LUMINA: A HANDHELD AR BASED PUZZLE GAME

BY

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A REPORT

SUBMITTED TO

Universiti Tunku Abdul Rahman

in partial fulfillment of the requirements

for the degree of

BACHELOR OF COMPUTER SCIENCE (HONOURS)

Faculty of Information and Communication Technology

(Kampar Campus)

JUNE 2024

UNIVERSITI TUNKU ABDUL RAHMAN

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It is hereby certified that Chiu Ken Boon (ID No: 22ACB00361) has completed this final year project entitled "Lumina: A Handheld AR based Puzzle Game" under the supervision of Dr. Ng Hui Fuang (Supervisor) from the Department of Computer Science, Faculty of Information and Communication Technology.

I understand that University will upload softcopy of my final year project in pdf format into UTAR Institutional Repository, which may be made accessible to UTAR community and public.

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ACKNOWLEDGEMENTS

Firstly, sincere appreciation goes to Dr. Ng Hui Fuang for his unwavering guidance, mentorship, and profound expertise throughout this project. His invaluable insights and advice have played a pivotal role in defining the project's trajectory and approach. Furthermore, his meticulous feedback, insightful suggestions, and thorough review of project deliverables have significantly contributed to enhancing the overall quality of the project.

Secondly, heartfelt gratitude is extended to Universiti Tunku Abdul Rahman for granting the opportunity to undertake a study on the handheld AR based puzzle game as my graduation project. The university's support and encouragement have been instrumental in facilitating the execution of this endeavour.

ABSTRACT

In the realm of interactive entertainment, the fusion of technological advancements and classic gaming concepts has led to the creation of innovative experiences. The mobile games have dominated the market. However, the prevalence of AR puzzle game still remaining relatively low due to different difficulties in attracting users. In this project, a handheld AR based puzzle game will be developed to address the challenge of infusing traditional puzzle genres with novel elements and aims to reshape the way players engage with gaming environments. The project's objectives encompass the design and development of an AR-based puzzle game that leverages light reflection mechanics as fundamental gameplay elements. To achieve the objective, Rapid Application Development methodology is adopted. The Unity Game Engine and Vuforia SDK are used for development. This project contributes to the evolution of AR technology in the gaming industry by introducing an immersive and intellectually stimulating gaming experience. By blending the real and virtual worlds seamlessly, the game offers players an interactive journey that pushes the boundaries of puzzle-solving and AR exploration.

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LIST OF ABBREVIATIONS

AR	Augmented Reality
RAD	Rapid Application Development
SDK	Software Development Kit
UI	User Interface
UX	User Experience
AR	Augmented Reality
RAD	Rapid Application Development
GEQ	Game Experience Questionnaire

CHAPTER 1 Introduction

1.1 Problem Statement and Motivation

The motivation for this project stems from the need to address the current limitations in AR-based puzzle gaming, specifically concerning engagement and innovation. While mobile gaming dominates the market, AR games, especially those centered on puzzles, remain relatively underutilized [1]. Existing AR puzzle games often fail to captivate users due to a lack of engaging and challenging puzzle designs, poor performance optimization, and subpar user experience and interface design. These issues hinder user enjoyment and limit the potential of AR gaming to provide immersive experiences that blend the virtual and physical worlds seamlessly.

The primary problem to be addressed is the lack of captivating and challenging puzzle designs in AR gaming. Many existing AR puzzle games fail to strike a balance between providing puzzles that are both challenging and solvable, resulting in player dissatisfaction and disengagement. Additionally, poor performance optimization leads to frustrating gameplay experiences, as users encounter lag, glitches, and other technical issues that disrupt immersion and enjoyment. Furthermore, inadequate user experience and interface design detract from the overall gameplay experience, making it difficult for players to navigate the game and engage with its mechanics effectively.

To tackle these challenges, this project intended to develop a handheld AR-based puzzle game that offers innovative gameplay mechanics and a captivating user experience. By incorporating the concept of light reflection into puzzle challenges, the game will provide players with intellectually stimulating and visually engaging gameplay experiences. Through thoughtful design and optimization, the game will deliver smooth and responsive gameplay on mobile devices, ensuring that players can enjoy immersive AR experiences without technical hindrances. Additionally, the game will prioritize intuitive user interfaces and controls to enhance player engagement and facilitate seamless interaction with the game world. Overall, the project seeks to elevate the standards of AR puzzle gaming, providing players with unique and rewarding gaming experiences that leverage the full potential of AR technology.

1.2 Objectives

The objectives of this project encompass several key aspects aimed at addressing the

identified problems and fulfilling the project's overarching goals:

- To design and develop a handheld AR-based puzzle game that leverages the capabilities of AR technology to overlay virtual puzzles onto the real-world environment.
- To introduce an AR-based puzzle game that incorporate light reflection mechanics as gameplay element.
- To enhance the gameplay experience of players in a diverse range of challenging puzzles.

Firstly, the aim is to design and develop a handheld AR-based puzzle game that capitalizes on the capabilities of AR technology. This involves overlaying virtual puzzles seamlessly onto the real-world environment, thereby creating an immersive experience where players can interact with puzzles in their immediate surroundings. By merging virtual and physical elements, the game aims to offer a unique and captivating gameplay experience.

Secondly, the project seeks to introduce light reflection mechanics as a core gameplay element within the AR-based puzzle game. This objective entails designing puzzles that require players to manipulate light and reflections strategically to overcome challenges. By incorporating this innovative mechanic, the game aims to provide players with intellectually stimulating gameplay that encourages creative problem-solving and experimentation.

Furthermore, the project aims to enhance the gameplay experience by offering a diverse range of challenging puzzles. This involves creating puzzle designs that cater to different skill levels, ensuring that players are continually engaged and motivated to progress through the game. By providing varied and engaging challenges, the game aims to captivate players' interest and maintain their engagement over time. Through these objectives, the project aims to deliver a compelling and rewarding gaming experience that showcases the potential of AR technology in the puzzle game genre.

1.3 Project Scope

The project scope entails the creation of a handheld Augmented Reality (AR)-based puzzle game that prominently features light reflection mechanics as a core gameplay element. This game aims to engage players by seamlessly integrating virtual puzzles into their real-world surroundings using AR technology.

By leveraging AR capabilities, players will interact with puzzles visible through their device's camera, strategically manipulating mirrors and objects to redirect beams of light and

solve puzzles of increasing complexity. The game will offer diverse thematic stages, each containing a set of puzzles, fostering a sense of progression. The project will prioritize a user-friendly interface and intuitive controls to facilitate player engagement and interaction.

1.4 Contributions

The proposed handheld AR-based puzzle game has the potential to offer a unique and immersive gaming experience, blending the real and virtual worlds seamlessly. The proposed puzzle game introduces a novel approach to gameplay by incorporating the principles of light reflection. This novel mechanic challenges players to think critically and creatively while interacting with the real world. It can serve as an engaging and educational tool, stimulating players' cognitive abilities while providing entertainment.

Furthermore, this project involves the complete design and development of the AR puzzle game, from concept creation to software implementation. Thus, this project will contribute to the advancement of AR technology in the gaming industry and provide valuable insights into designing interactive and user-friendly AR applications.

1.5 Background Information

Mobile Augmented Reality (AR) games have witnessed significant growth due to the widespread adoption of modern smartphones and tablets equipped with large screens, powerful processors, and cameras. These games blend virtual content seamlessly into real-world environments, offering context-sensitive experiences to users. Beyond mere entertainment, AR games hold immense potential for learning and engagement [2].

Mobile AR games leverage cutting-edge technologies such as AR, VR, and AI. As the AR game development market continues to expand, businesses are increasingly integrating these technologies to enhance user experiences. The estimated market value for AR game development is projected to reach $33.5 billion by 2027 [3].

As AR technology continues to evolve, future AR game development will likely focus on enhancing user engagement, refining interaction models, and exploring novel ways to merge physical and digital realities. This project embarks on an enthralling journey into game development, introducing an inventive project that harnesses the capabilities of AR technology. The aim is to create an AR-based puzzle game that skillfully incorporates the concept of light reflection, offering an immersive and intellectually captivating gaming venture.

1.6 Report Organization

This report is organized to provide a comprehensive overview of the project, from initial introduction through to conclusions and recommendations. Chapter 1, "Introduction," sets the stage for the report by outlining the problem statement and motivation behind the project, detailing the objectives, defining the project scope and direction, and highlighting the contributions and background information relevant to the study.

Chapter 2, "Literature Review," offers a thorough examination of existing research and development tools pertinent to the project. It discusses various AR game development tools, such as Unity 3D and the Vuforia SDK, and explores the design principles behind mobile AR games. This chapter also reviews existing systems and concludes with a summary of key insights gained from these systems.

Chapter 3, "System Methodology," describes the methodology employed in designing the system. It includes the system design diagram, detailing the methodology, system architecture, use case scenarios, and activity diagrams, which provide a structured approach to understanding the system's functionality and workflow.

In Chapter 4, "System Design," the focus shifts to the specifics of system design. It includes a system flowchart and a diagram of system components, illustrating the detailed design and the interplay of different elements within the system.

Chapter 5, "System Implementation," delves into the practical aspects of implementing the system. This chapter covers hardware and software setup, configuration, operational procedures, and any issues and challenges encountered during implementation. It concludes with a remark summarizing the implementation phase.

Chapter 6, "System Evaluation and Discussion," focus on the evaluation of the application, including testing setups and user playtest results. It discusses the refinements made based on initial feedback and assesses how these changes affected the system's performance and user experience. The chapter also addresses project challenges and evaluates whether the project objectives were met.

Finally, Chapter 7, "Conclusion and Recommendation," wraps up the report by summarizing the key findings and providing recommendations for future work. It offers a conclusion based on the project outcomes and suggests areas for further development or improvement.

CHAPTER 2 Literature Review

2.1 AR Game Development Tools

2.1.1 Unity 3D in AR Game Development

The evolution of augmented reality (AR) technology has brought about transformative possibilities in the realm of game development. One of the most versatile tools for harnessing these possibilities is the Unity 3D game engine. This section delves into the pivotal role that Unity 3D plays in addressing challenges and optimizing gameplay experiences within AR-based game development, as evidenced by the findings of a study by [4], [5].

Unity 3D emerges as a robust solution to challenges faced in early AR game prototypes. The study [4] highlights how Unity 3D effectively resolved issues that arose during the development of a prototype AR game. Particularly, the integration of virtual buttons through Unity's framework enhanced the intuitiveness of user interactions. This approach allowed players to engage more realistically by directly employing their fingers, revolutionizing the interaction dynamic between users and virtual elements.

Selecting a robust tool with extensive features is essential for the development of a successful game, and Unity emerges as a compelling choice in this regard. As discussed in [5], Unity 3D not only provides a comprehensive set of features but also boasts ease of learning and usability. Additionally, it offers a cost-effective solution, with a free version encompassing most functionalities. For developers requiring advanced features, the option to upgrade to the paid version remains available, ensuring flexibility to meet diverse development needs.

