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BSc THESIS

AUGMENTED REALITY AS A CULTURAL BUILDING PROMOTION MEDIUM

by

DIMITRIS PIRPIRIS

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Supervised by:

Professor
Nikolaos Vidakis

Abstract

Augmented Reality represents a burgeoning educational technology with the capacity to introduce inventive teaching approaches and foster captivating learning experiences. The integration of game-based design into Augmented Reality applications has the potential to enhance education by elevating motivation and engagement, ultimately leading to improved learning outcomes. Most applications adopting Augmented or Virtual reality for the presentation of buildings and artefacts offer a passive experience with limited interaction. The purpose of this thesis is to explore the intersection of technology and cultural heritage through the development of a gamified Augmented Reality (AR) application aimed at promoting cultural buildings. The software design of the AR application is detailed, emphasizing game design principles and the underlying architecture. The incorporation of various game activities, including navigating cultural buildings, solving puzzles, and matching labels, aims to create an engaging and educational user experience. This thesis contribution targets the different interactions as well as information presented to the user during their visit to cultural buildings using AR technology. The main focus of the study is the flow of the activities and guides within the application to keep the user engaged and entertained during their time on the resulting application. The thesis proposes game-based learning approaches for this purpose as those techniques have shown great results in the engagement and motivation of the users.

ΠΕΡΙΛΗΨΗ

Η Επαυξημένη Πραγματικότητα αντιπροσωπεύει μια αναπτυσσόμενη εκπαιδευτική τεχνολογία με την ικανότητα να εισάγει εφευρετικές διδακτικές προσεγγίσεις και να ενθαρρύνει συναρπαστικές μαθησιακές εμπειρίες. Η ενσωμάτωση του σχεδιασμού που βασίζεται σε παιχνίδια που υπάρχουν σε εφαρμογές επαυξημένης πραγματικότητας έχει τη δυνατότητα να ενισχύσει την εκπαίδευση αυξάνοντας τα κίνητρα και τη δέσμευση, οδηγώντας τελικά σε βελτιωμένα μαθησιακά αποτελέσματα. Οι περισσότερες εφαρμογές που υιοθετούν την επαυξημένη ή την εικονική πραγματικότητα για την παρουσίαση κτιρίων και αντικειμένων προσφέρουν μια παθητική εμπειρία με περιορισμένη αλληλεπίδραση. Σκοπός αυτής της πτυχιακής εργασίας είναι η διερεύνηση της διασταύρωσης τεχνολογίας και πολιτιστικής κληρονομιάς μέσω της ανάπτυξης μιας παιγνιοποιημένης εφαρμογής Επαυξημένης Πραγματικότητας (AR) που στοχεύει στην προώθηση πολιτιστικών κτιρίων. Ο σχεδιασμός λογισμικού της εφαρμογής AR είναι λεπτομερής, δίνοντας έμφαση στις αρχές σχεδιασμού του παιχνιδιού και στην υποκείμενη αρχιτεκτονική. Η ενσωμάτωση διαφόρων δραστηριοτήτων, συμπεριλαμβανομένης της πλοήγησης σε πολιτιστικά κτίρια, της επίλυσης παζλ και της αντιστοίχισης ετικετών, στοχεύει στη δημιουργία μιας ελκυστικής και εκπαιδευτικής εμπειρίας χρήστη. Αυτή η πτυχιακή εργασία στοχεύει στις διαφορετικές αλληλεπιδράσεις καθώς και στις πληροφορίες που παρουσιάζονται στον χρήστη κατά την επίσκεψή του σε πολιτιστικά κτίρια χρησιμοποιώντας τεχνολογία AR. Το επίκεντρο της μελέτης είναι η ροή των δραστηριοτήτων και των οδηγών εντός της εφαρμογής για να κρατήσει τον χρήστη αφοσιωμένο και ψυχαγωγημένο κατά τη διάρκεια που την χρησιμοποιεί. Η πτυχιακή προτείνει προσεγγίσεις μάθησης με βάση το παιχνίδι για το σκοπό αυτό, καθώς αυτές οι τεχνικές έχουν δείξει εξαιρετικά αποτελέσματα στη δέσμευση και τα κίνητρα των χρηστών.

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Dedication

I would like to dedicate my thesis to my family and friends who were by my side throughout this journey until the end.

Chapter 1 - Introduction

Augmented reality (AR) is a rapidly advancing technology that offers the exciting potential to overlay information onto real-world objects or provide real-time processing of 3D representations [1]–[4]. Mobile phones are particularly advantageous in the AR landscape as they don't rely on external hardware and are ubiquitous in society. The proliferation of AR on mobile phones has played a pivotal role in its growth, introducing users to many applications and offering companies new opportunities for gaining a competitive edge. These include immersive and personalized experiences for users in augmented reality (AR), virtual reality (VR), mixed reality (MR), and extended reality (XR). Due to their interactive experience, they provide in both the real and virtual worlds, they have a wide variety of appliances [5].

One of the appliances of AR is in the tourism industry which has witnessed a profound transformation with the integration of AR technology. Travelers can now experience destinations in an entirely new way. For instance, AR applications can provide real-time information about historical landmarks, local culture, and nearby attractions, enhancing the overall travel experience. AR adds layers of interactivity and engagement to tourism, making it more immersive and educational. Additionally, in the realm of cultural heritage, AR serves as a powerful tool for preservation and education. It allows users to explore historical sites and artifacts in unprecedented detail. AR applications enable individuals to witness the past by superimposing digital reconstructions onto real-world locations. This enriches cultural heritage experiences by providing historical context and narratives [6]. Moreover, digital storytelling can offer contextual information through smartphone screens to enrich the comprehension of artworks such as frescoes or paintings, providing historical and narrative depth to the viewer's experience [7].

Not only in tourism, but AR applications have also gained significant traction in various domains, including advertising, entertainment, and education. Location-based AR, a notable subset, connects digital content to real-world locations through geographic markers. These applications, typically run on GPS-enabled mobile devices, have proven beneficial in education by boosting student engagement and satisfaction. Moreover, when coupled with gamification and storytelling techniques, AR enhances the learning experience, making it more immersive and enjoyable [8].

AR technology can seamlessly integrate with gamification and Game-Based Learning (GBL) approaches, as the experience with AR applications often evokes a gaming atmosphere. AR enhances the learning process by making it interactive and engaging. GBL leverages the immersive capabilities of AR to create realistic simulations and scenarios, enabling students to learn through experience. The combination of these elements sparks interest and enhances the overall educational experience [7].

Contribution

This thesis contribution targets the different interactions as well as information presented to the user during their visit to cultural buildings using AR technology. The main focus of the study is the flow of the activities and guides within the application to keep the user engaged and entertained during their time on the resulting application. The thesis proposes game-based learning approaches for this purpose as those techniques have shown great results in the engagement and motivation of the users.

Thesis Structure

The rest of this thesis is structured as follows: In Chapter 2 the background knowledge required for the subject is provided, while Chapter 3 provides a literature review and the state of the art. Additionally, Chapter 4 describes the software design of the application, and Chapter 5 the implementation. Chapter 6 outlines the results & discusses the findings of this research. Chapter 7 concludes the report and provides insights for future directions.

Chapter 2 - Background

Extended Reality

Extended reality (XR) has emerged as an umbrella term for technologies that blend virtual and real worlds, including virtual reality (VR), augmented reality (AR), and mixed reality (MR) [9][10]. XR, also known as extended or X reality, acts as a powerful bridge converging virtual physical dimensions and demonstrates the ability of digital systems to interact with real-world environments, enabling enhanced engagement and problem-solving capabilities.

As described by Pavlik et al. [11], XR emerges as a product of the convergence of ubiquitous sensor/actuator networks and virtual online shared worlds. This combination creates a "mixed reality situation" - a term used to describe the interaction between concrete objects and the observable world. This model offers a unique continuum of reality and virtuality (Figure 1), a spectrum of "reality complete" to "completely realistic" inclusive, according to the results by Milgram et al. [1].

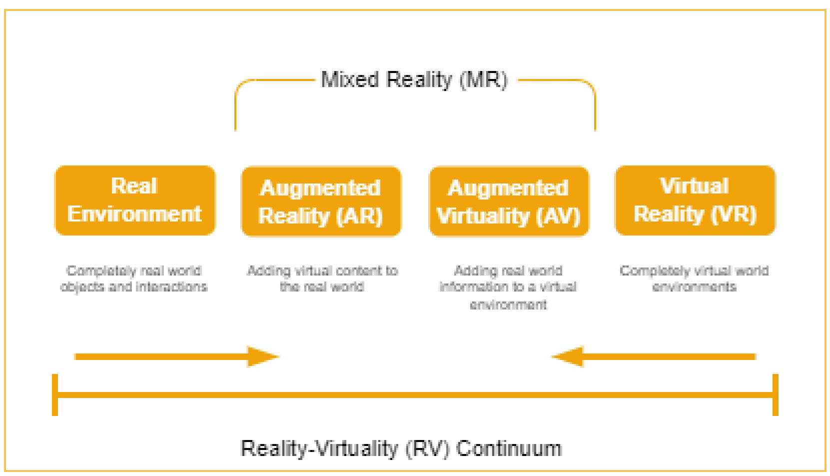


Figure 1. Milgram’s Taxonomy

The possibilities for the XR are far-reaching and exciting. From improving human efficiency in business tasks to streamlining maintenance activities and strengthening decision-making processes, XR demonstrates its utility in various industries through input and communication simplicity. Through immersive simulations and intuitive interfaces, XR empowers individuals to interact with tasks and information, fostering heightened efficiency and informed decision-making. Finally, XR aims to seamlessly blend or replicate the physical world with a "digital twin world," capable of interactive engagement with its physical counterpart [12], [13]. This innovative approach seeks to create a cohesive environment where the boundaries between reality and its digital representation converge, facilitating enhanced interactions and insights for a neutral audience to comprehend.

