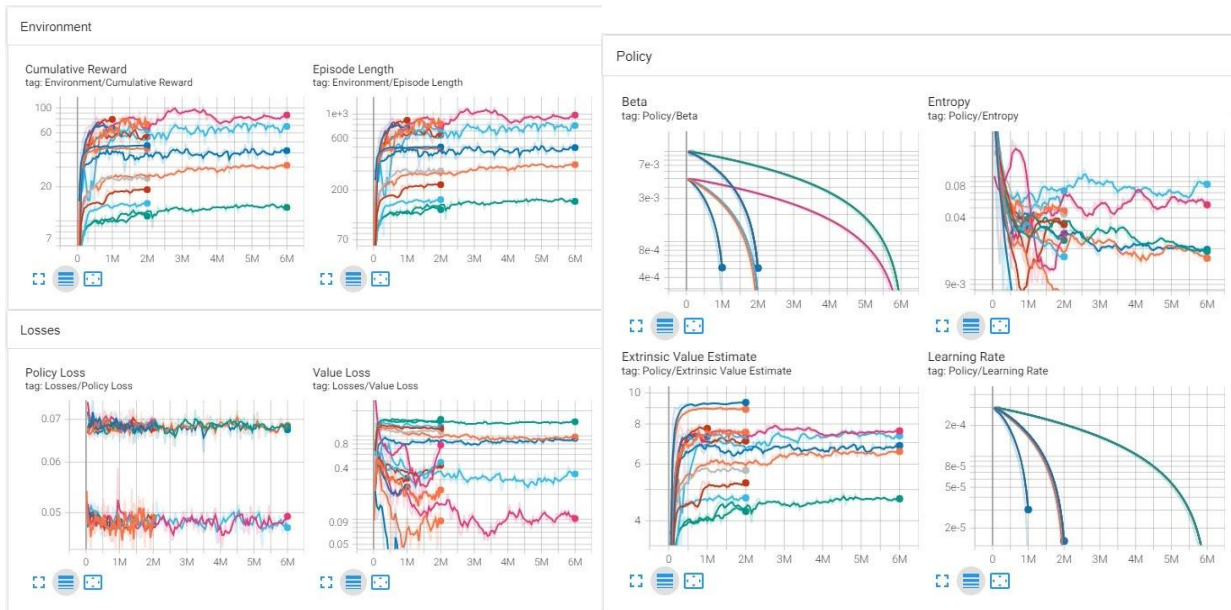


Chart 1: Tensorboard Graphs

The most important graph is the Cumulative Reward (Chart 2), since it shows how well the agents are learning over time. The highest rated (the red line) is the agent with Grid Sensor, a Neural Network with 2 layers and 6 million training steps:



Chart 2: Cumulative Reward

The Grid Sensor makes the agent live longer and accumulate a larger reward compared to the Ray Sensor probably because it provides 360° information around the agent, while the Ray has a $70^\circ + 70^\circ$ limit (Figure 52 and Figure 53). Therefore, the agent equipped with the Grid Sensor has more chances to detect other Tron drivers in its rear and flanks and try to evade them.

4.3.3.3 Section 6 - Ubiquitous Computer: Mixed Reality

The Ubiquitous Computer is the pillar of the modern digital era. It is the driving force behind all recent technological leaps. It is found everywhere: the processor in our mobile phones, Artificial Intelligence chipsets with a dedicated neural processing unit [48], Internet of Things (IoT) with all its smart devices, servers hosting petabytes of data, devices that combine the real and constructed digital worlds, autonomous cars providing streaming services to the passengers and many more.

Therefore, for this time period, a typical living room was designed and developed. It offers three unique Human Computer Interaction (HCI) devices. These can be experienced by the user to showcase the capabilities of these technologies. Moreover, the entire scene (see Figure 64) can be enhanced with other original appliances, machines or gadgets by future developers.



Figure 64: The Mixed Reality Scene

- a. The first one is the VR headset that rests on the dining table. It is a grabbable object which when placed on the user's head it will teleport you to space, simulating a VR environment inside the VR experience. The headset is shown in Figure 65 and the space environment in Figure 66. There are three space environments and when the player dons the headset, one of them is randomly chosen and rendered. When the headset is unequipped, the user is teleported back to the same position in the living room. The aim is to showcase the enormous immersion capabilities of the VR technology.

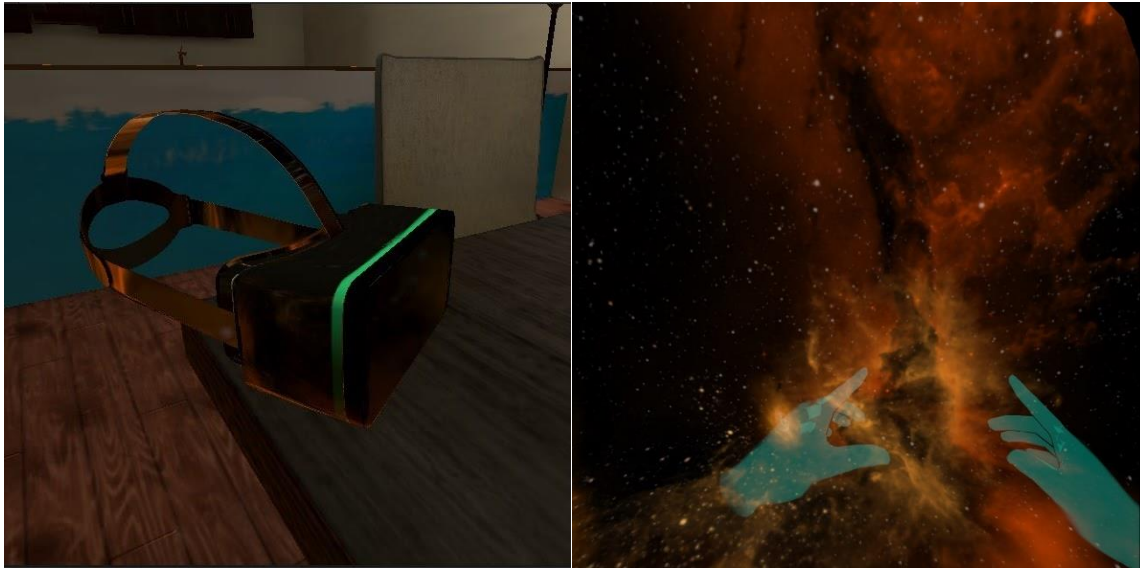


Figure 65: The VR Device and Figure 66: Space

- b. The second device is a mobile phone with Augmented Reality (AR) capabilities. AR lets real world objects become enhanced by computer-generated perceptual information and digital content through a camera and a display screen. As a technology, it became widely known by the game Pokemon Go [49] in 2016 and has evolved much since then, with eyeglasses [50] being the most exciting prospect. The AR phone is presented in Figure 67 and the digital content in Figure 68.