The speed and ease of development facilitated by Unity 3D are noteworthy aspects that emerged from the study. The article [4] highlights that the Unity version of the game was developed more swiftly and with less programming effort than the initial prototype. This underscores Unity's capacity to streamline the development process and empower developers with an intuitive toolkit. By expediting development, Unity provides game creators the space to allocate more time to refining gameplay mechanics and optimizing user experiences.

In conclusion, the utilization of Unity 3D in AR game development offers multifaceted benefits. It effectively addresses challenges related to interaction design, graphical expression, and development efficiency. The study [4], [5] demonstrates Unity's pivotal role in mitigating challenges and enhancing user experiences, underscoring its significance in the ever-evolving landscape of augmented reality game development.

2.1.2 Vuforia SDK in AR Game Development

Augmented Reality (AR) has emerged as a dynamic field in mobile applications and human-computer interaction. The integration of Vuforia within AR development, as explored in [6], [7], [8], showcases its pivotal role in elevating AR experiences.

Vuforia, an AR Software Development Kit (SDK) by Qualcomm, introduces a powerful dimension to AR applications. It employs cutting-edge computer vision technology to detect and capture planar images and 3D objects in real-time. This process allows for the seamless juxtaposition of virtual content onto the physical world, creating a tangible bridge between the two.

The article [7] emphasizes Vuforia's role in generating real-time feedback by superimposing virtual objects on live camera feeds. This feedback loop offers users a compelling experience where the virtual seamlessly integrates with the real. Such synchronization is instrumental in fostering a sense of presence within augmented environments.

Moreover, the integration of Vuforia SDK ensures compatibility with a wide range of mobile devices, eliminating the need for specialized hardware like Head Mounted Devices (HMDs) [6]. This versatility makes the AR system suitable for deployment in various educational environments, thereby enhancing character education initiatives effectively.

In summary, Vuforia's contribution to AR is monumental. By merging real-world inputs with virtual overlays, Vuforia propels AR experiences to new heights. Its advanced computer vision capabilities, dynamic tracking, and interactive features provide developers with the tools to create captivating AR applications that blur the lines between the physical and digital realms.

2.2 Mobile AR Games Design

Mobile Augmented Reality (AR) games have emerged as a significant area of interest within the field of digital game design, combining the physical world with virtual elements to create immersive experiences. The motivations behind playing digital games, particularly AR games, are multifaceted and have been explored in various studies.

A review by Shimul et al. highlights the diverse motivations that drive individuals to engage with digital games [9]. These motivations range from social interaction to the fulfillment of personal achievements. The immersive nature of AR games amplifies these motivations by

integrating the real-world environment, thus enhancing the player's engagement and experience.

The evolution of mobile technology has played a pivotal role in the development of AR games. With the advent of smartphones equipped with advanced sensors, cameras, and processing capabilities, AR games have become more accessible and sophisticated. The IEEE paper on AR games design discusses the technological underpinnings that enable these games to overlay virtual content onto the real world seamlessly [10].

Wetzel et al. provide insights into the design considerations for mobile AR games [11]. The paper emphasizes the importance of context-awareness, user interface design, and the balance between real-world and virtual elements. It also discusses the challenges of creating AR games that are both entertaining and usable in a variety of physical spaces.

2.3 Existing Systems

2.3.1 Archaica: The Path of Light

"Archaica: The Path of Light" is a puzzle game developed by Two Mammoths, a small independent game development studio [12]. The game was released in 2017 and is available on various platforms.

This game is known for its visually stunning art style and challenging puzzle gameplay mechanics centred around manipulating beams of light. In the game, players are tasked with solving intricate puzzles by manipulating mirrors, prisms, and other objects to guide beams of light to specific targets. The puzzles are often set within beautifully crafted environments, adding to the overall atmosphere of the game, as shown in Figure 2.1.

The game combines elements of logic and creativity, requiring players to think critically and strategically to find solutions to increasingly complex puzzles. The concept of using light as a central gameplay mechanic sets it apart from traditional puzzle games and adds an element of scientific curiosity to the gameplay.

Figure 2.1 Archaica: The Path of Light

Strength:

- Provides tutorial which helps the player to understand the mechanisms of the game.
- Beautiful aesthetic and extraordinary atmosphere in every single scene. The game boasts visually captivating environments with intricate details and a polished aesthetic.
- Innovative gameplay concept. The central mechanic of using mirrors to manipulate beams of light introduces a fresh and engaging puzzle-solving concept.

Weakness:

- Poor optimization, some players reflect that they have low fps while playing the game. Also, sometimes the game will have crashes that locked up the game.
- Poor implementation of achievement system. The game records the player progress permanently. If the players failed to complete one of the achievements, they have to delete their game data to reset the game in order to acquire 100% achievement completion.

2.3.2 Cyberlaser

"CyberLaser" offers an enchanting journey into the realm of augmented reality (AR) puzzle gaming, where players are invited to explore a captivating interplay between digital challenges and their physical environment [13]. This innovative game seamlessly melds the real world with intricate puzzles that revolve around the manipulation of laser beams to reach energy crystals. This is achieved through a combination of strategic mirror placement, skillful portal usage, and calculated explosions.

At the heart of "CyberLaser" lies a gameplay mechanism that ingeniously integrates augmented reality technology. By placing the game's hologram on a flat surface, an AR gaming board materializes, creating an interactive space that serves as the canvas for puzzle-solving endeavours. A well-lit indoor or outdoor environment is essential to fully embrace the immersive AR experience.

Within this inventive framework, players are tasked with delicately manoeuvring laser beams to their targets. This involves strategic manipulation of mirrors, precise utilization of portals, and the calculated use of controlled explosions to navigate toward energy crystals as shown in Figure 2.2. The game's strength lies in its seamless amalgamation of creative problem-solving and precision execution as players navigate through intricate puzzles.

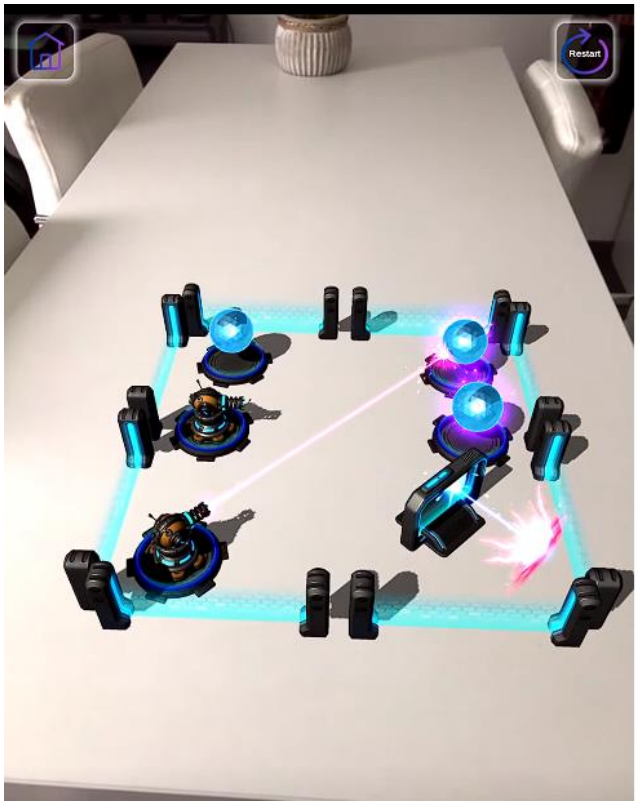

Figure 2.2 Cyberlaser

Strength:

- Innovative augmented reality integration. AR-based gaming board in real life environment enhance the gameplay experience.
- Chaptered progression and content variety. The game's division into distinct chapters, each with its own thematic focus and challenges, enhances the sense of progression and variety.
- Engaging puzzle mechanics. The game's intricately designed levels progressively introduce new elements, fostering engagement and intellectual growth.

Weakness:

- Short playtime. The overall playtime might be perceived as relatively short. Players could potentially desire more content or extended gameplay to enhance longevity.
- Limited game mechanism. The puzzle mechanism is too simple and keep repeating in the whole game.
- The lack of storyline and achievement system makes the game fails to motivate players to keep playing the game.

2.3.3 Monument Valley

"Monument Valley" is a captivating puzzle game that artfully merges surreal landscapes with mind-bending challenges [14]. Developed by ustwo games, the game invites players to guide Princess Ida through a series of visually mesmerizing levels characterized by impossible architecture and optical illusions. Lauded for its innovative mechanics, breathtaking visuals, and evocative storytelling, the game has received numerous accolades, including the Apple Design Award and BAFTA recognition, cementing its position as a standout in the puzzle genre.

Figure 2.3 illustrates the gameplay, where players control the character Princess Ida as she journeys through a series of mazes designed with optical illusions and seemingly impossible geometric shapes. These mazes, known as "Sacred Geometry," serve as the core challenge of the game, and the player's goal is to navigate through them. The game utilizes an isometric perspective, requiring players to manipulate the environment to uncover hidden routes and reach the end of each level. It consists of ten levels, each featuring a unique central mechanic. Player actions involve moving platforms, manipulating totems, and constructing bridges to progress.

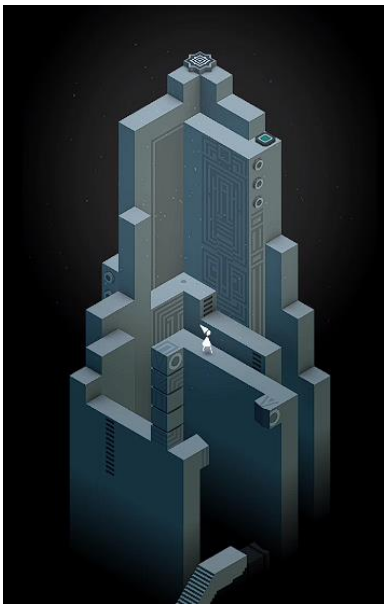

Figure 2.3 Monument Valley

Strength:

- Incredible art and sound design. The game's ethereal soundtrack complements its visuals, creating a cohesive and immersive atmosphere.

- Unique gameplay design. The game introduces unique gameplay mechanics that center around manipulating impossible architecture which is a strong interaction gameplay.
- Well designed storyline and background world. The game's narrative is delivered subtly through its environments, interactions, and the emotional journey of its characters.

Weakness:

- Lack of difficulty. The game's puzzles are designed to be accessible, which may result in experienced puzzle enthusiasts finding the challenges to be less difficult than desired.
- Short playtime. “Monument Valley” is relatively short, with only a few hours of gameplay required to complete the main story.
- Poor AR experience. The game integrated AR function but only to display the game elements, not involving the gameplay.