The most well-known standard for developing XR applications is OpenXR developed by Khronos Group. OpenXR is a royalty-free, open standard that provides high-performance access to AR/VR - or R - and aims to make developing AR/VR software easier [14]. It allows applications to work on different devices without needing extensive changes to their code, allowing the same software to run on various hardware. With the release of the OpenXR 1.0 specification, developers can now create immersive experiences that work across different platforms. OpenXR It's all about making cross-platform XR (Extended Reality) applications a reality. This chapter analytically examines the role of XR in the broader industrial landscape, explaining its basis, theory, and practical implications.

Augmented Reality

Augmented Reality (AR) is a technology that enriches the real world with virtual information like images, sounds, and 3D objects [15]. AR systems should possess certain features: combining real and virtual imagery, real-time interactivity, and 3D alignment with reality [16]. This technology is not just limited to visual augmentation; it can also extend to senses like hearing and touch [17].

AR's notable aspect is its ability to track features in the environment, which allows placing virtual objects within the real world [15]. Tracking methods fall into three categories: sensor-based (using sensors like optical, magnetic, acoustic, and inertial), vision-based (using optical sensors for marker-based and markerless tracking), and hybrid (combining sensors and images for robust tracking) [18]–[20]. The devices for AR experiences include computers, smartphones, glasses, and head-mounted displays. Smartphones are popular due to their portability, while computers offer processing power and accuracy. However, desktops often require external components for certain functionalities [15]. Within the context of AR fall the following categories:

Diminished Reality (DR): This involves selectively removing or diminishing real-world elements from a scene [21].

Projection Mapping: This technique involves projecting images or content onto real-world objects to create interactive and immersive experiences [22].

Spatial AR: This refers to AR experiences that are tightly integrated with the physical surroundings, often using spatial mapping and tracking for precise interactions [23].

Wearable AR: Wearable AR devices, such as smart glasses, provide a hands-free augmented experience, overlaying information onto the user's field of view [24].

Virtual Reality

Virtual reality (VR) represents cutting-edge technology that creates unique immersive encounters through simulated environments [25]. These enhancements are accomplished through VR headsets, special wristbands, and customized devices, allowing users to enter and immerse themselves in these virtual realms of strongly conceptualized reality VR. VR technology is known for its mastership in delivering state-of-the-art computer graphics, rich sound effects, and sensory resonance. As VR becomes more accessible and connected, it finds its way into industries, offering new modes of engagement. However, the true appeal of VR extends beyond the technical stuff. It is about reimagining our relationship with the world. Using VR users are able to engage all of their senses and fully immerse themselves in different places, stories, and experiences. VR includes the following subcategories:

- **Immersive VR:** This emphasizes deeply engaging and sensory-rich VR experiences that transport users to entirely virtual environments [26].
- **360-Degree VR:** This type of VR captures a full spherical view of a real-world location or scene, enabling users to look around in all directions [27].
- **Cinematic VR:** Focused on storytelling, cinematic VR offers immersive narratives and experiences that users can explore [28].
- **Social VR:** These platforms enable multiple users to interact and engage with each other in shared virtual spaces [29].

Mixed Reality

According to this continuum, Mixed Reality (MR) falls within the intermediary region between these two extremes. MR mixes virtual elements into the physical environment, allowing users to interact with both real-world and digital objects. This interaction ranges from less immersive to highly immersive experiences. MR is an innovative technology that fuses the realms of the physical and the virtual, crafting an experience that seamlessly merges both for users [30]. What sets it apart from conventional Virtual Reality (VR) is its integration of real-world components into the virtual sphere, unlocking heightened interactivity and a more organic engagement. MR is accessible through diverse tools like smart glasses, head-mounted displays, and wearables, offering a spectrum of possibilities. Its applications span many domains, from gaming and entertainment to education and industrial contexts. The term can be relative to AR, but currently, this term is used to describe mobile or smart glasses applications that overlay information on top of the real world in 2D (i.e. notifications, messages, and general information). Some MR techniques and categories are described below:

- **Augmented Virtuality (AV):** As a subset of MR, this concept blends real-world elements into predominantly virtual environments [31].
- **Mirror World:** A type of MR where the physical world is closely mirrored in the virtual domain, often used for simulation and data analysis [32].
- **Hyper-Reality:** Although it blurs the line between physical and virtual, hyper-reality could be classified as a form of MR due to its mixed nature [33].

Game-Based Learning and Gamification

Game Based Learning

The educational landscape is undergoing a transformative shift, departing from the goals established in previous decades—centered on knowledge acquisition and traditional teaching models—and embracing a fresh paradigm. At the heart of this new approach lies a twofold objective: not only the practical application of knowledge, but also the cultivation of an enriching classroom environment that fosters creativity [34]. Through deliberation, exploration, and experimentation, students are empowered to ignite their curiosity, infusing dynamic interactivity into the learning process.

Game-Based Learning (GBL) emerges as a strategic framework, engendering heightened motivation among students when juxtaposed with conventional instructional methods. Games serve as catalysts, galvanizing greater participation and overall enthusiasm for the subject matter [35]. Research by Fotaris et al. underscores the profound impact of digital games on education, unveiling significant strides in comprehension, diligence, and motivation [36]. Herein, games metamorphose into educational tools tailored to realize pedagogical aims, concurrently fostering improved performance and fortified interpersonal bonds [37].

According to Prensky, the essence of an educational game transcends mere skill development; its essence rests in the translation of acquired competencies to tangible, real-world contexts. This fusion of education with everyday life serves as a conduit for nurturing metacognitive proficiency and heightened awareness of pertinent matters [38]. Inextricably interwoven, these elements orchestrate a holistic educational milieu primed for holistic growth.

In the realm of game-based learning, a game is harnessed as an instructional conduit, enabling users to learn through immersive play. Tasked with assignments to complete, users traverse tasks and levels, where points and achievements stand as supplementary elements rather than primary motivational drivers [39]. Game-based learning extends an opportunity for learners to cultivate soft skills—ranging from leadership to team and time management—through the act of problem-solving to progress within the game [40], [41]. The realm of game-based learning weaves an environment of enjoyment that in turn stimulates creativity among learners [34].

Perspectives on game-based learning theory manifest in three dimensions [40]. The first vantage point perceives learning as an outcome of gameplay, an approach that envisions learning through the lens of game technologies [38], [42]. The second stance integrates pedagogical theories and game technologies, acknowledging that learning arises not solely from gameplay but also from supplementary activities conducted alongside the game [43]. The third perspective embarks on leveraging game mechanics to gamify the learning journey, channeling innovation in learning experiences through game design concepts [44]. In concert, these perspectives configure a diverse landscape of game-based learning, illustrating the dynamic synergy between pedagogy and technology.

Gamification

Gamification entails the integration of game elements and principles into contexts outside of gaming, offering users experiences akin to games to amplify engagement [45]. Rooted in users' instincts and desires, gamification taps into motivations like competition, mastery, and achievement. Common gamification strategies encompass reward systems that fuel users' sense of advancement, completion, and competition, thus enticing them to immerse themselves in the learning process. Notably, game design elements like point and badge systems, leaderboards, narratives, avatars, and collaborative elements are harnessed to engender engagement and meaningful interaction within learning scenarios.

- **Points:** Points serve as rewards bestowed upon users upon task completion, often measuring progress or performance [46]. Research indicates that point-based systems act as motivators, nurturing students' desire for rewards stemming from engagement in learning endeavors. Points imbue a sense of challenge, reflecting learners' advancement [47]–[49] thus instilling a participatory ethos conducive to student-centered learning [50].
- **Badges:** Badges constitute a reward system that acknowledges individuals' achievements within gamified activities [51]. Parallel to point-based systems, badges stimulate motivation and foster performance progression [52]. Beyond recognition, badges enrich social interactions among learners [53], solidifying a sense of achievement and facilitating an inclusive community of badge holders. Moreover, badges wield influence in shaping choices, guiding learners toward challenges and pathways guided by the allure of earning badges [54].
- **Leaderboards**: Leaderboards orchestrate users' ranking based on specific criteria, gauging success within learning activities. A competitive mechanism, leaderboards aim to elevate motivation [51] and performance by driving learners to ascend the ranks. While leaderboards offer positive incentives, it's paramount to acknowledge that ranking lower on the leaderboard could yield the opposite effect [55]. Engagement in learning activities is also kindled through leaderboards, spurred by the urge to bolster scores and ascend the ladder of rankings [56].
- **Performance Graphs:** Contrasting leaderboards, performance graphs gauge users' performance vis-à-vis their own progress within the game [57]. This serves as an evaluative yardstick, offering users insights into their growth trajectory and an avenue for improvement. Notably, this technique propels users toward mastering tasks founded on motivational theory benchmarks [57].
- **Levels:** Levels establish a hierarchical system reflecting individuals' progression through stages predicated on tasks and challenges, each tier symbolizing varying degrees of difficulty [58]. This approach fuels motivation, concentrating learners' focus on tasks at hand as they strive to surmount challenges en route to level completion [48], [59]–[61]. Levels, adept at goal setting, engender a steady trajectory of performance enhancement.
- **Meaningful Stories:** Employing meaningful stories, gamification imparts depth to otherwise routine tasks, imbuing them with purpose and direction. Infusing narratives into activities can be as simple as crafting a compelling title or weaving intricate

storylines akin to those within role-playing games [44]. Meaningful stories elevate motivation and pique users' curiosity, employing narratives as a potent hook.

- **Progress Bar:** Progress bars, a prevalent gamification element, predominantly amplify motivation and engagement by enabling learners to track their advancement [53], [62]. In addition, progress bars double as tools for evaluating individual contributions within group activities, affording a visual representation of overall participation and involvement [53], [62].
- **Avatars:** Avatars materialize as users' virtual personas within the gamified environment [55], reflecting their selected or created identities. Spanning simple images to 3D models, avatars serve as alternate identities within the gamified realm, facilitating user interaction [63].
- **Teammates:** Anchored in fostering collaboration, this technique assembles users into teams, coalescing efforts toward shared objectives [55]. Collaboration emerges as the cornerstone, as users collaborate to achieve collective goals, resonating with the ethos of cooperative.

Chapter 3 – State of the Art Systems

This section offers a literature review to identify state-of-the-art research in the field of cultural building presentation in AR and VR environments. Subsequently, the chapter outlines the most significant research, providing insights and directions for the development of this system. Additionally, this review identifies gaps in the literature that directed the system in its current design.