Figure 67: The AR Phone and Figure 68: Augmented Content

The user can pick up the phone from the small table and if they point to the QR code on the floor, they will be able to see the digital robot “Kyle” dancing. If they don’t use the phone, then nothing can be seen in the same place. It is an intriguing idea to use AR inside a VR scene.

- c. The third interaction is through the Amazon Echo Dot smart speaker [51]. The Echo has offline speech recognition functionalities and can control the living room's television. They are displayed in Figure 69 and Figure 70.



Figure 69: The Amazon Echo Dot and Figure 70: Speech-controlled TV

The player may click on the button with the ear symbol to make the Echo start listening. At that time, the speech recognition service starts accepting input from the VR device's microphone. The objective is to control the TV set, thus demonstrating the utilization of IoT devices in a smart home. The self-explaining, available voice commands are:

- "Turn on the tv".
- "Play the movie".
- "Pause the movie".
- "Stop the movie".
- "Switch off the tv".

The commands list could be extended and, more importantly, other home appliances could also be connected and controlled by Echo, approximating a smart home to a greater degree.

The button with the ear and the line will make Echo stop listening, so it won't interfere with the user's gameplay if the speech recognition service is not desired any more.

There is also an analog clock which queries the operating system and tells the real time.

5. EVALUATION

After the project's development was completed, an exploratory study, based on opinions and questions, was performed. A total of 16 participants, from different age groups and backgrounds took part in the study. This chapter presents the evaluation procedure, its results, as well as the findings that emerged from the structured interview and open discussion that accompanied it.

Figure 71 shows a photograph (with permission) of a participant of the study while trying the application.



Figure 71: Photograph of Study Participant

5.1 Methodology

The evaluation aspired to first test the VR project in terms of its usability, second to measure user experience and finally to discuss and brainstorm with the participants. The evaluation methodology followed a qualitative approach, as the nature of the experience is much better suited to qualitative methods, which are more concerned with gaining insights from the participant's perspective (as described in [52]).

The main method used was a structured interview, i.e. an interview guided by a questionnaire. The oral interview occurred both during the application's usage and after the session was completed. Some participants chose to voice their actions or ask questions while they were trying out the project. This fact helped to document their concerns and queries accurately since some of this information could be forgotten if this was done in the end. The interview's main advantage is that it helps the researcher to obtain a better understanding of the user's general opinion about the system and its various components. It was a semi-structured discussion built on prepared questions to guide the researcher through the process.

The design of the questionnaire is based on [53], [54] and [55]. There were 8 general questions mainly about the Museum project, its graphics, its gameplay and the level of attained presence. Then followed 3 questions about the usability of the application and its interactions. The last 7 questions were about the 3 mini-games that accompany the main project. The questions did not use a measuring scale, such as the Likert, but instead were open-ended, designed to advance the discussion and talk about topics that were not explicitly set in advance.

5.2 Participants and Procedure

We recruited 16 participants (10 female and 6 male), with a median age of 34.5 years, by sending an open call to our university circles. An online scheduling system was set up with available date and time slots that were spaced so enough time was allowed for sterilizing the equipment between sessions.

The evaluation took place in an office with ample space for users to walk around while being immersed in the virtual environment. In the beginning, each participant read the study information sheet containing a brief summary of the project and an explanation that withdrawal from the study is allowed at any time. The participant was also informed about the risks of wearing and using VR headsets, such as nausea or dizziness. If the user was not familiar with the VR controllers, then a brief description was offered by the researcher.

During the evaluation, some users were asking questions about certain interactions or were stating verbally that something specific caught their attention or excited them. Upon completing playing the VR application, the participants took part in the semi-structured interview, where the researcher asked them the aforementioned questions.

All the comments were noted down, along with ideas on how to improve certain aspects or how to change others. Because the project is open-source and modular, with mini-games able to be added to it or removed, it was also important to assess what the participants thought of the existing mini-games, so they can be reworked in future updates. The impressions about the Virtual Reality Museum's structure, architecture and aesthetics were also documented, with the purpose of forwarding this information to the museological and architectural team, in case these could inform further design adjustments.

5.3 Results

The observations and discussions with participants resulted in material that was analysed using a qualitative approach.

In terms of the participants' profiles, more than half had completed or are currently enrolled in their Bachelor's degree in the Department of Informatics and Telecommunications. Familiarity with VR technology was fairly average; on a scale from 1 (none) to 5 (maximum), the average rating was 2.875.

5.3.1 The virtual museum experience

Regarding their experience, all apart from one stated that they felt immersed in the virtual Museum, while 11 reported that they "lost the sense of real space and time". All 16 of them felt free to explore the environment.

Concerning the quality of the graphics, all except one agreed that the graphics were very good, bright, lively and were improving the aesthetics of the space. On the other hand, a couple participants thought that the overall color scheme was blunt and the white text was blurry and didn't stand out in the bright background. Three more complained that the resolution of a few images was low and the absence of antialiasing resulted in jagged lines.

About the gameplay, all participants thought it was interesting and enjoyed it. The main reason was the VR interactions, such as grabbing a pen and drawing in 3D space.

Regarding usability, most (11/16) found the application easy to use. They did not experience difficulties in understanding what they were supposed to do. However, three felt that available instructions were not adequate. The main issue, mentioned by the majority of participants as a major usability problem was the absence of interactivity affordances, i.e. visual cues of what is interactable or not. This issue was extensively demonstrated by the fact that most participants could not perceive how to enter the mini-games.

There were also questions for open discussion, specifically: a. what impressed you the most and b. what you would like to change. About the first question, 11 participants mentioned the ability to interact with VR objects in the Museum and in the mini-games. The other 5 claimed that they were fascinated by the Museum's architecture and aesthetics. The most common answer (7 users) of the second question was to include more information about technology and more exhibits, preferably interactable; for instance, the headphones models could play audio stories about specific technologies.

The last generic question was if after experiencing the VR Museum, you would like to visit the physical one too. Fourteen people replied that they would visit, mainly because they were intrigued by the VR version. One user said that they would think about it since they liked VR's freedom and interactions. Finally, the user who did not express interest in visiting the physical museum explained, "No, I would not want to visit the real museum because it would not have the mini-games".