2.3.4 YuMe: Alice’s Dream

"YuMe: Alice’s Dream" is an alluring augmented reality (AR) puzzle game developed by NetEase Games. Set within an ethereal and dreamlike fantasy realm, the game follows the journey of Alice, a protagonist on a quest to recover her lost memories. Through the artful amalgamation of surreal landscapes and captivating musical accompaniment, the game delivers an immersive and visually captivating experience.

Central to "YuMe: Alice’s Dream" is a series of intricate puzzles that exploit optical illusions and visual perception. By manipulating the AR environment, players must strategically align objects and surmount challenges, thereby engendering a distinctive and thought-provoking gameplay dynamic, as shown in Figure 2.4. The puzzles exhibit a sophisticated level of complexity, necessitating players to actively interact with their physical surroundings and engage in creative problem-solving to advance.

"YuMe: Alice’s Dream" transcends the bounds of mere puzzle-based diversion, presenting an artistic odyssey that fuses evocative visuals, immersive storytelling, and pioneering AR mechanisms. The amalgamation of optical illusions and engaging puzzles not only challenges players’ cognitive faculties but also offers a serene and contemplative gameplay experience. Whether one is a neophyte in the realm of AR gaming or a seasoned enthusiast, "YuMe: Alice’s Dream" beckons players to traverse a domain where perception and imagination interlace.

Figure 2.4 YuMe: Alice’s Dream

Strength:

- Artistic visual design. The game's incorporation of traditional Chinese landscape paintings and artistic aesthetics creates a visually captivating and culturally rich environment.
- Innovative AR puzzle mechanics. The integration of optical illusions and spatial manipulation challenges players' perception and encourages creative problem-solving.
- Physical interaction. The requirement to move around and view puzzles from different angles encourages physical movement and engagement with the game environment, providing a unique and immersive aspect of gameplay.

Weakness:

- Limited challenge. The puzzle difficulty may be perceived as relatively moderate, potentially leaving experienced puzzle enthusiasts wanting more complex challenges to solve.
- Tracking accuracy. Some players may experience tracking issues that disrupt the seamless integration of AR elements into the real world, affecting the overall gameplay experience.
- App interruptions. The game does not remember the player's last location when switching to another app, requiring them to start from the beginning of a level.

2.3.5 Summary

Table 2.1 Summary of Existing Systems

	2.3.1 Archaica: The Path of Light	*2.3.2 Cyberlaser*	*2.3.3 Monument Valley*	*2.3.4 YuMe: Alice's Dream*
Mobile App?	Yes	Yes	Yes	Yes
Support AR?	No	Yes	Limited	Yes
Has storyline?	Yes	No	Yes	Yes
Difficulty?	High	Low	Moderate	Low
Playtime?	Long	Short	Short	Moderate
Achievement system?	Yes	No	Yes	Yes

In the proposed system, the developed application should have fully support for AR. Also, an impressive graphic design should be integrated into the game to add depth and context to the player's gameplay experience. Next, the difficulty of the puzzles should increase from easy to hard as the game goes on. However, the players might be frustrated if they failed to find out the solution. Hence, there should be a measurement of puzzle difficulty to avoid such situation. To increase the playtime, the most effective way is to develop more stages and story. Despite this fact, it is hard to achieve while the development team is small. Hence, the more effective way is to integrate an achievement system.

CHAPTER 3 System Approach

3.1 System Design Diagram

3.1.1 Methodology

The chosen methodology is Rapid Application Development (RAD), a prototyping-oriented approach renowned for its suitability in scenarios where time constraints are significant. The process comprises distinct phases crucial to project evolution as shown in Figure 3.1.

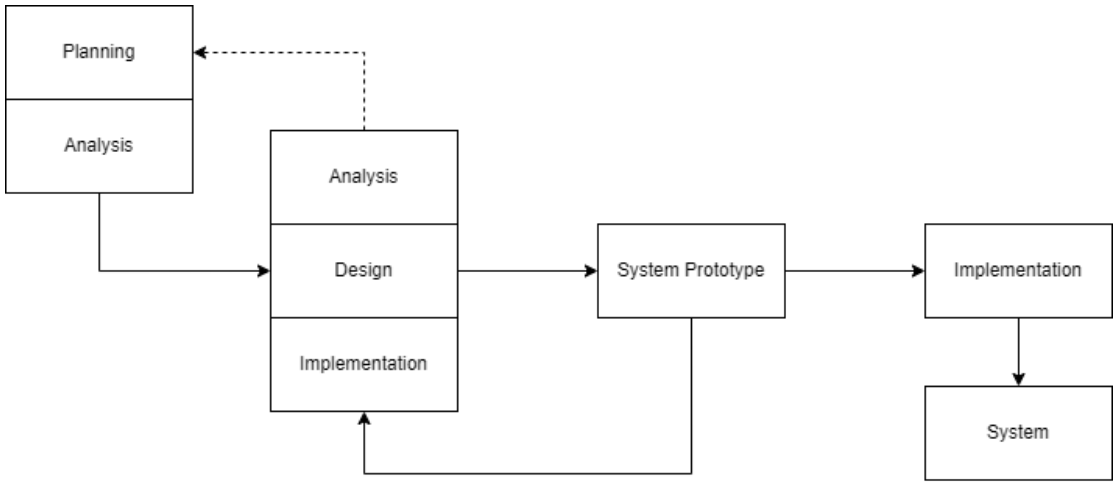

Figure 3.1 RAD Methodology

During the initial planning and analysis phase, the system's overall concept is outlined, which includes specifying its features and assessing the necessary technologies for development. These features are then divided into different versions. Each phase involved testing prototypes before progressing to the subsequent iteration. The final version is the completed product and deployed as the fully functional system.

3.1.2 System Architecture Diagram

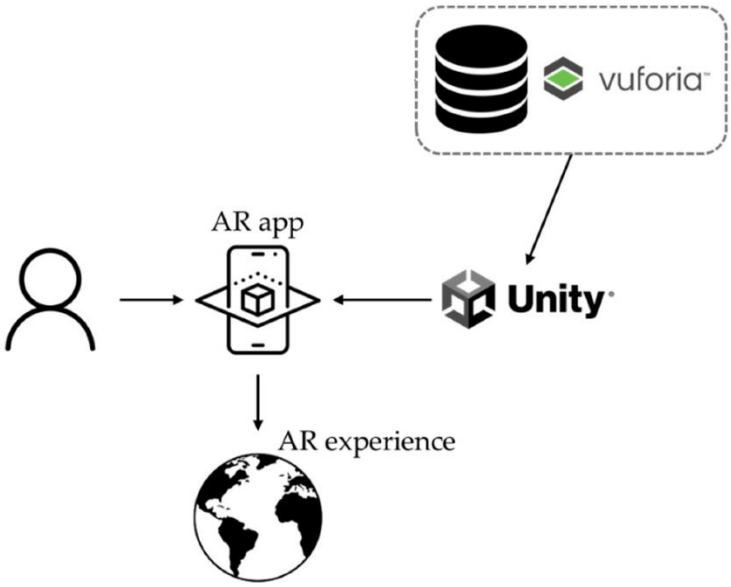

Figure 3.2 System Architecture Diagram

The application is developed in the Unity Game Engine using the C# programming language. The Vuforia Engine, widely recognized as a prominent platform for AR development, is employed for real-time image tracking and recognition, along with the overlay of 3D virtual objects onto physical reality, which is the AR experience.

3.1.3 Use Case Diagram

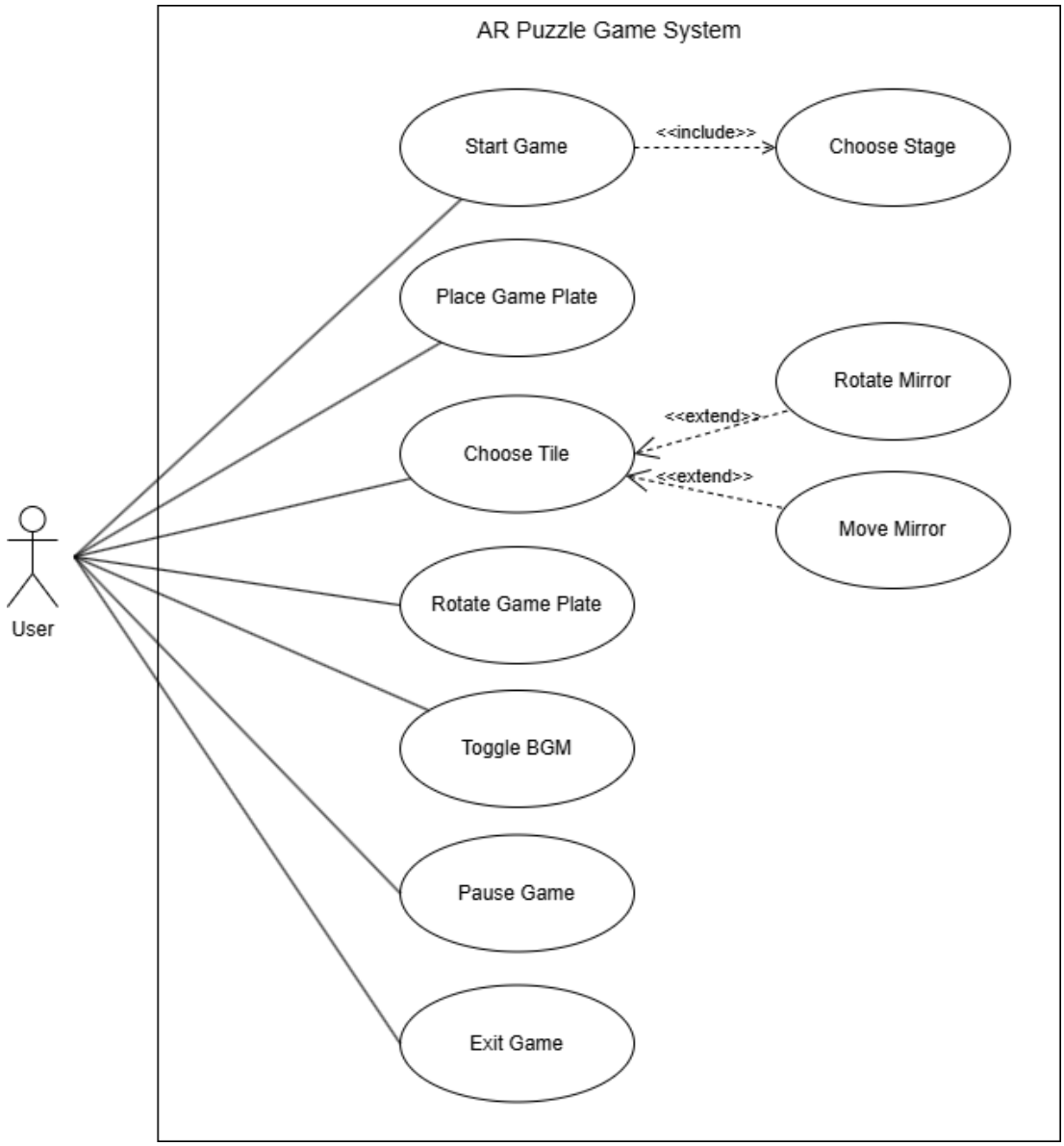

Figure 3.3 Use Case Diagram

There is only one actor (user) and 10 use cases in this system. First use case is the start game function, and it included the stage selection. The following is the AR game plate placement which allows users to place the game plate on their targeted location. After that, the next use case is choosing tile that enables users to select a mirror and perform rotation or reposition. In order to provide better view, the game plate can be rotated by 90 degrees. Also, the users can toggle the background music (BGM). The second last use case is to pause the game and enables users to return to main menu. Finally, the exit game use case allows users to terminate the system.