"ARTS, an AR Tourism System, for the Integration of 3D Scanning and Smartphone AR in Cultural Heritage Tourism and Pedagogy"

Exploring the interplay of cultural heritage, tourism, and pedagogy within urban environments, this study focuses on Lukang's Shih Yih Hall site. Introducing an Augmented Reality Tourism System (ARTS), this smartphone-based platform utilizes 3D scans for a dynamic interaction experience [64]. Comprising real-time viewing, space-switching, and AR guide graphics, ARTS facilitates scenario initiation, projection, annotation, and customization. The system's effectiveness is underscored by a Post-Study System Usability Questionnaire (PSSUQ) evaluation, affirming its usability and utility in intertwining urban fabric, cultural heritage tourism, and pedagogy.

Figure 2. Combination of real environments and 3D models

“An integrated VR/AR framework for user-centric interactive experience of cultural heritage: The ArkaeVision project”

ArkaeVision [65] redefines Cultural Heritage engagement through immersive experiences. Its goal is an enriched exploration of monuments, artworks, and stories. This user-centric system merges 3D exploration with digital fiction, exemplified by VR at Hera II Temple and AR at the Swimmer Tomb slab. Emotion is pivotal, spurring the use of HTC Vive for rapid learning. Gamification further involves users, guiding choices to boost engagement. ArkaeVision's approach shows promise for education and cultural experiences.

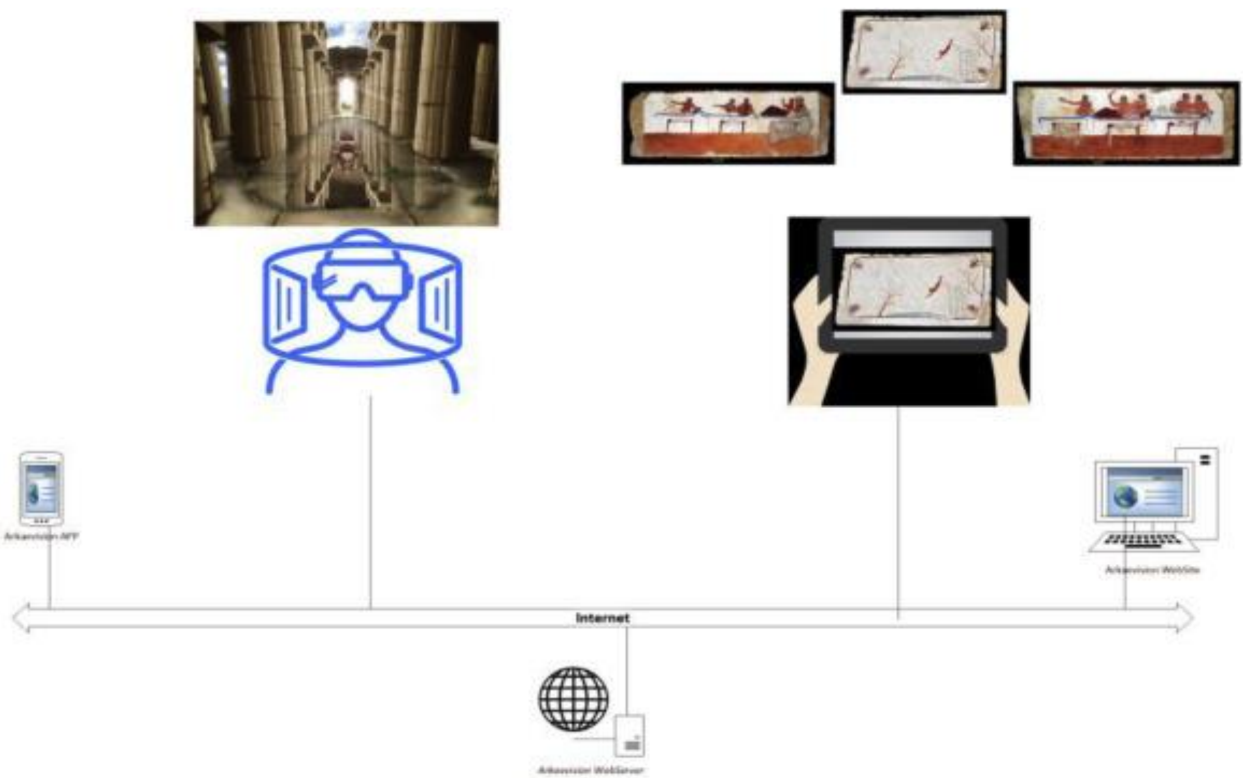


Figure 3. Overall view of Arkae Vision framework

“Mixed Reality for Cultural Heritage”

This paper introduces two Mixed Reality approaches for enhancing students' understanding of ancient Greek culture and history [66]. The first explores the potential of AR in museums, virtually augmenting ancient statues and providing visitor guidance. The second addresses challenges in mobile and stationary VR systems for educational use in schools and museums. Additionally, a novel VR-streaming solution, SaMaXVR, is proposed, merging the benefits of mobile and stationary VR while addressing their drawbacks. These cost-effective alternative holds promise for educational institutions. A demo application showcases complex 3D scans, transporting users to historical contexts, and envisioning artifacts as they once were.

Figure 4. Athena with virtual Spear – Reconstructing parts with blue

"Rethinking the consequences of postmodern authenticity: the case of a World Cultural Heritage in Augmented Reality"

Augmented Reality (AR) has significantly enhanced the tourism experience, influenced by postmodern authenticity and presence theory. This study [67] examines the impact of postmodern authenticity on Sense of Presence and Telepresence, along with their influence on visitor satisfaction and travel intention at the AR-based World Cultural Heritage Site – Mount Tai, China. Surveying 225 respondents, the findings reveal that postmodern authenticity positively correlates with presence, satisfaction, and travel intention, with a stronger effect observed on the Sense of Presence. Both types of presence contribute positively to satisfaction and travel intention, with Sense of Presence demonstrating a more pronounced effect. The study holds implications for theory and management.

"Location-Based Augmented Reality for Cultural Heritage Education: Creating Educational, Gamified Location-Based AR Applications for the Prehistoric Lake Settlement of Dispilio"

This research introduces two educational location-based AR apps that employ gamification and storytelling to convey cultural heritage insights about a prehistoric lake settlement [8]. The study aims to inspire educators and guide them in creating captivating AR experiences for educational trips to archaeological sites and museums. Preliminary evaluations involving higher education and school students demonstrated promising results in terms of usability, student satisfaction, and perceived educational value.

Figure 5. Puzzle game from the application

This multimedia content aids users in comprehending the narratives and symbolism within the images. Human factors play a pivotal role in such applications, ensuring that the user remains focused and immersed without distractions. This paper delves into a case study involving a mobile AR app designed to guide visitors through the interpretation of frescoes within the Basilica of Saint Catherine of Alexandria in Galatina [7]. The research seeks to explore the interconnectedness of usability, user experience, and mental workload in AR-based digital storytelling.

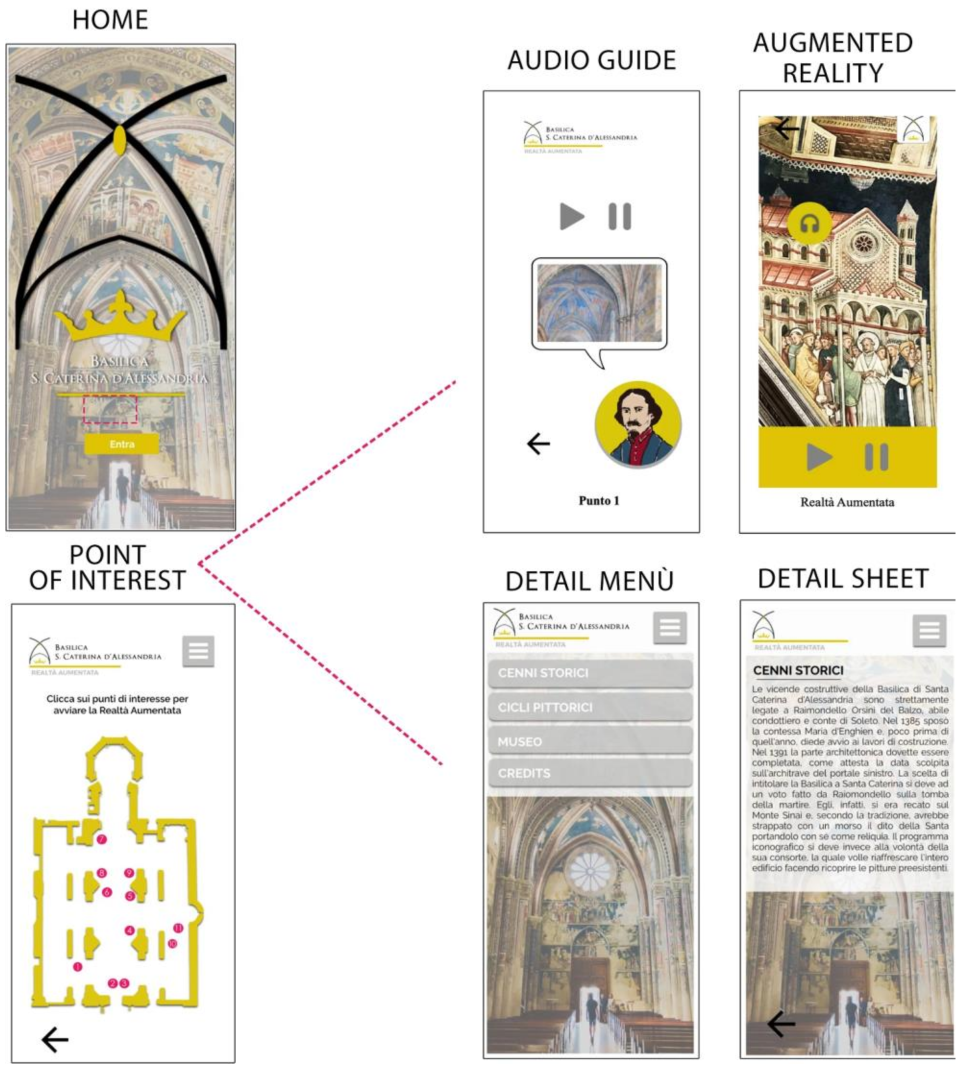
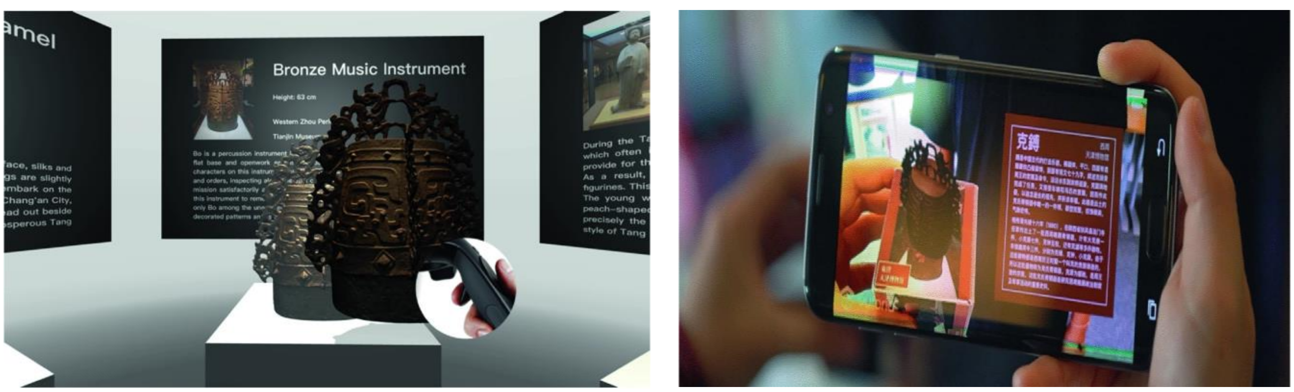