5.3.2 The mini-games

The questionnaire also included queries about the 3 mini-games. The first question was which was your favorite out of the three. Tron had 8 votes, while the Bandu and the Mixed Reality mini-games had 4 each. Most people liked Tron because it is an action,

challenging game with a clear purpose. Then, there were two questions for every game: what did you enjoy the most and what would you suggest to change.

Let's examine the most popular answers for the Tron game first. Seven answered that they liked that it was difficult, while 4 appreciated the futuristic environment. There were 3 positive votes for these categories: the opponents, the gameplay, the music and the affiliation with the movie and the franchise. Some (6) participants would have preferred if the bike turning was smoother and not an abrupt 90 degrees turn. Others (3) said that it was too challenging for them and maybe it could have various levels of difficulty. A couple of people mentioned that they did not like the change of controls in the mini-game Tron, where the player is lying on top of the bike and can only turn it through the controllers' thumb-sticks. A couple of participants made suggestions for improvements, e.g., suggesting that the bike should lean when it turns; there should be an explanation of the gameplay and controls; the player should appear on top of the bike in the room-scale tracking mode; and the game should provide more information during the session, for example who killed who, who won, what position the player ended up in.

Regarding the second game, Bandu, the same two questions were set. Most (11) of the people appreciated that it was a multiplayer game in VR which provided social interaction. Just one person thought it was fun playing a VR version of a table board game, one other enjoyed the gameplay and a last one the variety of the pieces' colors and shapes. Finally, an idea from a participant was to use this game as a tutorial for teaching novices how to grab and manipulate objects in VR. The most (4) common suggestion was to fix the network synchronization of the pieces' positions and physics. A few participants found it a bit boring, would have preferred a different environment (for example a living room to simulate the table board game conditions), and would have wanted a larger white base on the table so a game session would last longer since more pieces could fit.

For the last mini-game, Mixed Reality, many of the participants (7) thought that donning a VR headset inside a VR application was an entertaining idea. Four users enjoyed using an AR phone with a QR code and another four enjoyed the realistic home environment. The voice recognition interaction was liked by only a small number of participants; many (11) did not appreciate the voice recognition service because it was difficult to operate and the commands were not recognized correctly. Six people did not discover that the AR phone should scan the QR code. Five users complained about the VR headset that it got bugged and disappeared. Concerning suggestions for improvement, participants suggested adding more interactions (for example to control the fridge) and more technologies to explore. Lastly, it was reported by some that it did not feel like a game and there should be a combination of story and gameplay to make it a more gamified experience.

5.4 Discussion

The participant's interview included not only the questionnaire, but also an open discussion mostly about the Museum scene and not so much for the mini-games, since they can be replaced or removed as needed. The following list summarizes the most important points of the discussion:

- The Museum architecture and aesthetics were generally appreciated. Especially the people who had seen a demo of an earlier version of the VR museum during the online presentation of the MI&T in April 2021, felt that the new VR scene is more colorful, vivid and realistic looking.

- The greatest issue for the majority of the users was that they could not discern which object is interactable or not. At the moment, there are not any indications, so people had to use trial and error. An infamous example is the 3D model of a floppy disk which is placed as a virtual exhibit on top of a desk in the main room of the virtual museum. Everybody was trying to pick it up in an attempt to place it in a computer, but the disk is a static object that cannot be moved. The lack of interaction indicators, resulted also in participants missing the opportunity to interact with objects that were indeed interactable, such as the pushable timeline screen, the grabbable seats, the rotatable “Computers” prisms. This problem can be solved by placing visual cues on any interactable object, for example a glowing outline or a small circle in its center.
- Similarly, many participants missed the mini-games. They did not have a hint, of some sort, that the black screens in several sections could be clicked to teleport them to the corresponding mini-game. They also did not notice the ray appearing as a virtual extension of their hand when it was pointing to one of these screens. Again, stronger visual indicators are needed to inform the player about the presence of available interactions.
- Regarding the different “historical” time periods and mini-games, there was not a clear connection between them. There was not any explanation why, for instance, the game Tron was developed to represent the Creative Computer era. If there was an explanation pointing out that the movie Tron (1982, [40]) was one of the first movies that made extensive use of computer animation, then a visitor would construct the mental connection of the Creative Computer used in the Arts and the game Tron.
- In addition to that, some mini-games had, or may have in the future, different control schemes or instructions. One (Bandu) has a wall with the instructions written on top, while another (Mixed Reality) has its instructions on the player’s left hand UI. Therefore, it would be better for all scenes to be consistent and follow the same rules: The controls should appear in the left hand UI and the mini-game’s instructions should be presented in a wall screen.
- The sprites-images of some UI buttons did not feel intuitive. An example is the button in the drawing device with an image of a Home. This button returns the pen to its start position if, let us say, it drops to the ground. But most participants had trouble extrapolating this functionality just from its sprite. So, few UI images could be reassessed and replaced.
- Several people thought that the Museum was relatively empty. It does not have any exhibits in contrast to the real one. Creating 3D models of the exhibits would be a time-consuming endeavour, but it would most certainly be worth it, since it would make it feel like a real museum. The exhibits could be accompanied by screens or any other means of presenting information about them. The same should happen for the six time periods / sections: provide the reasoning behind each classification and more data about it.
- Similarly, it was suggested for the Museum to have more interactions such as the timeline, the Computers screen and rotatable prisms, the drawing marker, the grabbable wooden seats. Interactions give the application life and immerse the user further into the virtual world. They also help any kind of educational process to become more enjoyable and thus efficient. A quick example is the various headphones that are currently just hanging on the cylindrical columns. They could be turned into interactable objects that the user puts on to hear a related audio

story (called little and tech stories), which blends perfectly with the previous point too. Or the projector, hanging from the ceiling in time period 5, could play a relevant video.

- The last issue was that almost all the participants skipped the tutorial scene, because they were too bored to read the instructions. But, later in the main Museum scene, they had trouble interacting with the objects or even moving around. This could be remedied by replacing text instructions with some other kind that would be considered less 'boring', for example an animated 3D controller model that could show the controls and the corresponding results. Or the "Skip Tutorial" button could be placed in a more discreet location, indirectly forcing the players to continue with the training. One last thing, that was mentioned by few people, was that the way the tutorial scene is setup currently, does not help them guess that there are more tutorial rooms in the other end of the corridor.

6. CONCLUSIONS

We have presented an immersive VR version of the physical Museum of Informatics and Telecommunications. The project depends on the architectural designs to create a VR environment of how the Museum could be transformed in the future. It includes some interactions with reference to the history of ICT, such as the pushable VR timeline. It also encompasses three mini-games which are thematically connected to the six important time periods of ICT history.