Use Case Description

Table 3.1 Start Game Use Case Description

Name	Start Game	
Actor	User	
Description	Use case to enable the user to start the game.	
Basic Path	1	User presses on start game button.
	2	System displays the select stage menu.
	3	User selects the stage.
Alternate Path – Cancel Stage Selection	3.1	User selects back button.
	3.2	System displays the main menu.

Table 3.2 Choose Stage Use Case Description

Name	Choose Stage	
Actor	User	
Description	Use case that allow user to select a stage to play.	
Main Path	1	User selects the stage.
	2	System displays the target scene.
Alternate Path	-	-

Table 3.3 Place Game Plate Use Case Description

Name	Place Game Plate	
Actor	User	
Description	Use case that allow user to place the AR game plate.	
Main Path	1	User enters a stage.
	2	System displays the indicator for AR game plate.
	3	User touches on the screen.
	4	System displays the game plate on targeted place.
	5	User presses the confirm button.
Alternate Path – Reset Game Plate	5.1	User touches on the screen again.
	5.2	System displays the game plate on targeted place.

Table 3.4 Choose Tile Use Case Description

Name	Choose Tile	
Actor	User	
Description	Use case to allow user to select a mirror to reposition it.	
Main Path	1	User touches on a tile.
	2	System highlights the selected tile.
	3	System checks if the tile has a mirror on it.
	4	System highlights the movable area and show rotate buttons.
Alternate Path – Tile Without Mirror	3.1	The tile has no mirror on it.
	3.2	System does not show the rotate buttons.
Alternate Path – Choose Another Tile	4.1	User touches on another tile.
	4.2	System highlights the selected tile.

Table 3.5 Rotate Mirror Use Case Description

Name	Rotate Mirror	
Actor	User	
Description	Use case to allow user to rotate the mirrors.	
Main Path	1	User presses on rotate button.
	2	System rotates the mirror.

Table 3.6 Move Mirror Use Case Description

Name	Move Mirror	
Actor	User	
Description	Use case to allow user to move the mirrors.	
Main Path	1	User touches on a movable tile.
	2	System moves the mirror to the target tile.
Alternate Path – Invalid Target	1.1	User touches on an unmovable area.
	1.2	System cancels the tile selection.

Table 3.7 Rotate Game Plate Use Case Description

Name	Rotate Game Plate	
Actor	User	
Description	Use case to allow user to rotate the game plate.	
Main Path	1	User presses on rotate button.
	2	System rotates the game plate.

Table 3.8 Toggle BGM Use Case Description

Name	Toggle BGM	
Actor	User	
Description	Use case to allow user to turn on or turn off background music.	
Main Path	1	User touches on music button.
	2	System stops the music.
Alternate Path – Toggle On	1.1	User touches on music button.
	1.2	System plays the music.

Table 3.9 Pause Game Use Case Description

Name	Pause Game	
Actor	User	
Description	Use case to allow user to pause the game.	
Main Path	1	User presses the pause button.
	2	System displays the pause menu.
	3	User selects the resume option.
	4	System resumes the game.
Alternate Path – Home Button	3.1	User presses main menu button.
	3.2	System displays main menu scene.

Table 3.10 Exit Game Use Case Description

Name	Exit Game	
Actor	User	
Description	Use case to enable user to terminate the game.	
Main Path	1	User selects the quit option.
	2	System terminates.
Alternate Path	-	-

3.1.4 Activity Diagram

Main Menu Module

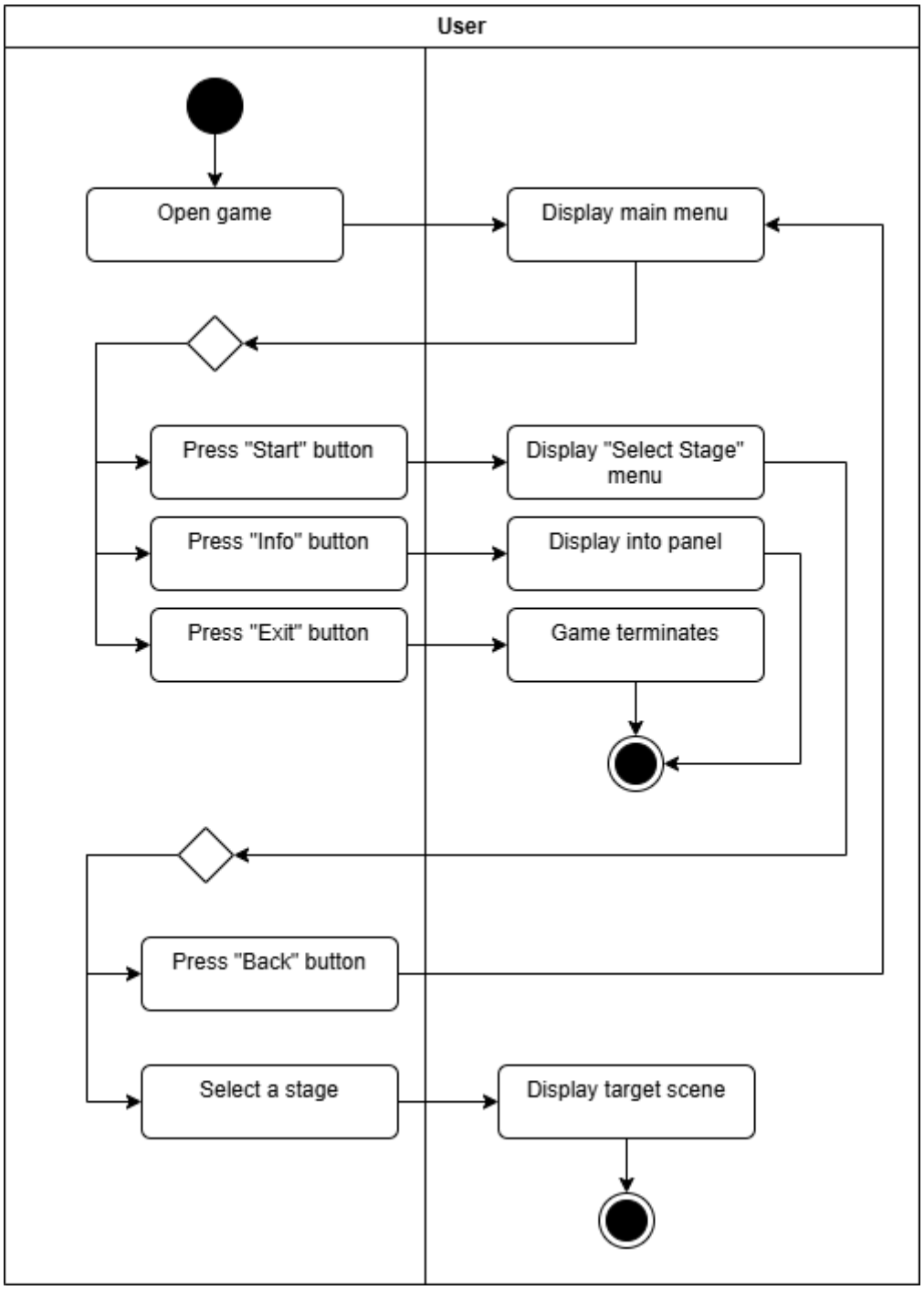

Figure 3.4 Main Menu Activity Diagram

The user will press start button to select a stage or exit the game by pressing exit button. The select stage menu will enable users to select unlocked stages to play. Once the user selects

a stage, the system will change to the game scene. Alternatively, the users can view the game information by pressing the info button.

Game Plate Module

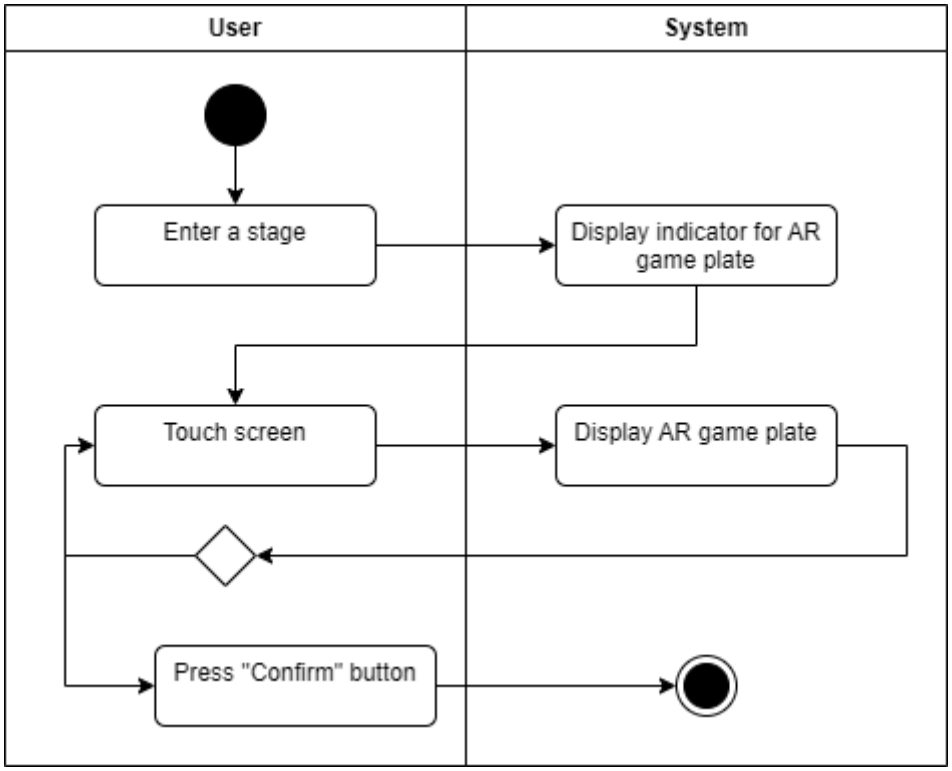

Figure 3.5 Game Plate Activity Diagram

Once the users enter a stage, an indicator will show while detecting ground plane. The users can touch on the screen to place the game plate until they satisfied with it. Then, the user can confirm the placement.