Figure 6. Proposed application demo

“A Framework for Sharing Cultural Heritage Objects in Hybrid Virtual and Augmented Reality Environments”

Expanding the social landscapes where ideas and interpretations are exchanged poses hurdles for Extended Reality (XR) technologies. A key aspect of this challenge revolves around grasping the essence of Extended Reality within the vast continuum between physical and virtual realms. As users settle into this spectrum via their preferred devices, it becomes essential to probe the feasibility of communication between users embracing different XR modes. This chapter delves into three characteristics of virtual objects and delves into the notion of a Hybrid Virtual and Augmented Reality (HVAR) environment [68]. It examines how users across various realities could interact and communicate within a shared space through objects. HVAR environments are seen as a promising avenue for interconnecting these realms, fostering interactions around virtual objects, much akin to how social media empowers user-generated content and collective interpretations. This hybrid space concept aims to bring together diverse communities, fostering discussions about objects of interest.



(a) (b)

Figure 7. (a) VR application and (b) AR application

Chapter 4 – System Design (Methodology)

In this chapter, the focus revolves around game design and a comprehensive software analysis of the application. It describes the game concept and the activities chosen to be developed in the game to deliver the goals of it. Additionally, it explains how these elements combine to provide an engaging and immersive user experience. Furthermore, a detailed software analysis discloses the underlying architecture, coding techniques, and the technological framework that powers the application. Through this in-depth analysis, the chapter aims to provide readers with a comprehensive understanding of the application's core elements.

Game Design

This section focuses on discussing game design. This section will delve into the various elements that constitute the game's design, including gameplay mechanics, user interfaces, and game activities. By thoroughly examining the game design, a solid foundation will be established for the subsequent software analysis, ensuring a holistic understanding of the application's development and functionality.

Game Concept

The game concept is about presenting cultural buildings in the user's sight as they were in real life. This requires a large area for the users to run the application, but in this way, the result is more immersive, and the users can really experience the exploration of the virtual building as they are insight. This is the core principle of the application. Present cultural buildings and try to offer the most realistic experience to the user. The provided activities also help the user to explore further every piece of information available for the buildings.

Game Activities

The application embraces game-based learning by providing captivating puzzles and matching mini-games for user engagement. It takes a thoughtful approach to maintain an immersive experience while preventing user disinterest. This is achieved by applying the principles of flow theory, which strike a harmonious balance between enjoyable and adequately challenging tasks. The presentation of content is guided by cognitive theory to optimize the learning process. Additionally, a quest-like structure is incorporated into all activities, adding a gamification element that imparts a sense of purpose and accomplishment.

Observe the Buildings

Navigating within cultural buildings becomes a captivating journey in AR, offering users the ability to traverse the intricacies of these structures with unprecedented detail. Every nook and cranny is at the fingertips of the observer, revealing the inner workings and architectural marvels that define these cultural gems. Through AR, users can immerse themselves in the historical richness of these buildings, exploring the interiors with a level of detail that transcends the limitations of traditional mediums. Technology allows for a dynamic encounter where users can engage with virtual objects within the buildings, tapping into a reservoir of information, sounds, and interactive features that breathe life into the cultural narratives housed within.

Figure 8. Cultural Building Viewing

Navigate Inside Buildings

Navigating within cultural buildings unfolds as a captivating exploration, granting users a virtual passage through historical spaces with thorough attention to detail Figure 9. This is an immersive experience for the users as they can walk through the interiors of cultural edifices and explore the architecture, decor, and historical artifacts that can be found within the buildings. From the arrangement of exhibits to the architectural intricacies, users can virtually step into the past and explore the cultural richness of these spaces. This feature not only fosters a profound connection with heritage sites but also serves as an educational tool, allowing users to absorb the historical significance of each element within the building's interior.

Figure 9. Navigation in internal space of the buildings [69]

Complete Puzzles

One of the activities available in the game involves solving puzzles related to cultural monuments Figure 10. In this activity, players must collect scattered pieces and arrange them within the designated outline of the fountain. The successful completion of the puzzle allows them to view the 3D model of the actual monument.

Figure 10. Puzzle completion within the application

Puzzle games in augmented reality (AR) have demonstrated their appeal to children [70] . However, it is essential to note that overly challenging puzzles could potentially diminish a player's confidence in the game [71]. To address this concern, the puzzles included in the application are intentionally designed to be straightforward, featuring a limited number of pieces for ease of solving.

Matching Labels

Matching labels is a classic activity usually found as mini games within applications, offering an interactive and fun educational experience Figure 11. In this game, players are presented with a set of labels that need to be correctly matched with corresponding objects or locations. This type of activity engages the users in a cognitive challenge as they pair the labels with the relevant elements. This activity not only enhances memory and cognitive skills but also adds an element of fun to the learning process. The incorporation of such games aligns with the principles of game-based learning, making education an engaging and enjoyable journey for users exploring the cultural heritage presented in the application.

Figure 11. Matching labels

Interact with Objects

Engaging with virtual objects within the buildings provides users with the opportunity to interact dynamically Figure 12. By tapping on these objects, users can explore them from various perspectives, allowing for a comprehensive understanding. This interactive experience goes beyond static observation, offering users the ability to access informative text, hear narrations, experience sounds associated with the objects, or simulate the working mechanisms of the object. The application ensures a multi-sensory encounter, enabling users to rotate and move the objects, providing a holistic exploration that enhances their cultural heritage experience. This interactive feature aligns with the overarching principles of immersive augmented reality, enriching the educational journey for users as they delve into the intricacies of historical artifacts within the application.

Figure 12. Interaction with objects within the buildings

Gameplay

The gameplay revolves around the exploration of the cultural buildings, from their positioning in the environment to navigating their interiors. Users can place the building into their environment and then look around for the details of it. While exploring, a variety of activities unveil themselves, ready to be triggered at the user's discretion. These activities manifest as quick mini games, providing brief yet engaging challenges. To maintain user engagement, the application incorporates various interaction techniques, ensuring a dynamic and immersive experience with the content.

Software Design

Application Architecture

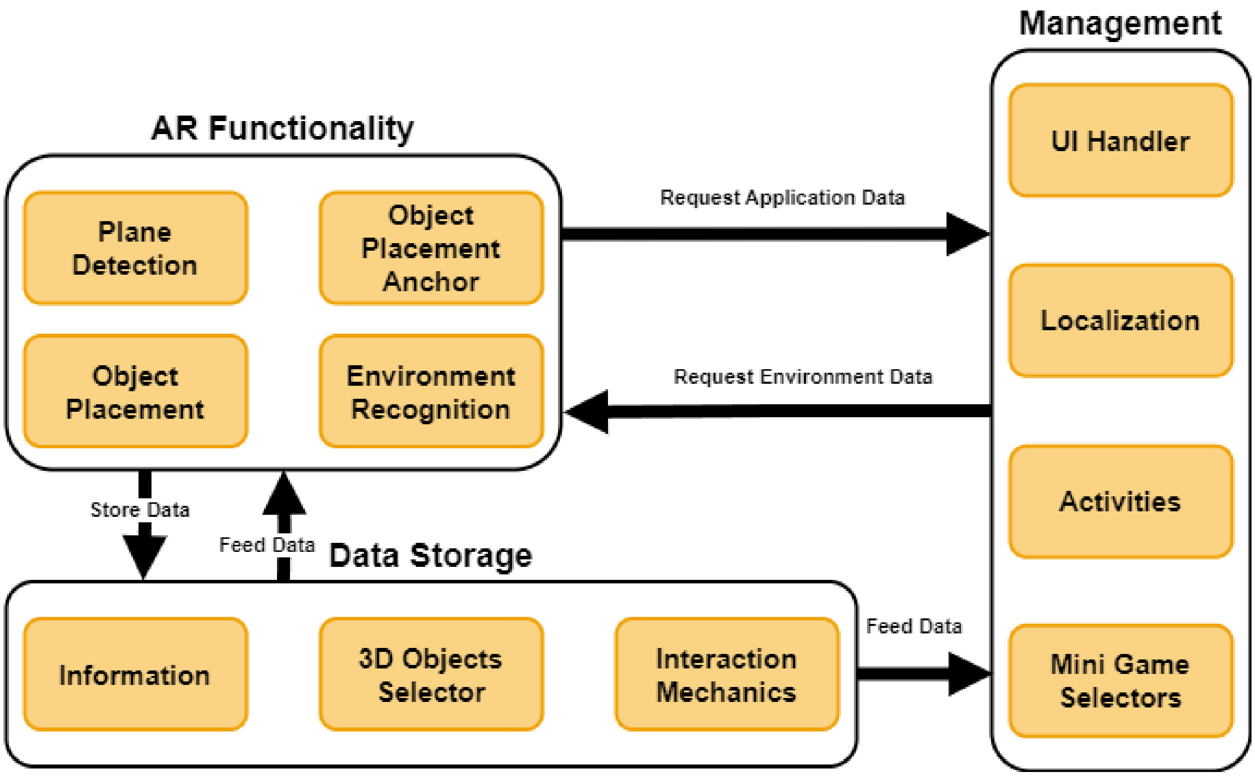


Figure 13. Cultural Buildings application Architecture

The overall architecture of the application contains three main parts, namely:

a) the AR Functionality,

b) the data storage,

c) the management.