It aims to become an interactive Virtual Museum that can use advanced methodologies, for instance narrative based on personas, user-driven storytelling, interactable exhibits or social participation, to create an experience which triggers multiple emotions reinforcing the learning procedure. It is also designed in a modular way that allows unlimited expansion by adding new interactive VR scenes, created by teams of numerous disciplines for educational or research purposes.

Ultimately, its goal is to act as a complementary tool for the physical Museum of Informatics and Telecommunications as quoted, very descriptively, by one of the evaluation's participants: "I enjoyed the VR Museum experience because it felt like an augmented real museum and it peaked my interest to visit the physical one".

The evaluation process helped identify many issues, with the most important being the absence of: a. visual cues identifying the interactable objects and b. some way of communicating information to the user, for example how a specific mini-game is related to a time period. These concerns could be remedied in future updates of the project, as detailed in the final section of the thesis, leading to a cultural experience with improved user satisfaction.

6.1 Limitations

The project was designed to have a main Museum scene which includes the principal exhibits, interactions and information about ICT, in conjunction with multiple mini-games that aim to showcase certain technologies of important time periods of the ICT history. To achieve a high level of immersion, the endeavour was constructed as a VR application, a fact that brings along several limitations:

- The lighting and the shadows of static objects should be baked and not real-time.
- The shadows of dynamic objects should be turned off, saving central processing unit (CPU) cycles.
- Graphics, texture images and sprites, should not be of very high resolution.
- The frames per seconds should not drop below 60 (Quest 1) or 72 (Quest 2) because people might feel nauseated. To achieve this, the total number of rendered polygons in the scene should be kept as low as possible. The same applies for categories that consume CPU cycles: physics calculations, animations, UI and C# scripts.
- Chance of locomotion sickness for prolonged use.
- Cost of purchase and maintenance of VR devices.
- Personnel should be familiar with the VR technology and the particular project to be able to assist the visitors.
- Need of dedicated physical space for VR users.

Another limitation is the application's need for internet connection. For instance, the mini-game Bandu is a multiplayer game that needs an internet connection so numerous people can join the same room on the server. Currently, there is no internet available in the Museum.

Moreover, it became apparent from the evaluation process, that it takes a VR-familiar user approximately 35 to 40 minutes to explore the tutorial scene, the main Museum scene and the three, currently available, mini-games. This time duration is considered prohibitively excessive, since there will be other people waiting for their turns.

In the manual of the Oculus Quest 2 VR device [56], it is mentioned that it should not be used by children under the age of 13. This rule also applies to other VR headsets [57], such as the HTC Vive, the Playstation VR, and more.

A last impediment is the covid-19 pandemic. VR devices are worn on the head, hence they could be considered as possible means of contamination. Therefore, they should be treated with disinfection and sterilization methods before being used by the next visitor.

6.2 Future Work

Future work should start from the issues derived from the open discussion in §5.3. These are the most important actions to be taken into consideration:

- Add some sort of visual cue to distinguish which objects are interactable. This will reduce a lot of the reported players' confusion.
- Similarly, add a hint or indication that the screens in each time period are clickable and will teleport the user to the corresponding mini-game. This will counter the missing games matter.
- Also, find a way to explain the connection and the reasoning behind creating a game for a specific time period to the visitor. This will assist in the educational aspect of the application.
- Create more exhibits and descriptive information about them, to make the Museum feel less 'empty'.
- Likewise, add more interactable objects in the main Museum scene to make the experience more enjoyable.
- Change the tutorial scene, for instance use animations instead of text instructions to teach the VR controls, so users will not find it 'boring' and skip it.

Other suggestions are:

- Provide some general guidelines or documentation to achieve development consistency between the mini-games. For the same reason, developers should try to use the same UI sprites, indicators or other assisting objects which also exist in the main Museum scene.
- In like manner, add more code comments or documentation to assist future fellow developers.
- Add more games so all six Sections have at least one.
- Create a mechanism that fades in and out the camera when there is a new level loading. At the moment, it looks a bit abrupt and disrupts the fluidity of the experience.
- Collaborate with the team of architects to implement new modifications of the Museum building and ceiling 3D models. For example, raising the lights or the ceiling.
- Possibly create a version of the application which only includes the main Museum scene and not the mini-games. That way, the whole experience will take less time than it does now and it will be more suitable for the VR devices that will be present in the physical Museum.

ABBREVIATIONS TABLE

3D	Three-dimensional
AI	Artificial Intelligence
AR	Augmented Reality
CAD	Computer-aided Design
CGI	Computer-generated Imagery
CL	Curriculum Learning
CPU	Central Processing Unit
DI&T	Department of Informatics and Telecommunications
HCI	Human Computer Interaction
ICT	Information and Communications Technologies
IL	Imitation Learning
IoT	Internet of Things
ML	Machine Learning
MI&T	Museum of Informatics and Telecommunications
MUVA	Virtual Museum of Arts El Pais
NN	Neural Network
NPC	Non Player Character
PPO	Proximal Policy Optimization
RL	Reinforcement Learning
UI	User Interface
VR	Virtual Reality

APPENDIX I. MUSEUM PHOTOGRAPHS

The following three Figure 72, Figure 73 and Figure 74 are from November, 2019:



Figure 72: Museum - Current State 01



Figure 73: Museum - Current State 02



Figure 74: Museum - Current State 03

The next three photographs, Figure 75 - Figure 77 are from September, 2021:



Figure 75: Museum - Current State 04



Figure 76: Museum - Current State 05



Figure 77: Museum - Current State 06

APPENDIX II. UV UNWRAPPING IN 3D STUDIO MAX

This is a detailed guide of how to unwrap the UVs of a mesh in the 3D Studio Max software. It is included, because future developers might need to unwrap either some meshes that have not been yet unwrapped, or some new imported objects. A wooden panel, of the first room, will be used as an example. This is the mesh (Figure 78):