Mirror Control Module

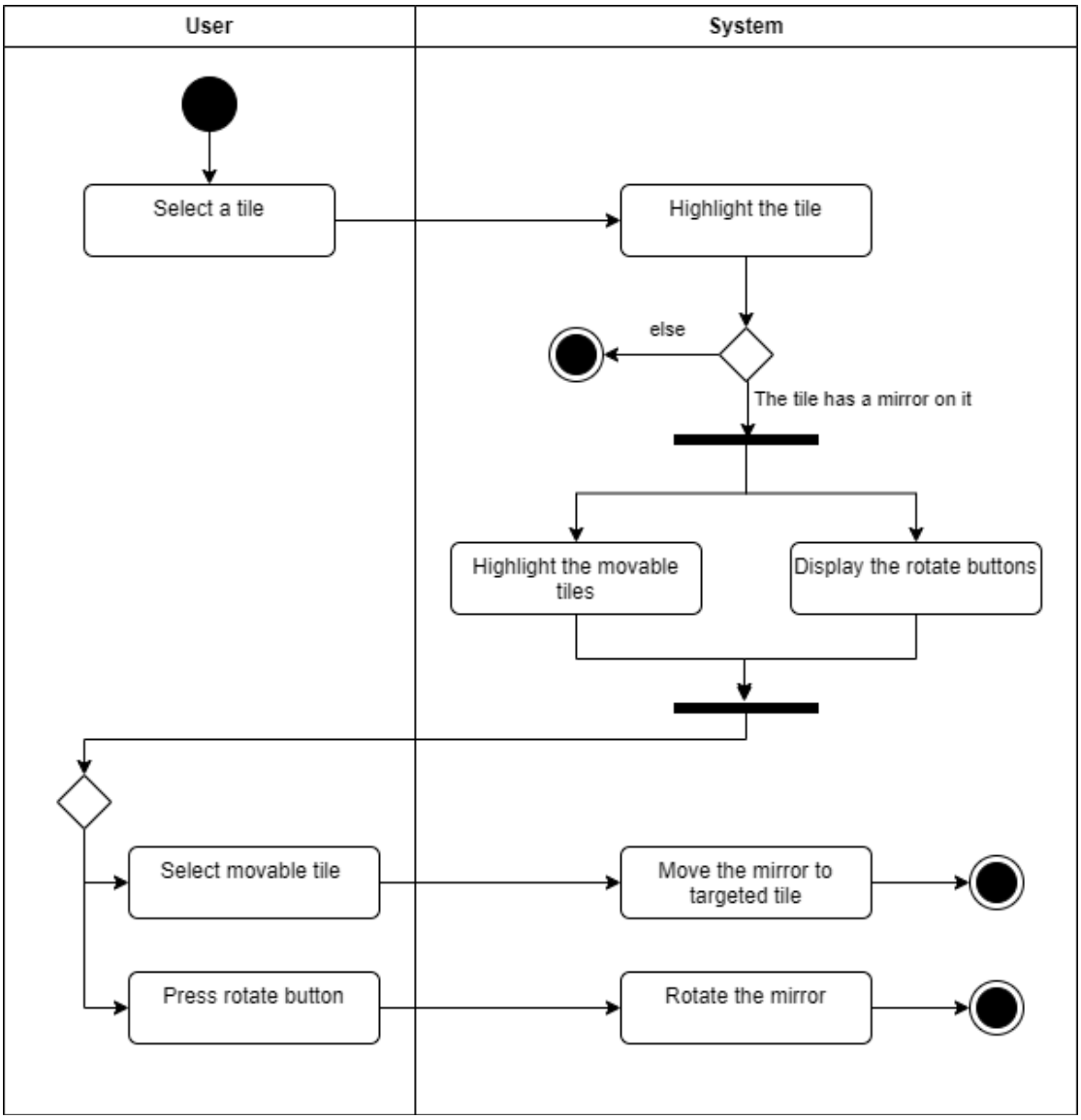

Figure 3.6 Mirror Control Activity Diagram

The users first select a tile to begin the interaction. Then the system will highlight the selected tile and check if there is a mirror on it. If it is, the movable tiles will be highlighted with green color and rotate buttons will be showed. Next, the users can move the mirror by selecting movable tile or rotate the mirror by pressing the buttons.

Game Management Module

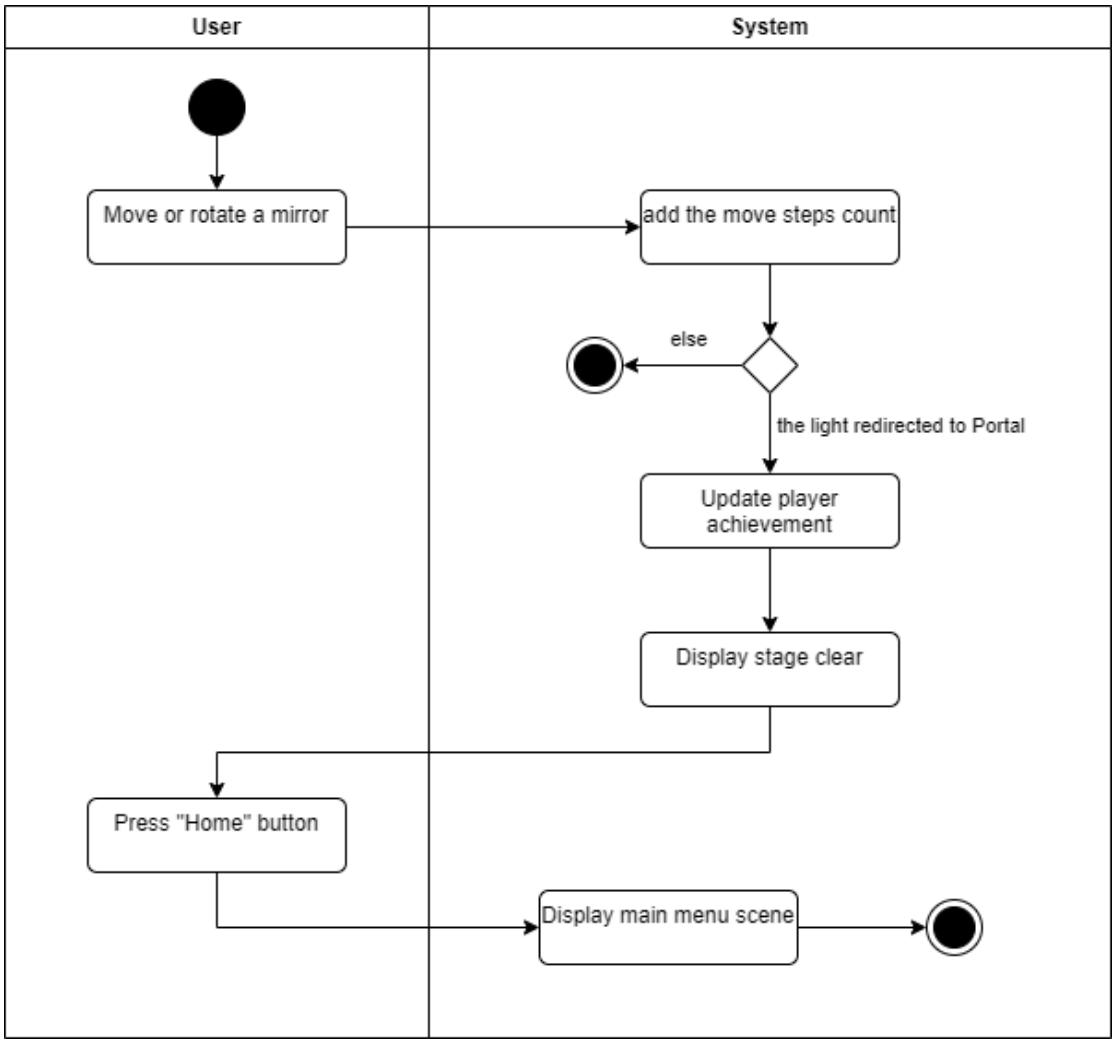

Figure 3.7 Game Management Activity Diagram

Each time the users move or rotate a mirror, the system will increment the move steps count. If the light is redirected to the end point, the system updates player achievement and stage clear panel will be displayed. Then, users will be redirected to the main menu.

Music Management Module

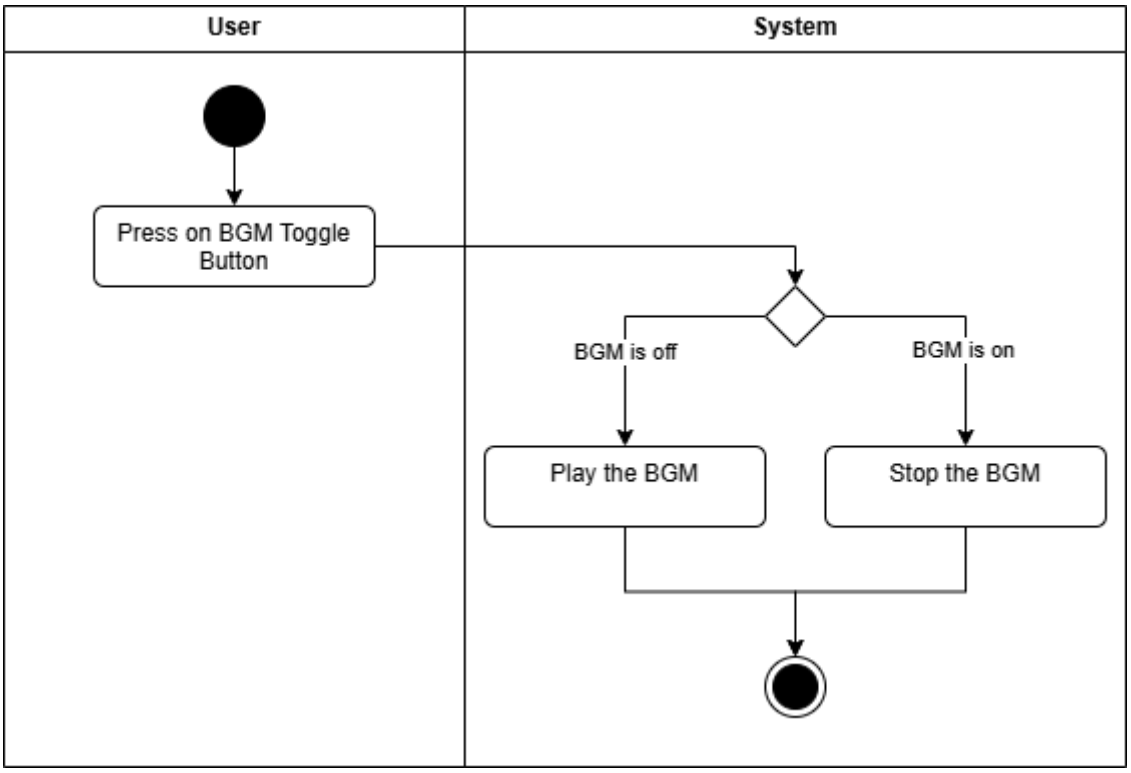

Figure 3.8 Music Management Activity Diagram

Each time the users press on the toggle, the system will check the current option. If the music is offed, it will turn it on, and vise versa.