Each of these parts encloses a set of processes responsible for the functioning of the application. The AR container defines and handles all the functions related to the environment. Such functionalities are the recognition of the environment, detection of the planes and surfaces within the environment, place the 3D object in it and assign anchors where those objects are placed so it is possible to present the object on the correct place even if it has been withdrawn from the scene and applied again.

The second container describes all the data that are stored within the application. Such data contain all the information about the mini-games, the cultural buildings that are imported in the application, and general rubrics about the application's interactions mechanisms, which are required for the launching of the activities and mini-games selectors.

The third container holds the managing functionalities of the system. These are the UI handling, the localization of the application, the activities and the mini-games selector which is used to launch the activities when requested.

Components

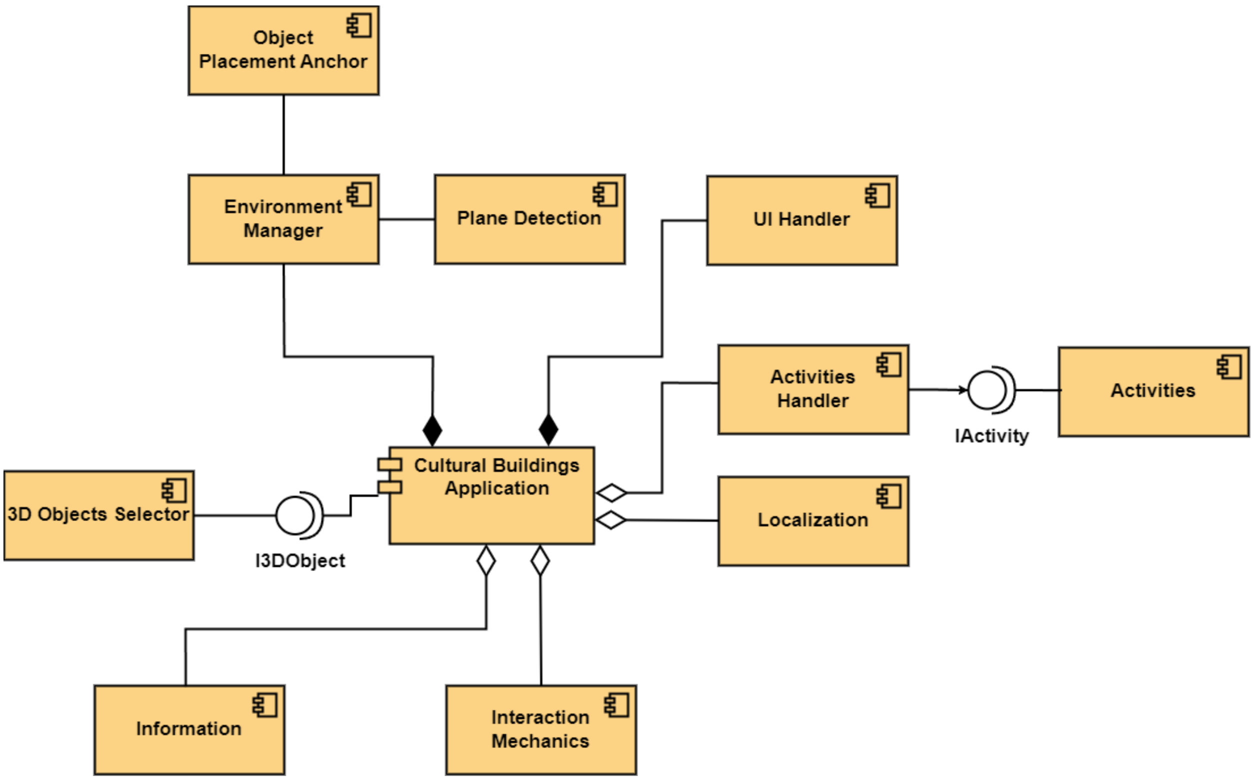


Figure 14. Application's Components Diagram

Object Placement Anchor: This component is responsible for initializing and storing an anchor containing the coordinates in the real world where an object is placed through the application. Other components can use this anchor to instantiate additional objects in the same place or swap back to the original object in the correct position.

Environment Manager: The environment manager detects and recognizes available planes for the objects to be placed. This component is responsible for providing the available locations where objects can be instantiated. Furthermore, this component manages the "Object Placement Anchor" and "Plane Detection components". Every functionality from these components is communicated to the rest of the application through this manager.

Plane Detection: This component scans and detects the environment for the horizontal and vertical planes available. This functionality is achieved through the native methods of each platform, leaving this component to act as a wrapper mediator.

UI Handler: Handling all the user interfaces of the application. Every option, notification, and navigation menu respond to the "UI Handler" commands. Through this component, every part of the UI is instantiated when it is required.

3D Objects Selector: The way that objects are selected and how they behave upon selection is handled by this component.

Information: Information stores all the required data about the content of the application.

Interaction Mechanics: The various interaction mechanics within the application are stored and accessed by this component.

Localization: Localization is a component that handles all the text of the application. This is the official way for Unity to handle multilanguage applications, and in order to comply with this design, this component stores the texts in Unity's proposed structure.

Activities Handler: The "Activity Handler" is responsible for the instantiation of each activity, as well as handling their overall lifecycle and ensuring their correct execution.

Activities: The "Activities" component describes the functionalities and content of each activity. In this component, each activity is defined and awaits to be called from the "Activity Handler".

Flowchart

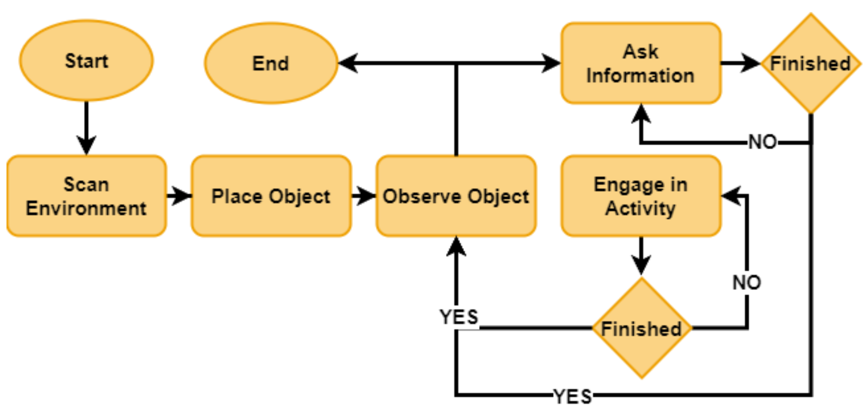


Figure 15. Basic Flow of the Application

Chapter 5 – Implementation

The application integrates game-based learning through captivating puzzles and interactive matching mini-games designed to engage users effectively. The principles of flow theory are meticulously employed to create an immersive experience that sustains engagement. By adeptly balancing enjoyable yet challenging tasks, the application ensures users remain engrossed and enthusiastic.

Furthermore, cognitive theory guides the strategic presentation of content, optimizing learning outcomes by delivering information in an effective manner. Adding to the experience, a quest-like approach is embedded in all activities, serving as a gamification element that instills users with a sense of purpose and accomplishment. This multifaceted approach amplifies user engagement and enriches their interaction with the application.

Development Tools and Platforms

Unity

The Unity 3D game engine [72] serves as a software framework that simplifies the creation of diverse applications like 2D, 3D, augmented reality, and virtual reality experiences. It comes packed with pre-built features, handling complex concepts like rendering and physics that can be daunting for users. Opting for this game engine for our project was driven by a few compelling factors. Unity boasts a user-friendly interface that's accessible to newcomers. It offers an extensive range of tutorials, catering from beginner to advanced levels, and well-structured documentation about its development tools and functions.

Unlike other game engines, Unity stands out with its intuitive editor and drag-and-drop capabilities, allowing content creation without coding. It's beginner-friendly and doesn't demand any payment until you've reached a certain revenue level. Unity's popularity is backed by 45% of independent developers who prefer it over other options. Sharing projects is a breeze with Unity's project and asset store, enabling easy downloads and imports. Importing and exporting projects are straightforward, thanks to its in-built tools.

Another asset of Unity is its compatibility with diverse platforms like Android, Windows, Linux, and Xbox. Augmented reality and virtual reality support is another strong asset, offering various avenues for developing applications, with a significant portion not requiring specific hardware. Finally, Unity’s built-in plug-ins for localization for easy conversion of languages in game, arcore xr plugin for the AR capabilities of the game, textmeshpro for handling all the texts in game and universal rp for rendering and shaders where used for this project.

AR Foundation

AR Foundation [73] is a library included in Unity's packages, responsible for engaging with augmented reality concepts. This package facilitates essential AR functionalities such as world tracking, light estimation, object tracking, human pose estimation, and eye tracking, while new functionalities arrive with every version. AR Foundation is designed around subsystems, each handling a distinct feature—like plane detection having its dedicated subsystem. Its multi-platform compatibility offers a uniform API for Android and iOS devices. To use AR Foundation, requires the installation of platform-specific augmented reality packages (ARKit for iOS and ARCore for Android). These packages contain the subsystem implementations (while AR Foundation supplies the interfaces). By wrapping the platform-specific implementations, AR Foundation delivers a unified Unity API through subsystems.