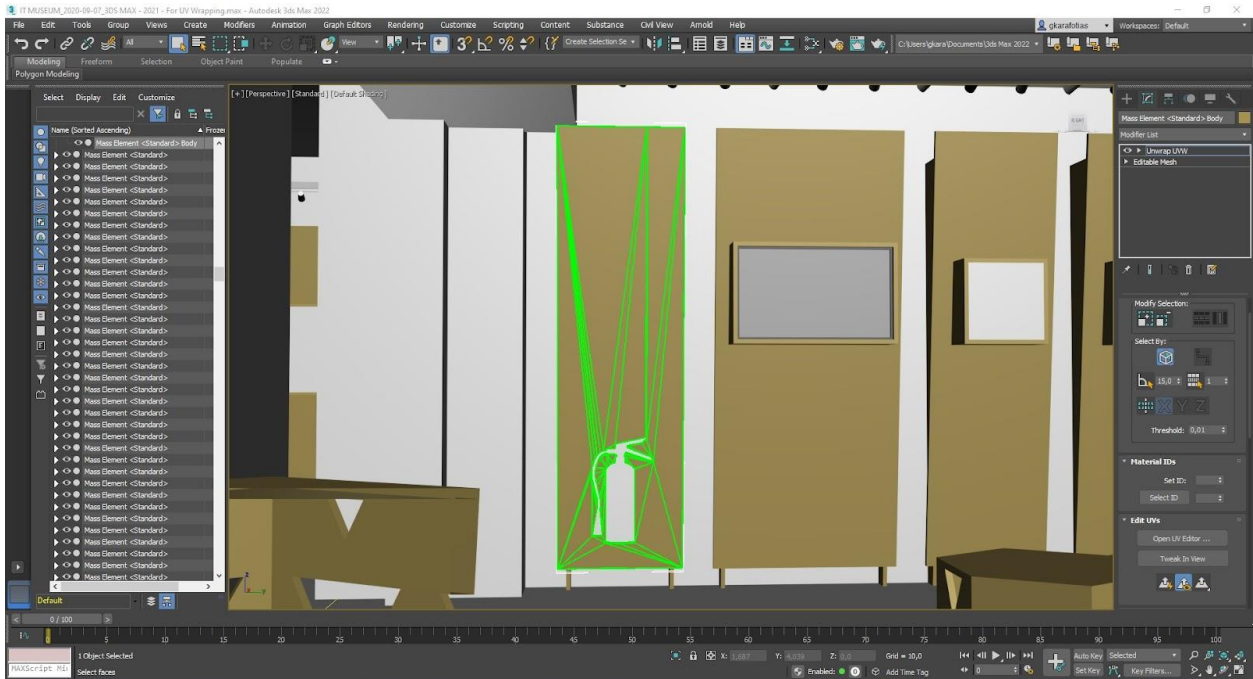


Figure 78: Unwrapped Panel Mesh

The mesh is selected and the “Unwrap UVW” modifier is applied to it. The modifier has an “Open UV Editor” button. From this new “Edit UVWs” window, the function: “Mapping => Flatten Mapping” is executed with the default parameters. This will flatten all the object’s surface polygons on a 2D grid. At this time, the UVs have been unwrapped and the polygons flattened. All the polygons are selected and they turn red (Figure 79):

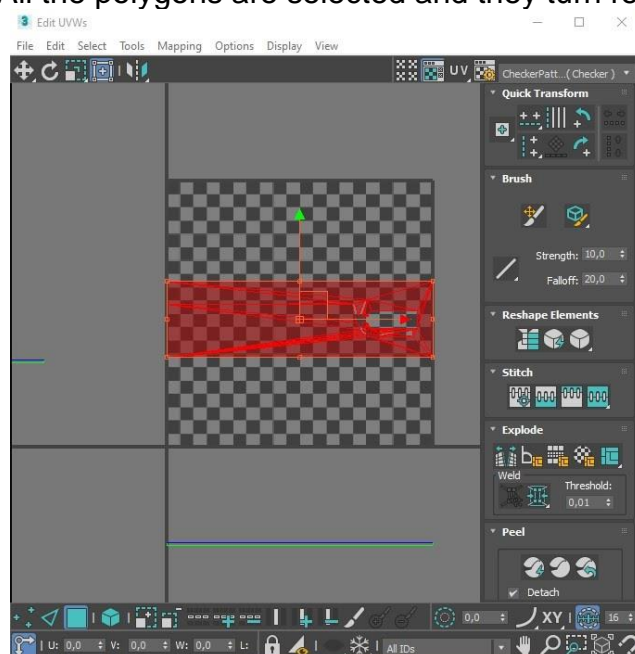


Figure 79: Flattened Polygons

Afterwards, the Material Editor window is opened from the main Studio menu (key: M). There, a physical material is created with a base color map (bitmap) where the desired texture image is assigned (see Figure 80).