Pause Menu Module

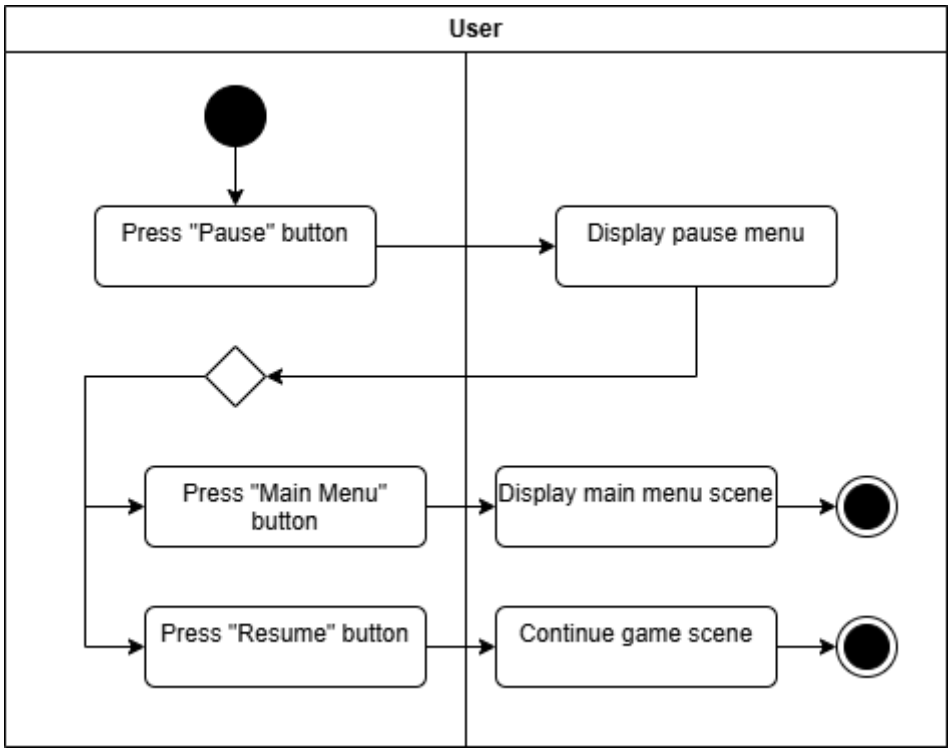

Figure 3.9 Pause Menu Activity Diagram

Once the users press on pause button, the pause menu will pop up. The users can redirect to main menu or resume the game by pressing the buttons.

CHAPTER 4 System Design

4.1 Game Flowchart

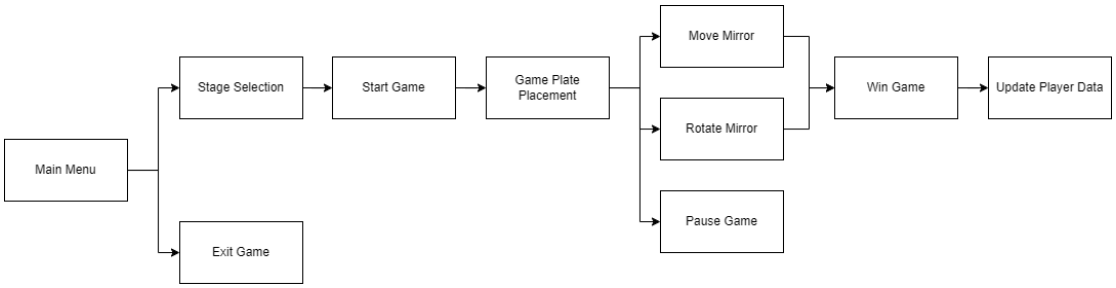

Figure 4.1 System Flow Chart

Main Menu

Figure 3.2 illustrates the comprehensive system flow of the AR puzzle game. Upon launching the game, a main menu is displayed and enables users to play the game or quit the game. When the users select start game, a stage selection menu will pop up and allows users to select a stage to play.

Game Scene

After selecting a stage, the user needs to place the AR game plate by touching the screen. Then they can start playing the game by trying to redirect a light beam from a staring point to the end point. The user can select a mirror by touching the tile under it and perform rotation or movement to redirect the light beam. Upon selection, the system will highlight the tile to indicate the user which tile is being selected. Also, if the mirror can be moved, it will highlight the moveable areas. While the user success to redirect the light beam to the end point, they win the game, and the system will update the player achievements. During the game, the user can pause the game and select if they want to back to main menu or restart the stage.

4.2 System Components Diagram

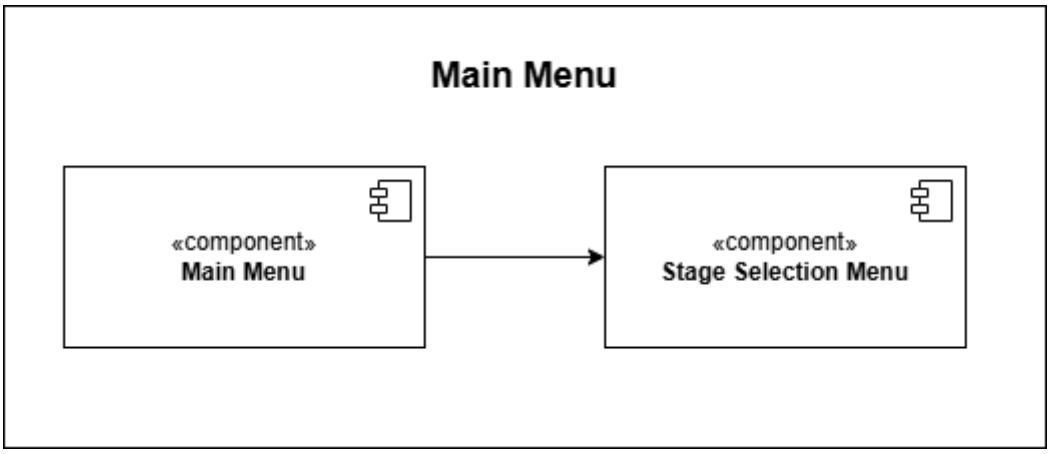

Figure 4.2 Main Menu Component Diagram

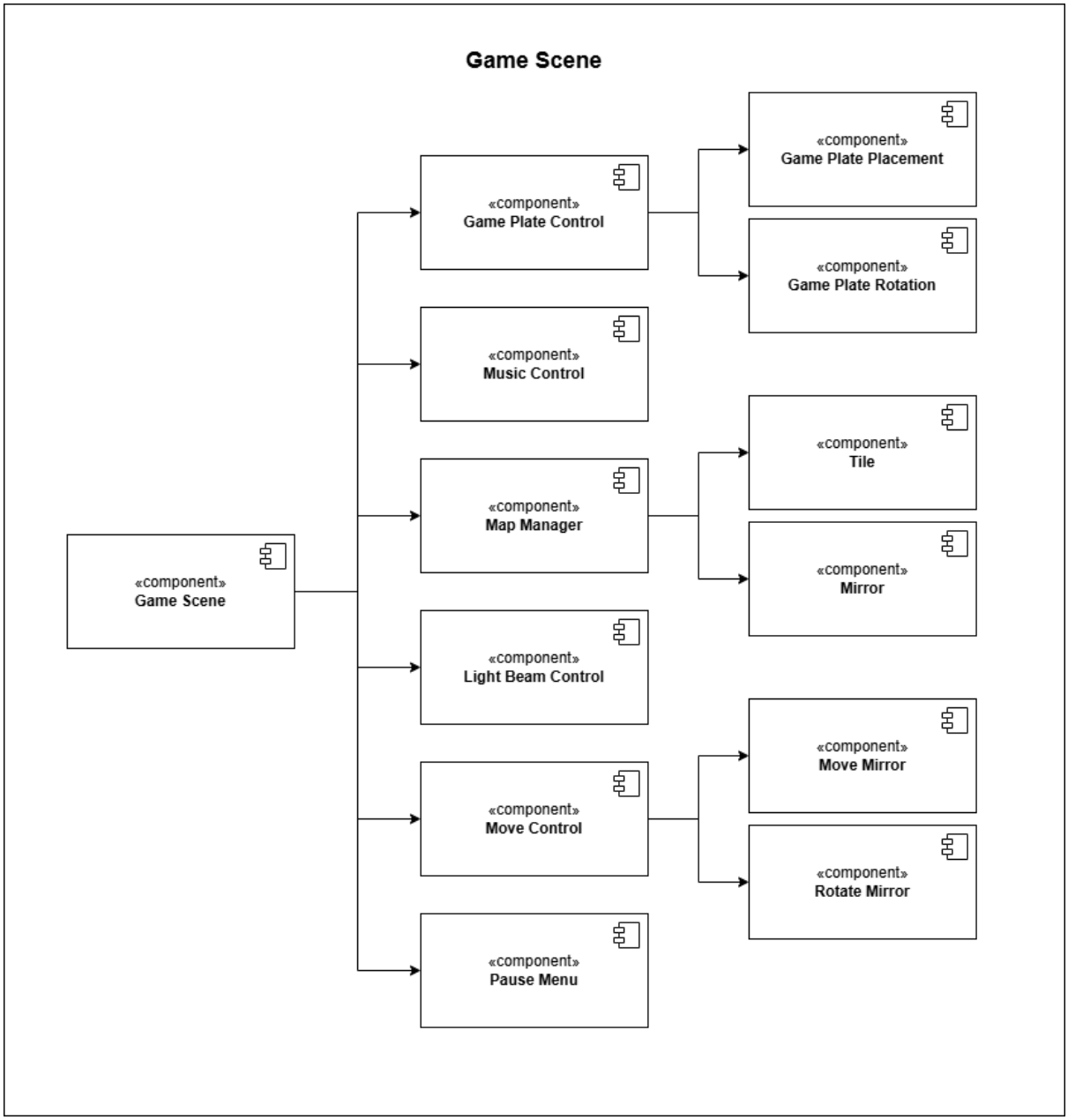

Figure 4.3 Game Scene Component Diagram

CHAPTER 5 System Implementation

5.1 Hardware

The system development utilizes both computer hardware and Android mobile devices. The computer serves as the platform for program implementation, while the Android mobile device is employed for application testing and deployment purposes.