AR Foundation Remote

The AR Foundation Remote plugin is a valuable addition to Unity's AR Foundation toolkit. It simplifies the process of developing and testing augmented reality applications by allowing real-time AR experiences to be viewed directly on a connected device. This plugin bridges the gap between the Unity editor and the target device, enabling developers to observe and interact with AR content seamlessly. Through AR Foundation Remote, developers can make adjustments and refinements to their AR applications while seeing the immediate impact on the connected device. This streamlined workflow accelerates the development cycle and enhances the overall quality of AR experiences.

DOTween

DOTween is an animation engine for Unity that facilitates the creation of smooth and dynamic animations effortlessly. With DOTween, developers can bring their game objects to life by applying various animation effects, such as movement, rotation, scaling, and color changes. The intuitive and straightforward API provided by DOTween simplifies the process of creating complex animations, making it accessible even to those with limited programming experience.

The ability to create tween animations with DOTween enhances the visual appeal and interactivity of Unity projects. This tool also contributes to improved user experiences by adding fluidity and responsiveness to in-game actions. DOTween's popularity within the Unity community is attributed to its user-friendly interface, robust features, and the efficient way it handles animation sequences. Whether for games or other interactive applications, DOTween empowers developers to enhance their projects by seamlessly incorporating animations that captivate and engage users.

Quick Outline

The Quick Outline asset in Unity is a handy tool for enhancing the visual appeal of objects in a game or application. It allows developers to easily create dynamic outlines around 3D models, adding a distinct visual effect that can be customized to suit the project's style. This asset simplifies the process of highlighting objects, making them stand out in various scenarios, such as highlighting interactive items or emphasizing characters during gameplay. With its user-friendly features and versatility, the Quick Outline asset is a valuable addition to a developer's toolkit, contributing to improved graphics and interactivity in Unity projects.

Code and Algorithms

Anchor Holding

In the Start function of the script, an “anchor” variable needs to be used for holding the 3D position of the anchor point. This will be achieved by passing the anchor point’s position inside that variable. Then this variable can be used as a position parameter for object instantiation. This results in the object will instantiate in the anchor point position.

Pseudocode

1. variable anchor: to hold the 3D position of the anchor point
2. variable objectPrefab: to hold the reference to the prefab you want to instantiate
3. function Start()
4. set the anchor position to a specific 3D anchor point
5. function Update()
6. instantiate objectPrefab at the specified anchor position

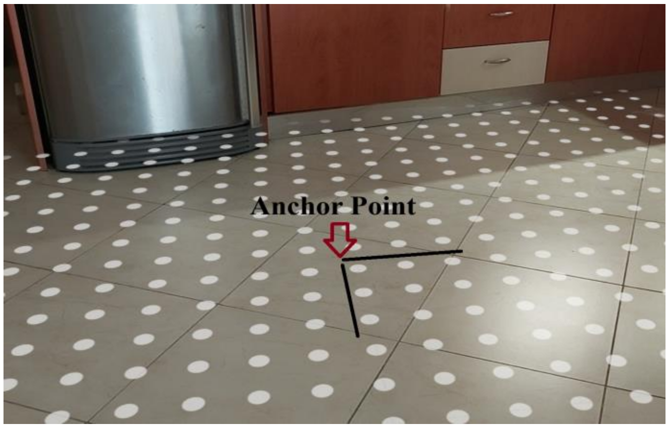


Figure 16. The anchor point position

Object Placement

For object placement an if statement is used. The if statement includes an ARRaycastManager. Unity's ARRaycastManager, is used for performing raycasts in augmented reality (AR) applications. The ARRaycastManager take three inputs: the TouchPosition representing the screen coordinates of a touch or click input, the ARRaycastHit which is used to store information about the result of raycast such as hit position and rotation, and PlaneWithinPolygon which is the type of trackable that the raycast is looking for. If that statement is true, the output is an instantiation of a 3D object prefab in the hit position.

Pseudocode

---

1. variable objectPrefab: store a reference to the prefab you want to instantiate
2. variable arRaycastManager: store a reference to the ARRaycastManager component
3. function Start()
4. initialize arRaycastManager by getting the ARRaycastManager component from the current GameObject
5. function Update()
6. if there is touch input do
7. get the first touch
8. if the touch phase is "began" do
9. pass to arRaycastManager the touch position, store the results in hits, and specify TrackableType is PlaneWithinPolygon
10. if hit is detected do
11. instantiate the objectPrefab at the position and rotation of the first hit from the raycast

---

Figure 17. 3D object placed in AR plane

Scriptable Objects for UI

Scriptable Objects are the best solution for flexible UI customization. To achieve this a script with UI data is needed. The UI data can take inputs like sprite data, button data and panel data. The next move is attaching the script to scriptable objects and then scriptable objects to UI elements. The output will be a customized UI belonging to the data passed from scriptable objects.

Pseudocode

---

1. Create a script named "UIDataScript" to hold the UI data
2. Define variables for UI data (e.g., sprite data, button data, panel data)
3. Create a method in UIDataScript to set UI customization data
4. Det the variables with the provided UI customization data

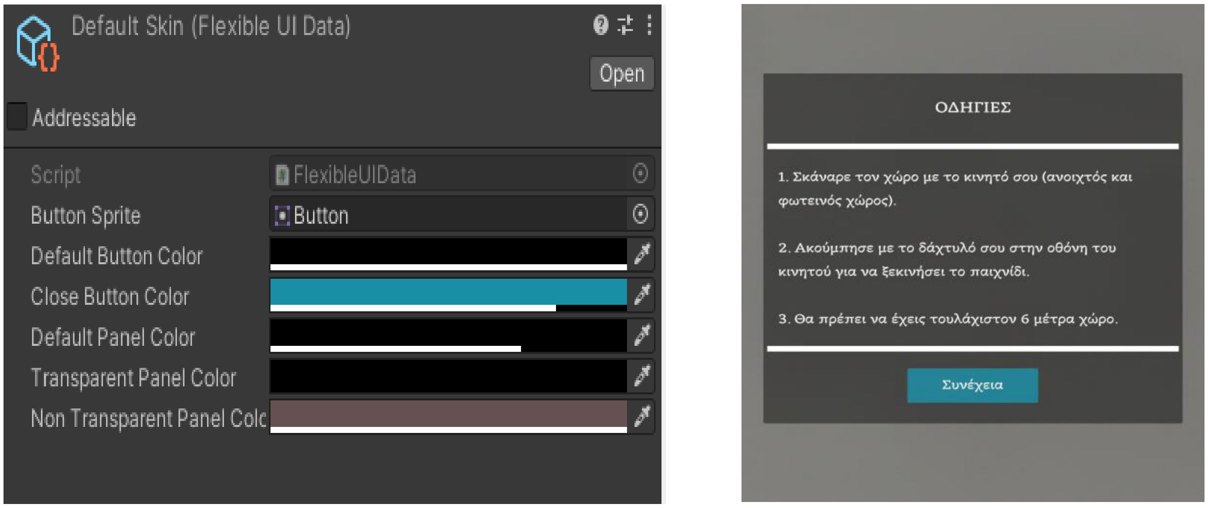
   In the Unity Editor:

5. Create Scriptable Objects of type UIData and attach UIDataScript to them
6. Customize each Scriptable Object with specific UI data (sprites, buttons, panels)

   In the UI manager script:

7. Create variables to store references to UI elements (e.g., sprites, buttons, panels)
8. Access the UIDataScript attached to the UIData Scriptable Object
9. Retrieve UI customization data from UIDataScript
10. Apply the retrieved data to the corresponding UI elements

---



(a) (b)

Figure 18. (a)The scriptable object settings and (b) the optical result in UI

Enable Activities

For enabling activities, a 3D object triggering is used. This can be achieved if colliders and tags are applied to 3D objects. Colliders are used to detect when an object is touched or when it collides with other objects. Tags allow you to identify and categorize GameObjects in your scene. A function with if statement can be used which takes as input the touch position and a game object tag comparison. Then with the use of touch the game recognizes which activity will take place.

Pseudocode

1. function Update()
2. if there is touch input do
3. get the first touch
4. create a variable ray to store a ray from the AR camera screen point to the touch position
5. use the ray, store the hit result in the variable hit
6. if the raycast hits an object do
7. if the hit object has the tag "Activity"
8. start activity

Figure 19. 3D pointer for activity triggering

Localization

Localization is used for multi-language support inside the app. To achieve localization a Localization Table is essential. This table gives all the data for text localization in the app. The most important data is the localization key which is a unique identifier or string that is used to reference a specific piece of text. Then these keys can be taken as data from scriptable objects and scriptable object can be applied to the application texts.

Pseudocode

```
variable languages: Dictionary of String to Dictionary of String to String
method LocalizationTable()
input new Dictionary() to languages variable
method AddLanguage(languageCode)
if not languages contains languageCode do
add languageCode to Dictionary
method AddTranslation(languageCode, key, translation)
if languages contains languageCode do
languageCode and key equals to translation
else do
```

```
output "Language does not exist. Add the language first."
method GetTranslation(languageCode, key)
if languages contains languageCode and languageCode contains key do
return languageCode and key
else do
output "Translation not found."
function Update()
input new LocalizationTable() to localizationTable variable
AddLanguage("language") to localizationTable
AddTranslation("language", "key", "String") to localizationTable
output GetTranslation("language", "key") from localizationTable
```