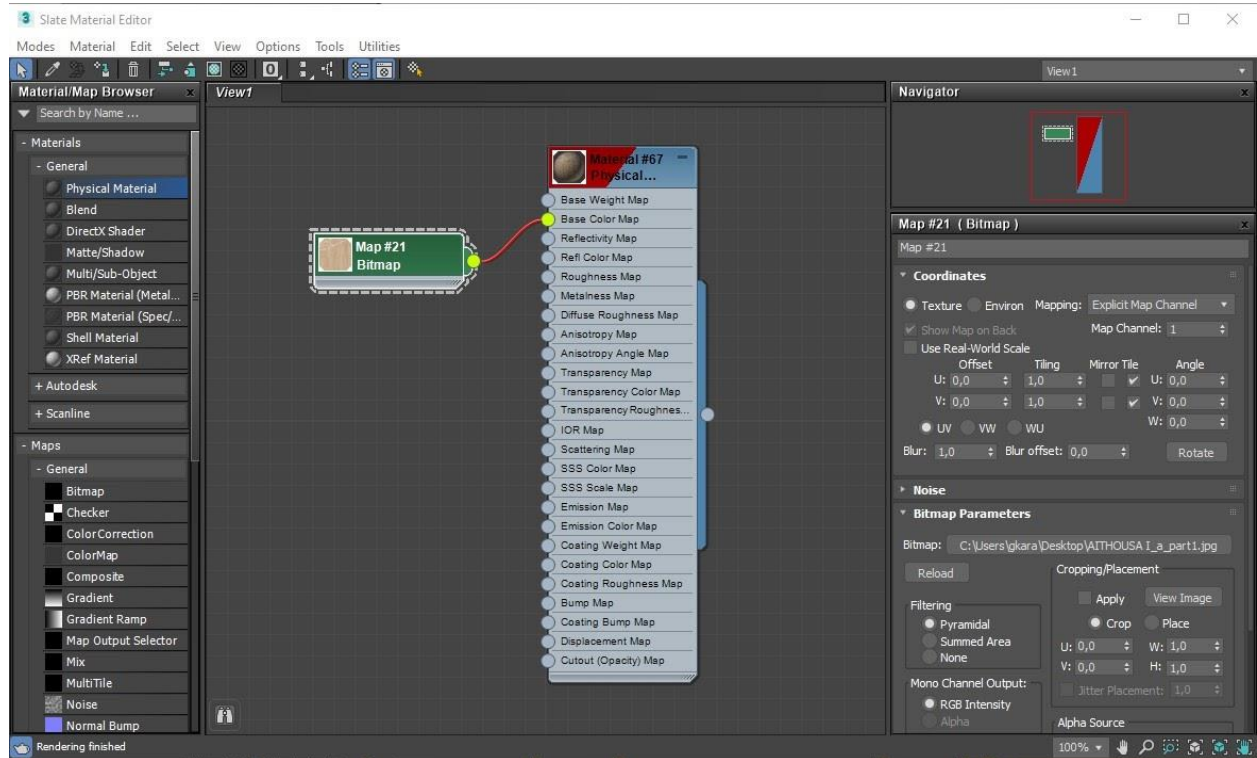


Figure 80: New Textured Material for the Mesh

Subsequently, with the command: “Material => Assign Material to Selection” (key: A), this material is applied to the selected polygons of the mesh. The main viewport window and the Edit UVWs windows should both be open to visualize (Figure 81) how the texture is ‘painted’ on the mesh surface.

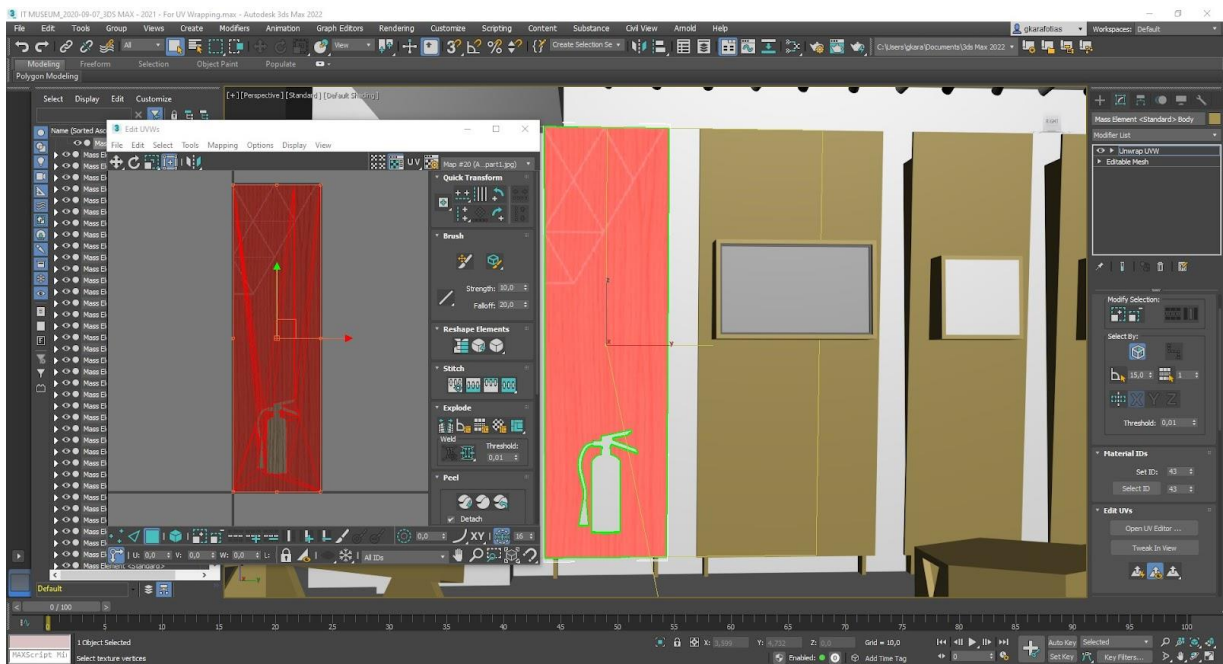


Figure 81: Material Assigned to Mesh

Certain polygons can be selected and moved manually on the part of the image that should appear on top of them. This, essentially, alters the UV values of these polygons' vertices. For instance, the polygon of the panel's side is selected and then moved to the right side of the wood texture (Figure 82).

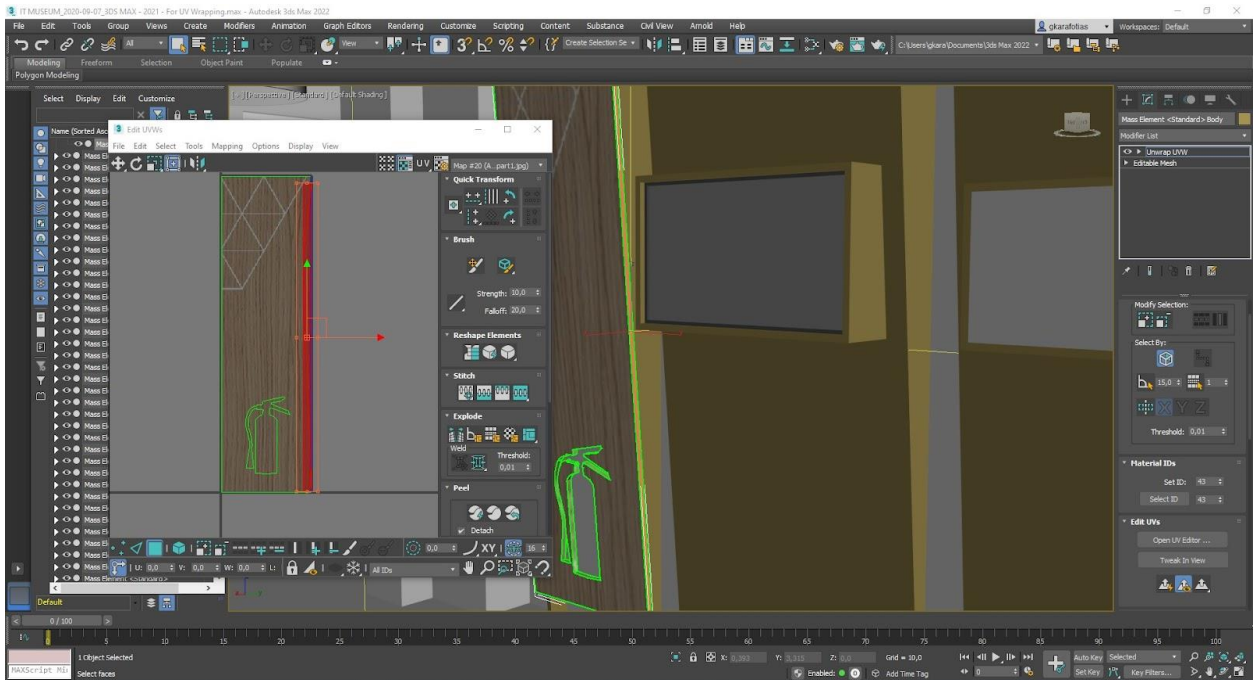


Figure 82: Moved Selected Polygon

The UV unwrapped mesh and its material are exported as a .fbx file. This will be imported in Unity to replace the original untextured mesh. The result is shown in Figure 83 and Figure 84:

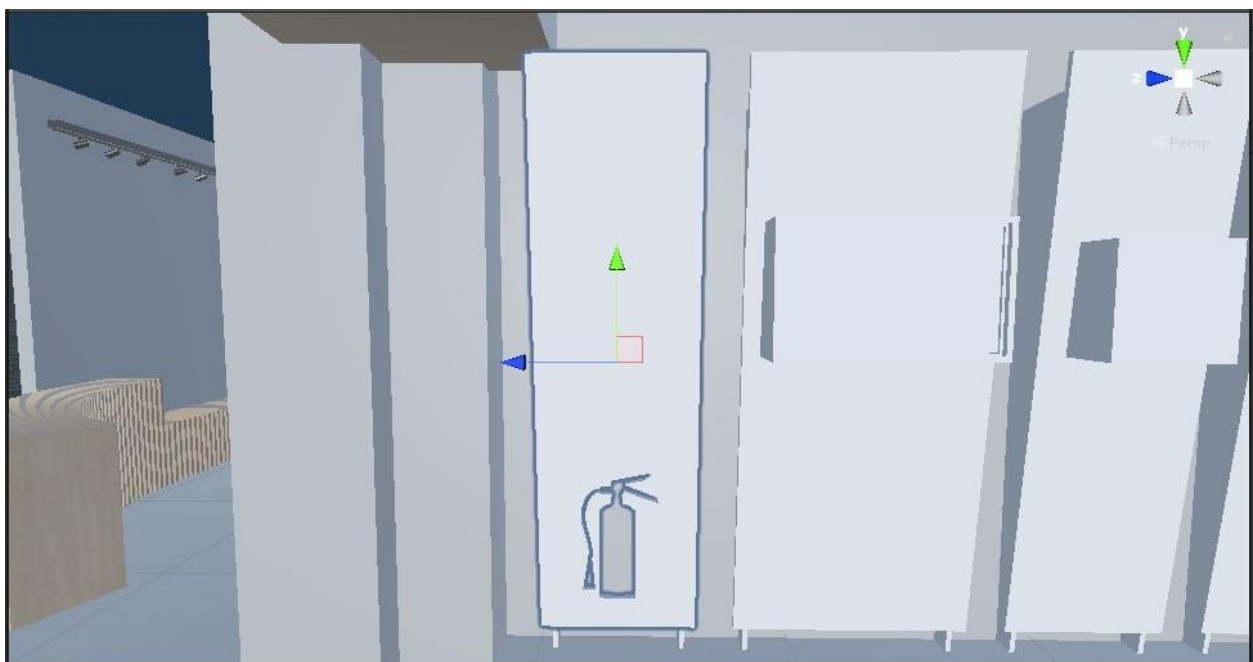


Figure 83: Untextured Mesh in Unity

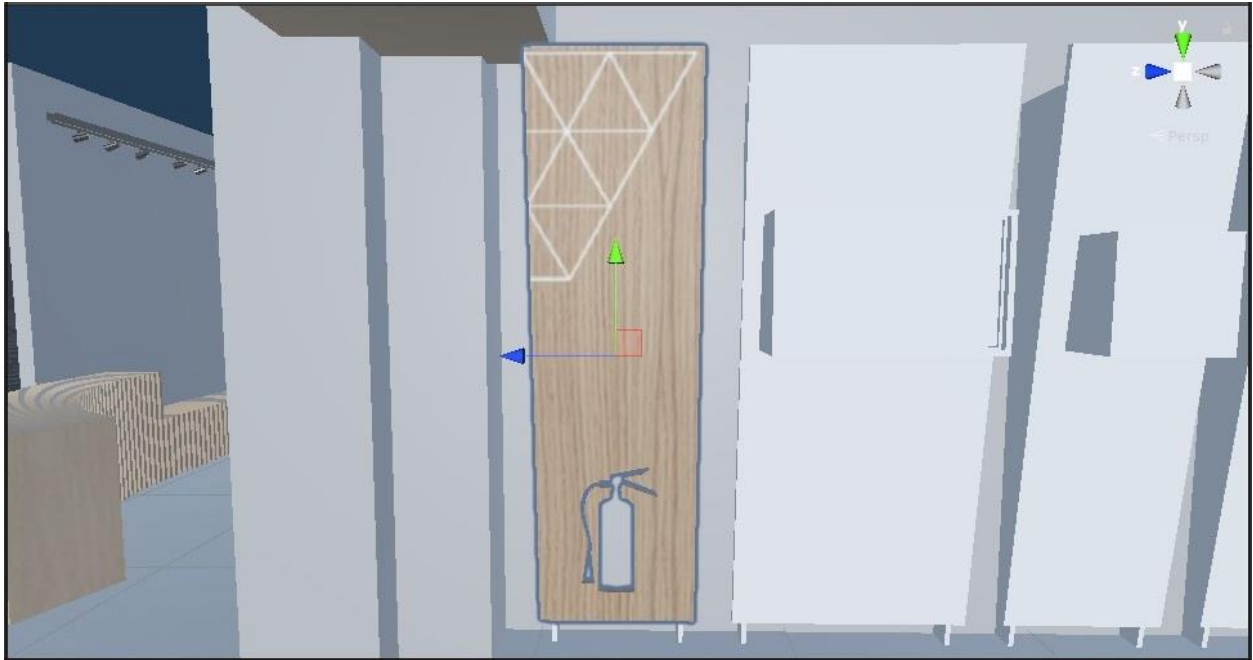


Figure 84: Unwrapped and Textured Mesh in Unity

A final note; Unity provides a view mode, titled UV Charts, that can help identify the geometry that might need its UVs or scale adjusted (Figure 85).