Table 5.1 Specifications of Laptop

Description	Specifications
Model	Lenovo IdeaPad Gaming 3 15ACH6
Processor	AMD Ryzen 5 5600H with Radeon Graphics 3.30 GHz
Operating System	Windows 11 Home Single Language – 64-bit
Graphic	NVIDIA GeForce RTX 3050 4GB
Memory	24GB DDR4 3200MHz
Storage	Samsung SSD 980 500GB

Table 5.2 Specifications of Mobile Phone

Description	Specifications
Model	POCO X3 GT 21061110AG
Chipset	Mediatek MT6891Z Dimensity 1100 (6 nm)
Operating System	Android 13
CPU	Octa-core (4x2.6 GHz Cortex-A78 & 4x2.0 GHz Cortex-A55)
GPU	Mali-G77 MC9
Memory	8GB
Storage	128GB

5.2 Software

Table 5.3 Software Specifications

Description	Specifications
Platform	Android 9.0 ‘Pie’ (API level 28) or higher
Game Engine	Unity 2022.3.40f1
Programming Language	C#
Integrated Development Environment (IDE)	Visual Studio 2022
AR Framework	Vuforia Engine 10.25

5.3 Setting and Configuration

Setup Unity project

1. Add a new project in Unity Hub.

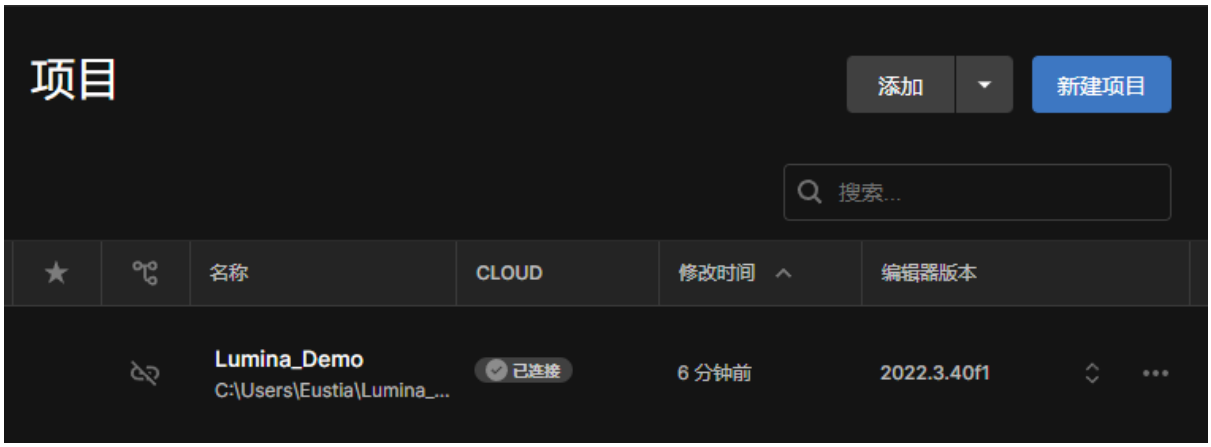

Figure 5.1 New Unity Project Creation

2. Use the 3D Core template.

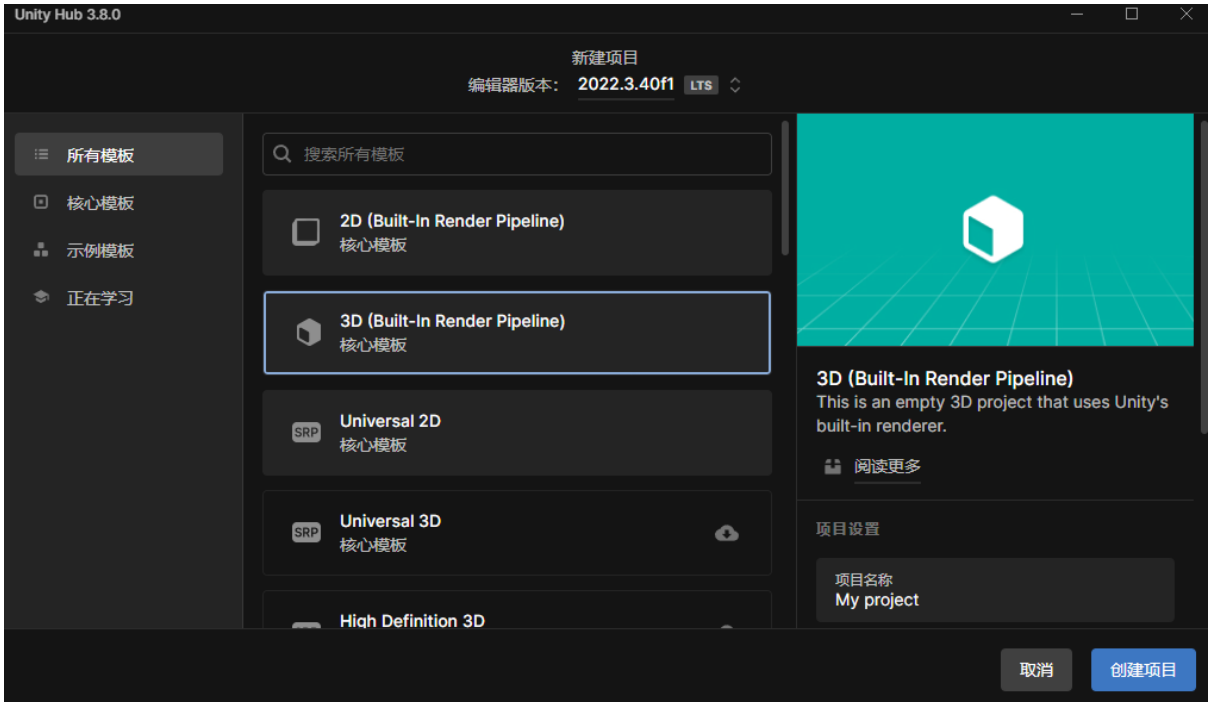

Figure 5.2 3D Core Template Selection