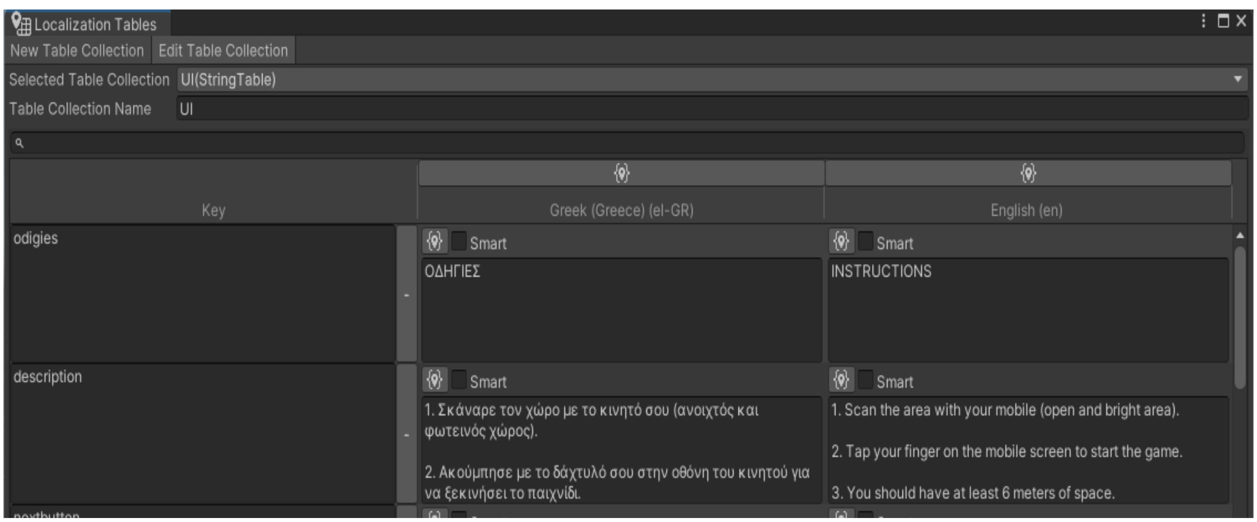


Figure 20. Localization table for UI

Object Random Position Spawning Mechanic

In the app a random spawning mechanic is used. To achieve this, a shuffle function with a for loop is needed. This function takes as input a list of positions, then the for loop takes as input the length of this positions and places each one at a random point. When this is done, another function is called which is used for object spawning. This function takes input a list of 3D objects and uses a for loop for instantiation. The for is keep looping until the number of 3D objects is completed. Inside the loop each 3D object instantiates in one of the random positions previously made.

Pseudocode

1. variable puzzleObjects: a list to store GameObjects representing puzzle pieces
2. variable spawnersPositions: a list to store Vector3 positions representing spawners for puzzle pieces
3. method ShuffleList(Vector3 list)
4. foreach element in the list do
5. swap the current element with a randomly selected element in the list
6. method InsantiatePuzzleObjects
7. Initialize an index variable to 1
8. foreach GameObject in the puzzleObjects list do
9. instantiate the current GameObject at the position specified by the corresponding spawnersPositions element
10. increment the index variable by 1

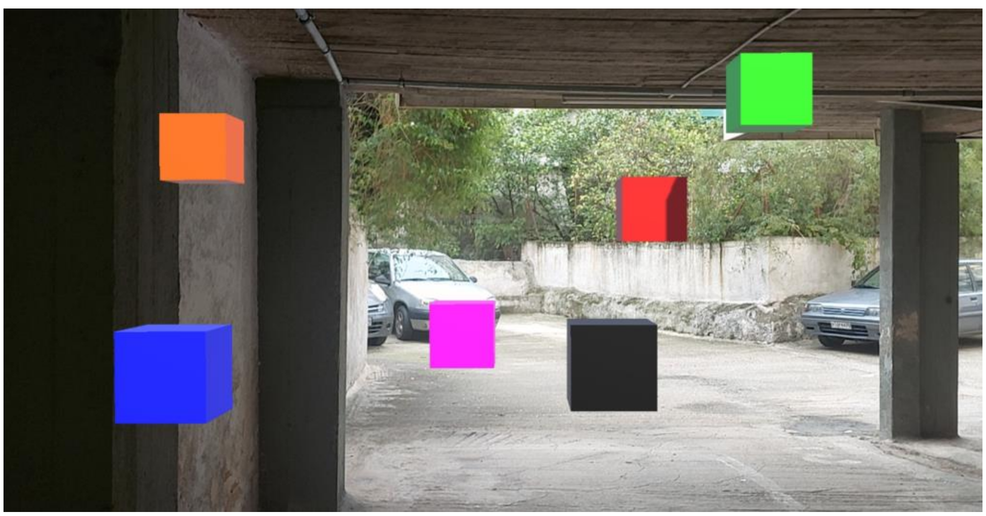


Figure 21. 3D objects spawned in random positions

System Requirements

The application is developed with low cost and portable devices in mind. For this reason the system requirements can be provided by the simpler smart phones published in market within the last 3-5 years. The only requirement for the device is to support AR Core or ARKit. The recommended hardware requirements for a smooth execution of the application include 6GB of RAM and a good CPU like the Snapdragon 845.

Chapter 6 – Results and Discussion

To evaluate the application, 7 users participated in a study using the application and, after that, answered the Game Experience Questionnaire (GEQ) [74]. This questionnaire was selected because the proposed application offers a gamified experience, and it adapts mostly to the flow of a game rather than a conventional mobile application. Table 1 shows the questionnaire with the average score per question from the users. From this questionnaire, the in-game GEQ was selected which is a sorted questionnaire for the Core Module. This is because the Core Module was too long and contained questions that were not the focus of this study.

Table 1. Game Experience Questionnaire Scores

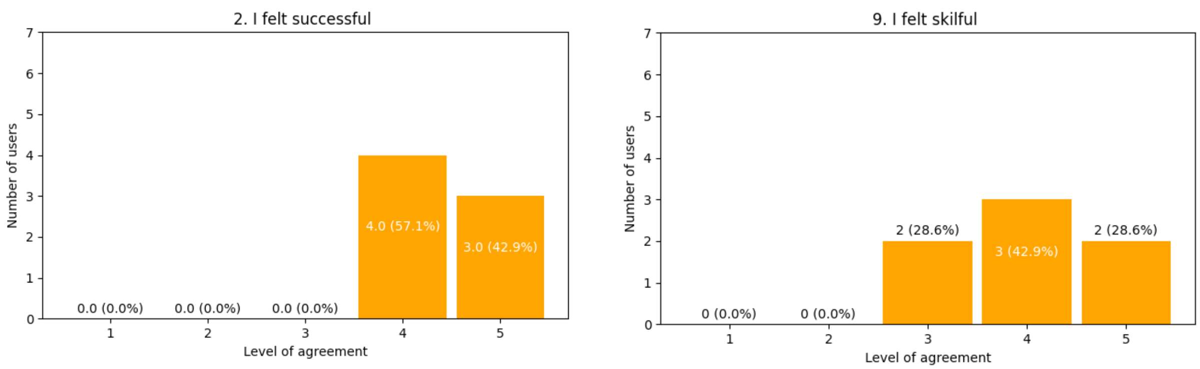
Question	Avg. Score
1. I was interested in the game's story	30
2. I felt successful	31
3. I felt bored	12
4. I found it impressive	30
5. I forgot everything about me	21
6. I felt frustrated	8
7. I found it tiresome	7
8. I felt irritable	7
9. I felt skillful	28
10. I felt completely absorbed	26
11. I felt content	30
12. I felt challenged	23
13. I had to put a lot of effort into it	17
14. I felt good	32

GEQ separates the questions into seven categories namely: a) Competence, b) Sensory and Imaginative Immersion, c) Flow, d) Tension, e) Challenge, f) Negative effect, and g) Positive effect. In the following tables (Tables 2-8) the questions for each category are outlined with the answers of the users in each question. Although the questionnaire has received criticism [75] as not a reliable source, it can provide a first impression of the resulting application.

The experimental process developed with the preparation of a Google Form. This form housed the 14 questions derived from the GEQ questionnaire. This form was made accessible through a public URL, eliminating the need for an email address or login credentials from participants. The initial page of the form presented a comprehensive project description, including the objectives, required legal information concerning personal data storage, and potential risks. Furthermore, the description provided guidelines for participation and withdrawal.

Upon finalizing the form, invitations were extended to familiar student groups of the Hellenic Mediterranean University, AISE, NILE lab members, and collaborators to install and actively engage with the resultant application. Instructions on how to use the application were not given, despite the information already available within the app. This decision was based on the desire to not influence the users on how they should engage. The procedure occurred during the personal time and in the individual settings of the participants. After completion of the application experimentation, participants were requested to complete the questionnaire, providing valuable insights into their experience.

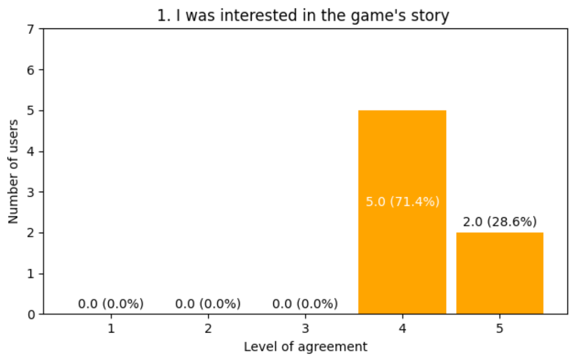
Table 2. Competence Scores



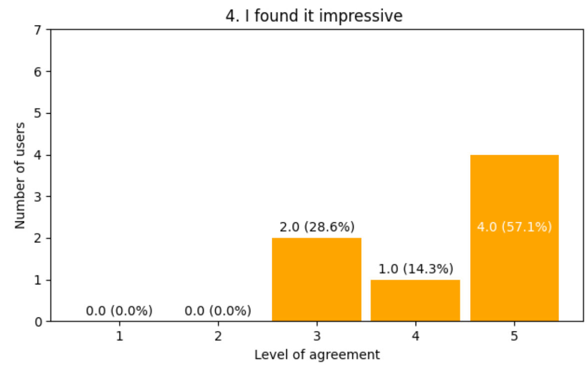
(a) **(b)**

The Competence average score is 59 deriving from questions 2 and 9. Table 2 shows the distribution of the answers between the users in those questions. As can be observed the score for this component is high with most users feeling successful while using the application, and skillful. From the distribution in question 9, two users have answered that they do not feel that skillful. This is because the activities are not designed to be hard or require an advanced skill set to be completed.