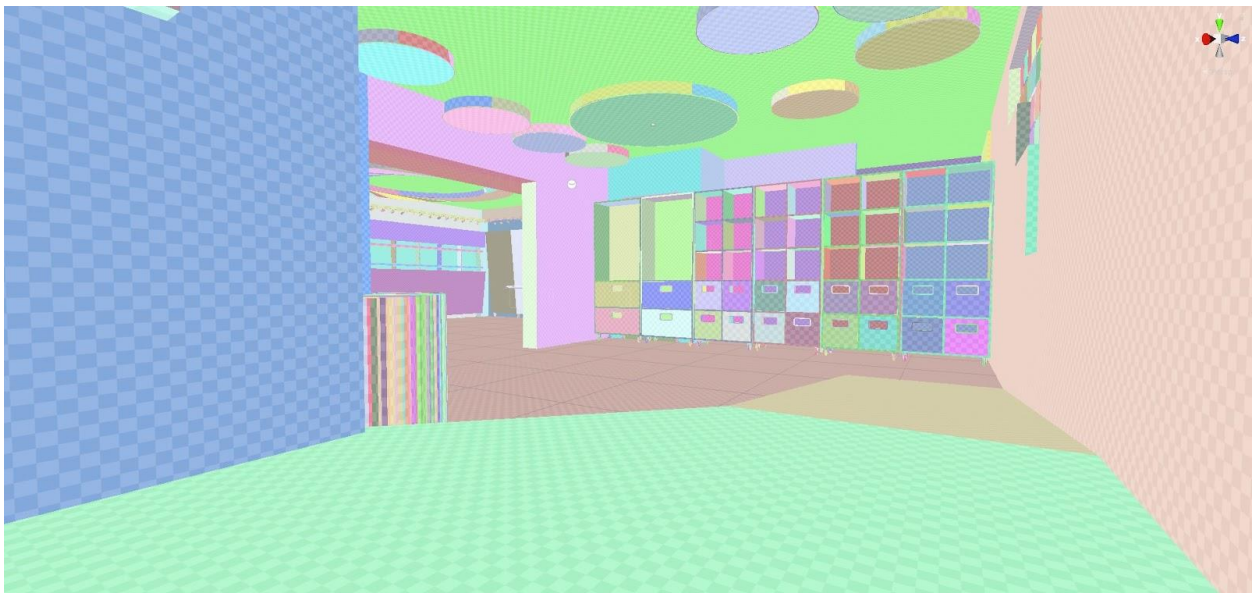


Figure 85: Unity Editor UV Charts

APPENDIX III. HOW TO INSTALL AND USE UNITY'S ML-AGENTS

This is a guide for the required steps to install and use the ML-Agents Unity package.

A. Installation of the mlagents python package:

1. Download and install the Anaconda Python platform:
<https://www.anaconda.com/products/individual>
2. Create and activate a virtual environment in Anaconda either through its GUI or via its command line:
conda env list
conda create -n mlagents
conda activate mlagents
3. Install pytorch package:
pip3 install torch~=1.7.1 -f
https://download.pytorch.org/whl/torch_stable.html
Or install the version without gpu-cuda:
conda install pytorch torchvision torchaudio cpuonly -c pytorch
4. Install mlagents python package:
python -m pip install mlagents==0.27.0

B. Use:

1. Clone the ML-Agents project from github. This project has the ML-Agents Unity package already installed. In another project, it should be installed using the Package Manager.
<https://github.com/Unity-Technologies/ml-agents>
2. Based on the project's examples, create a new .yaml configuration for a game (see Appendix IV), for instance TronGrid.yaml for the Tron game. The other configuration files exist in the folder:
cd "cloned project path"\config\ppo
3. Use the Python API to start the learning / training procedure. This command will use the TronGrid.yaml config file, with a time scale 10 x the default value and saves the results in the results/TronGrid01 sub folder.
mlagents-learn TronGrid.yaml --time-scale=10 --run-id=TronGrid01
4. If the training is paused in the Unity Editor, it can be resumed by:
mlagents-learn TronGrid.yaml --run-id=TronGrid01 --resume
5. Set a number, n, of concurrent Unity instances that are executed in parallel during training:
mlagents-learn TronGrid.yaml --num-envs=<n> --run-id=TronGrid01

C. Presentation:

1. Use Tensorboard to visualize the training results (from the /results folder):
tensorboard --logdir results
2. Show visualization in a web browser:
http://localhost:6006/

APPENDIX IV. TRON PPO CONFIGURATION FILE

This is the .yaml configuration file of the PPO algorithm for the Tron agent which uses a Ray Sensor:

behaviors:

Tron:

```
trainer_type: ppo
hyperparameters:
  batch_size: 128
  buffer_size: 2048
  learning_rate: 0.0003
  beta: 0.01
  epsilon: 0.2
  lambd: 0.95
  num_epoch: 3
  learning_rate_schedule: linear
network_settings:
  normalize: false
  hidden_units: 256
  num_layers: 2
  vis_encode_type: simple
reward_signals:
  extrinsic:
    gamma: 0.99
    strength: 1.0
keep_checkpoints: 5
max_steps: 600000
time_horizon: 64
summary_freq: 50000
```

APPENDIX V. QUESTIONNAIRE

Ερωτηματολόγιο

Ηλικία:

- 18-24
- 25-34
- 35-44
- 45-54
- 55-64
- 65-74

Φύλο:

Σχέση με VR τεχνολογία (1 = Καθόλου, 5 = Πάρα Πολύ):

Σχέση με το Τμήμα Πληροφορικής:

Γενικά

1. Ένιωθες ότι βρισκόσουν μέσα σε πραγματικό μουσείο;
2. Ένιωθες ελεύθερος/η να εξερευνήσεις τον χώρο;
3. Έχασες την αίσθηση του χρόνου και του πραγματικού χώρου;
4. Τι σου έκανε εντύπωση και γιατί;
5. Πώς σου φάνηκαν τα γραφικά;
6. Πώς σου φάνηκε το gameplay;
7. Έτσι όπως το βίωσες, θα ήθελες να επισκεφτείς το πραγματικό και γιατί;
8. Τι θα ήθελες να είχε παραπάνω ή να αλλάξει;

Ευχρηστία

9. Πόσο εύχρηστη βρήκες την εφαρμογή;
10. Κατάλαβες τι πρέπει να κάνεις;
11. Πώς σου φάνηκαν οι διάφορες αλληλεπιδράσεις;

Mini-games

12. Ποιό mini-game σου άρεσε περισσότερο και γιατί;

A. Bandu

1. Τι σου άρεσε περισσότερο και γιατί;
2. Τι δε σου άρεσε ή θα μπορούσε να αλλάξει;

B. Tron

1. Τι σου άρεσε περισσότερο και γιατί;
2. Τι δε σου άρεσε ή θα μπορούσε να αλλάξει;

C. Mixed Reality

1. Τι σου άρεσε περισσότερο και γιατί;
2. Τι δε σου άρεσε ή θα μπορούσε να αλλάξει;

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