Table 3. Sensory and Imaginative Immersion



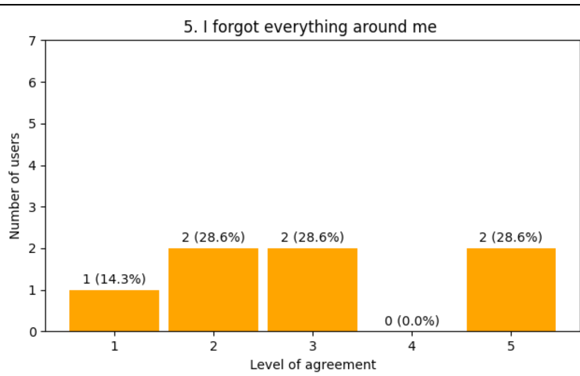
(a)



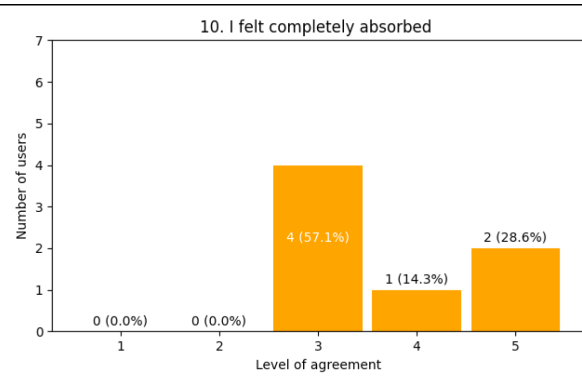
(b)

The Sensory and Imaginative Immersion average score is 60 deriving from questions 1 and 4. Table 3 shows the distribution of the answers between the users in those questions. From these plots, is inferred that the users were immersed in the augmented virtual environment of the application, while they found the story implied in the information offered for the buildings interesting.

Table 4. Flow



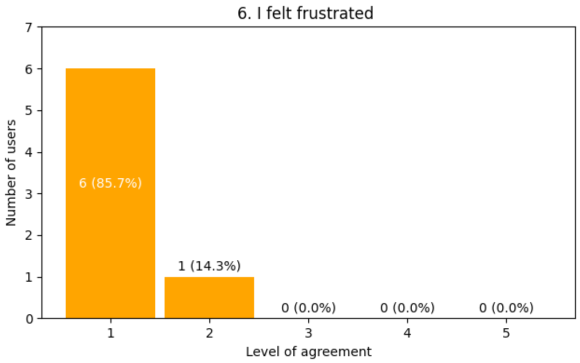
(a)



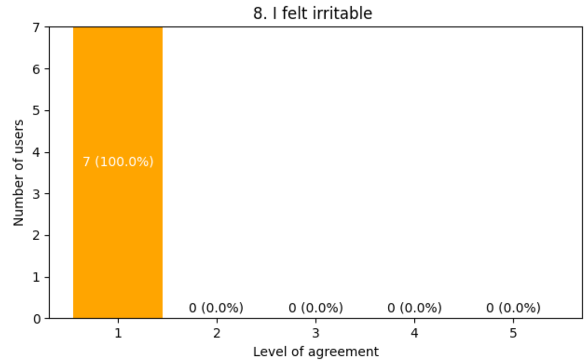
(b)

The Flow average score is 47 deriving from questions 5 and 10. Table 4 shows the distribution of the answers between the users in those questions. The flow components score is low, and that means that the users were not completely absorbed by the application. It is important to mention that the answers to these questions are not reliable as the users might misunderstand the questions and base their answers on the environment. If this is the case it is natural as the game is in AR so the users are aware of the environment most of the time.

Table 5. Tension



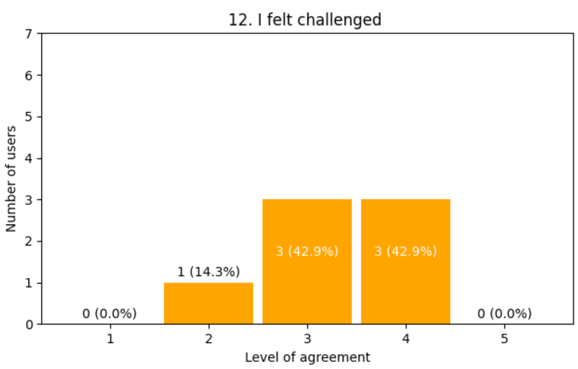
(a)



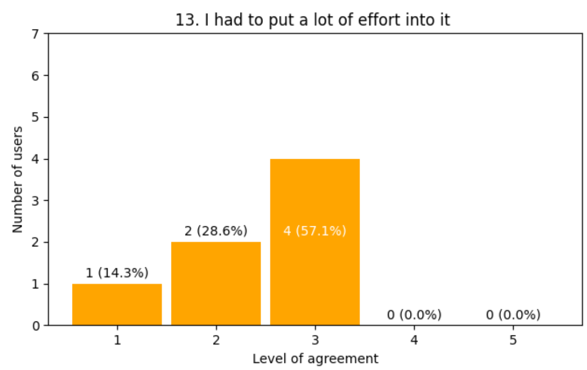
(b)

The Tension average score is 15 deriving from questions 6 and 8. Table 5 shows the distribution of the answers between the users in those questions. Tension components answers are on the lowest possible values, except for one user the answer presents possible frustration. This confirms the choices about activities flow and difficulty levels within the application. It is important at this stage that the game ensures a relaxing experience.

Table 6. Challenge



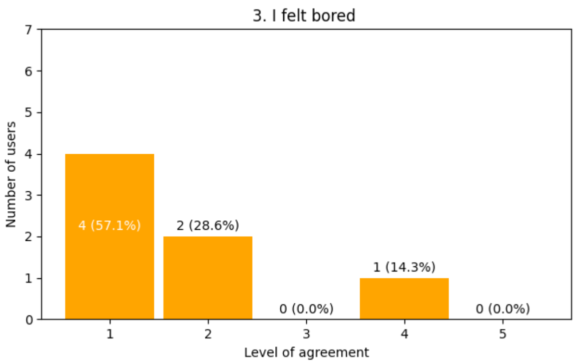
(a)



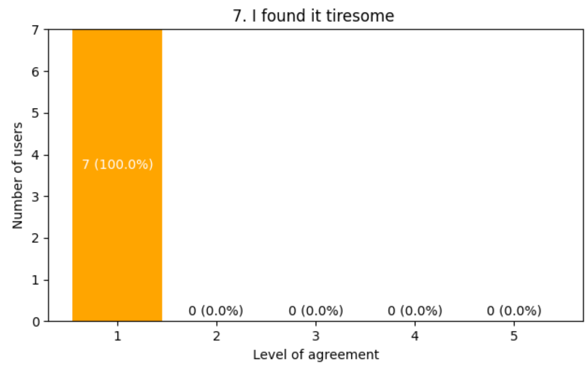
(b)

The Challenge average score is 40 deriving from questions 12 and 13. Table 6 shows the distribution of the answers between the users in those questions. These questions show that the challenge levels of the activities are not high. This is intentional, as the application addresses a wide range of users, where not everyone likes to be challenged. At this point, it is important to note that we have not taken into account player styles which might reveal that some of the users would like higher levels of tension, and the desire to feel skillful and challenged. Measuring the player styles and possibly trying to adapt these levels depending on the style within the application in real-time would be an interesting feature for future work.

Table 7. Negative effect



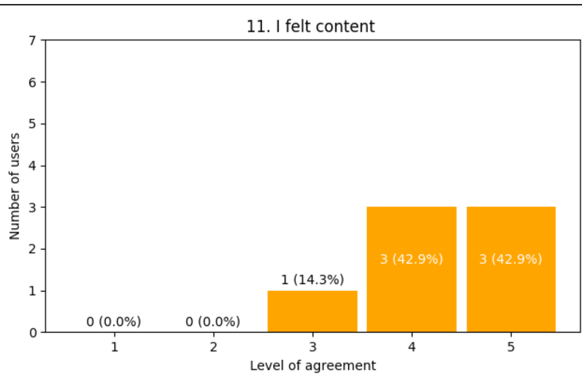
(a)



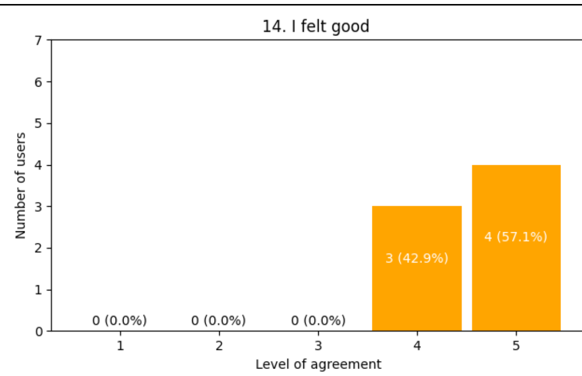
(b)

The Negative effect average score is 19 deriving from questions 3 and 7. Table 7 shows the distribution of the answers between the users in those questions. Negative effect components conclude that the game is pleasant to engage in (question 7). Question 3 shows that some users find the game boring. This effect might be due to the player styles which we have not considered at this stage.

Table 8. Positive effect



(a)



(b)

The Positive effect average score is 62 deriving from questions 11 and 14. Table 8 shows the distribution of the answers between the users in those questions. Finally, from these questions, the conclusion is that the application leaves a good feeling of satisfaction and happiness to the users.

Chapter 7 – Conclusion and Future Work

Conclusion

In this thesis, a gamified application for cultural building promotion using AR is presented. Through the application, the user has the ability to navigate and observe cultural buildings from every angle and engage in activities provided within those buildings. The application provides information about those buildings to the user when requested. This type of presentation and interaction with cultural buildings in AR has shown that user perception has increased. Through those mini-games, interest in, and engagement with the content are highly increased, leading to high user satisfaction levels.

Future Work

Create a user-friendly interface in Unity for non-programmers to add new buildings and configure activities. This intuitive interface should allow users to add new buildings with details like names, descriptions, and visual representations. This interface should facilitate the definition of essential information about buildings, activities, and mini games. Users should be able to use visual or audio tools integrated into Unity's interface or inspector. To enhance accessibility, visual tools should support drag-and-drop functionality, graphical parameter settings, and tooltips for guidance. Audio tools can provide spoken prompts, ensuring an inclusive experience. This approach aims to democratize the customization of the virtual environment, making it accessible to a broader audience with diverse skill sets and abilities.

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