3. In the Project Settings, modify the minimum API level to Android 9.0

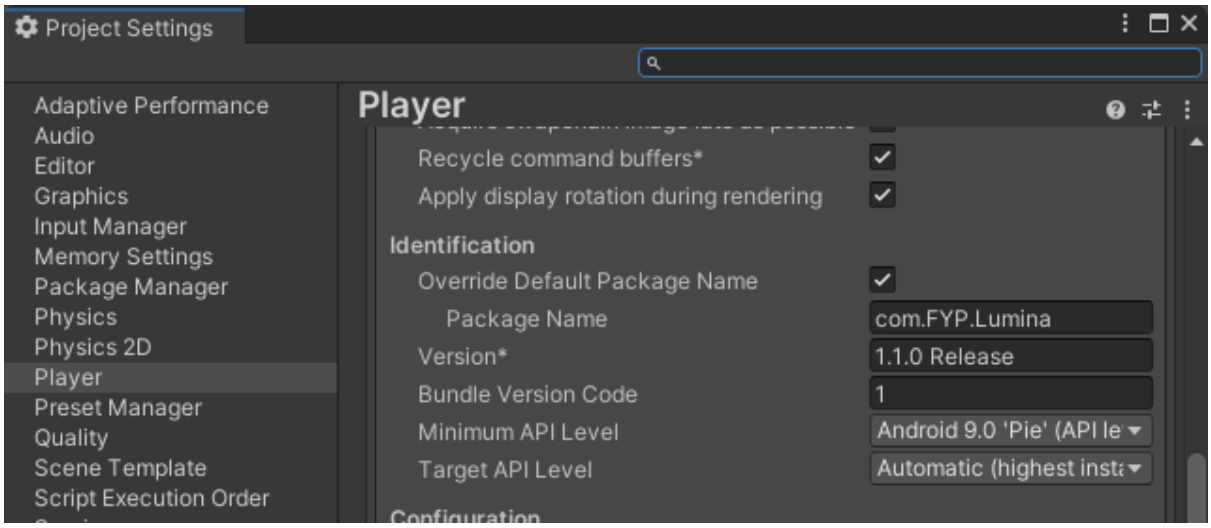

Figure 5.3 Project Setting

Setup Vuforia SDK

1. Download the Vuforia package for Unity on official website.

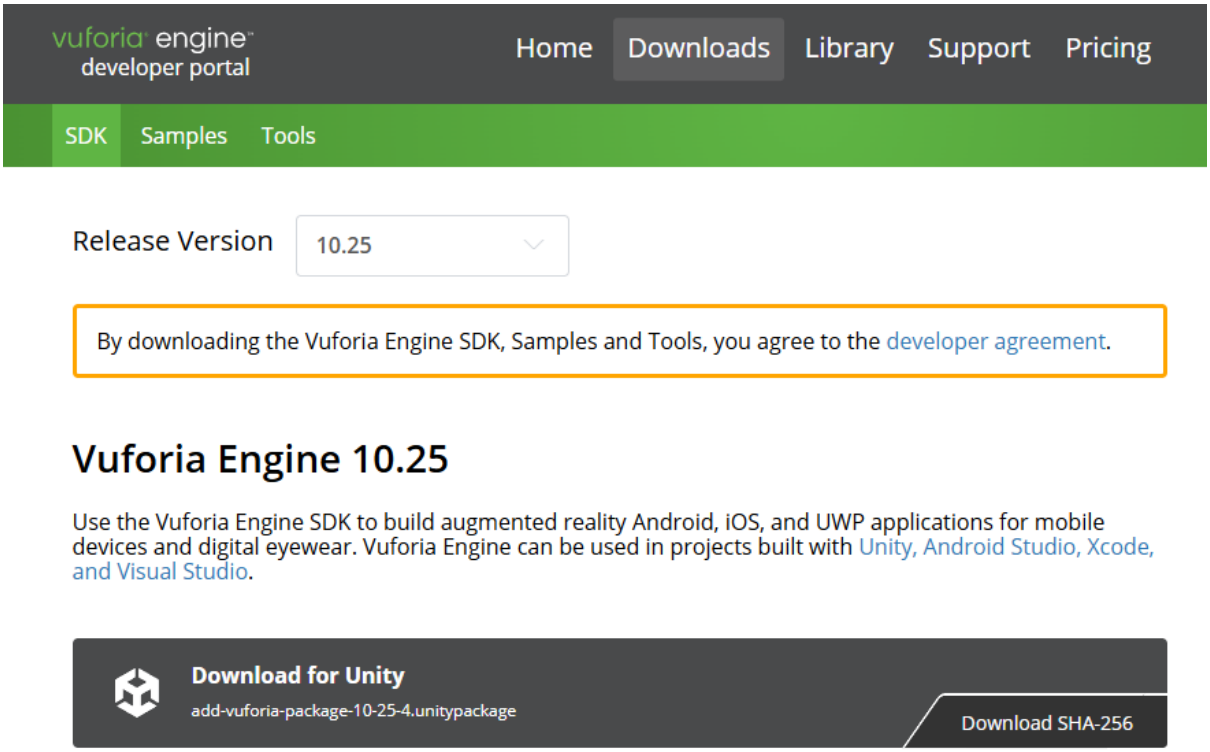

Figure 5.4 Download Vuforia Engine

2. Import the package into Unity Project.

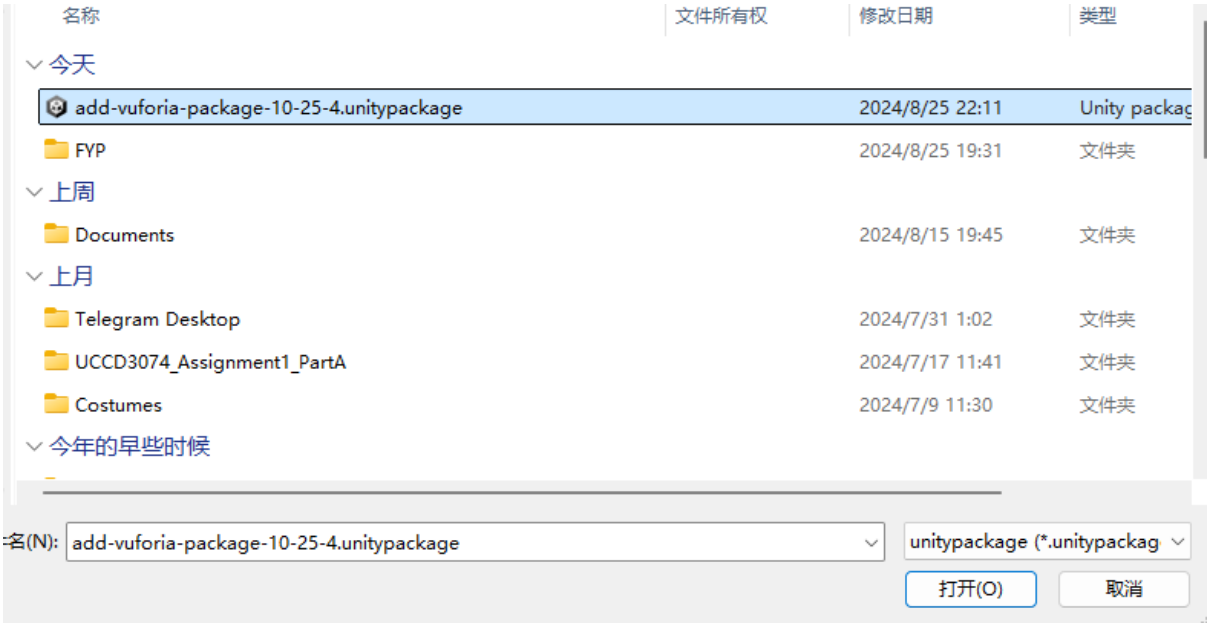

Figure 5.5 Import Vuforia Engine

3. Input the license key in the configuration.

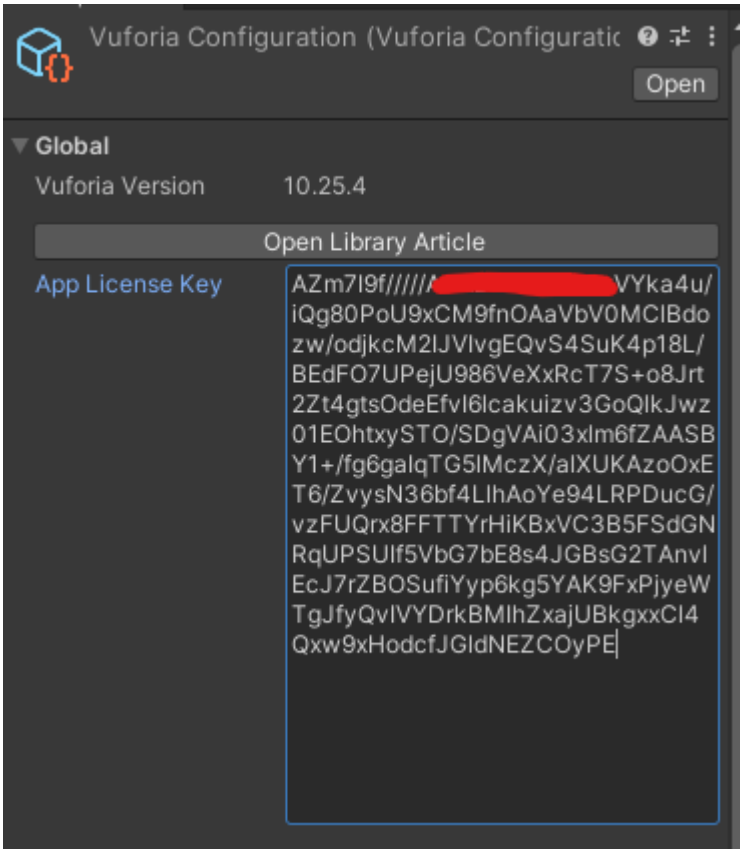

Figure 5.6 Vuforia Engine License Key

Setup Assets

1. Lowpoly Environment

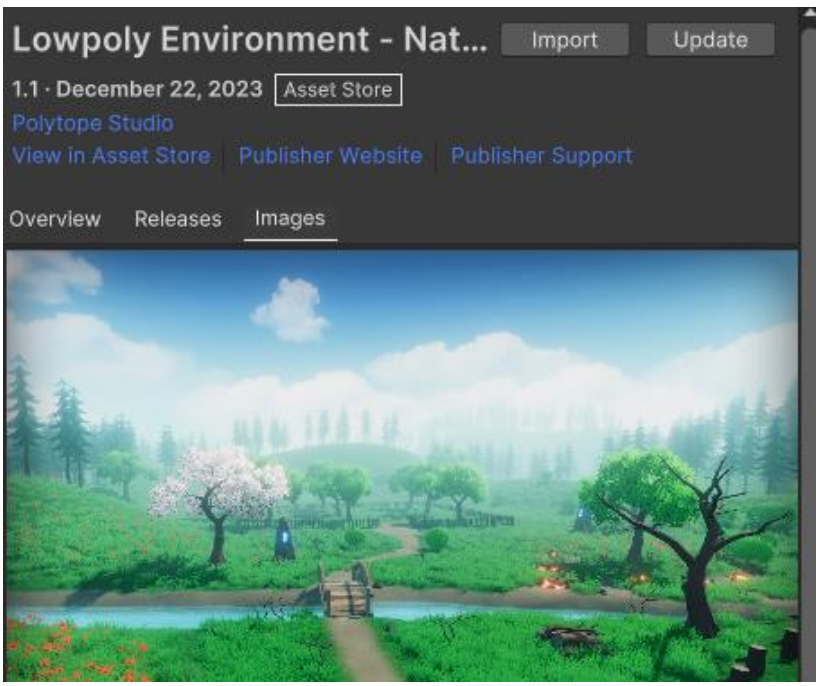

Figure 5.7 Lowpoly Environment

2. LowPoly Server Room Props

Figure 5.8 LowPoly Server Room Props

3. Fantasy Cemetery & Necropolis Pack Lite

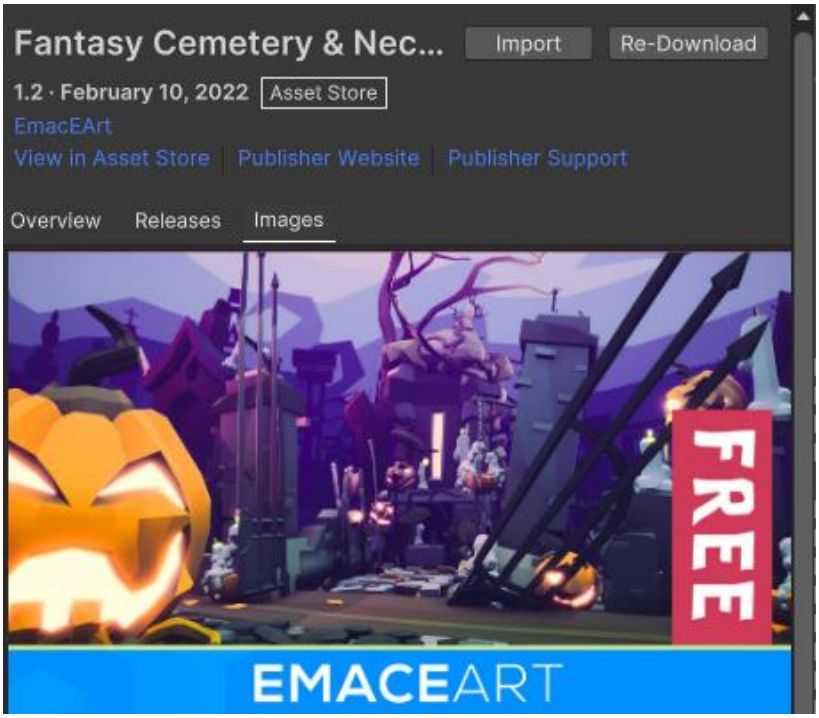

Figure 5.9 Fantasy Cemetery & Necropolis Pack Lite

4. Free Casual Game SPX Pack

Figure 5.10 Free Casual Game SPX Pack

5. Free UI Click Sound Pack

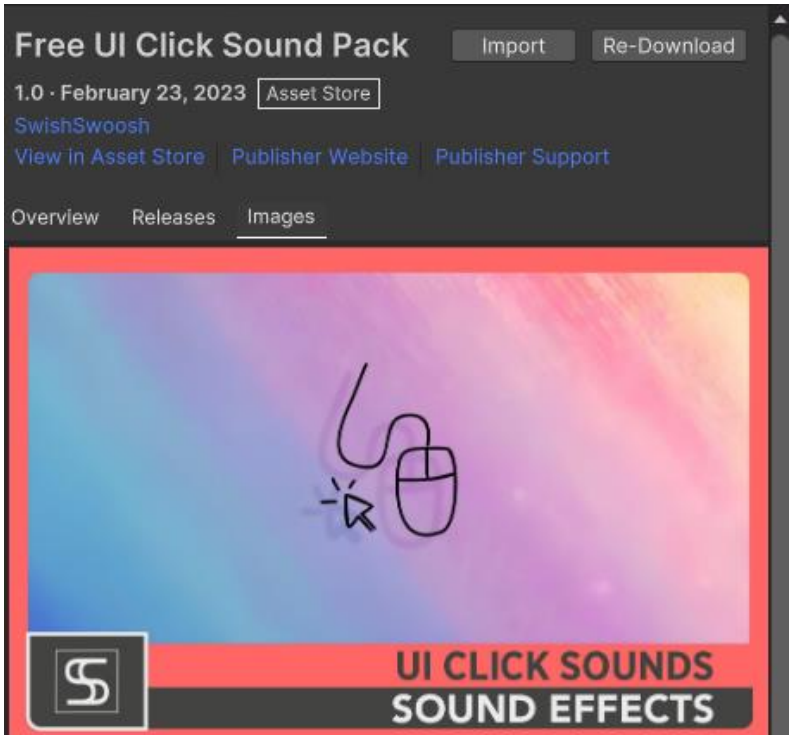

Figure 5.11 Free UI Click Sound Pack

6. Sleek Essential UI Pack

Figure 5.12 Sleek Essential UI Pack

7. The Portal Collection

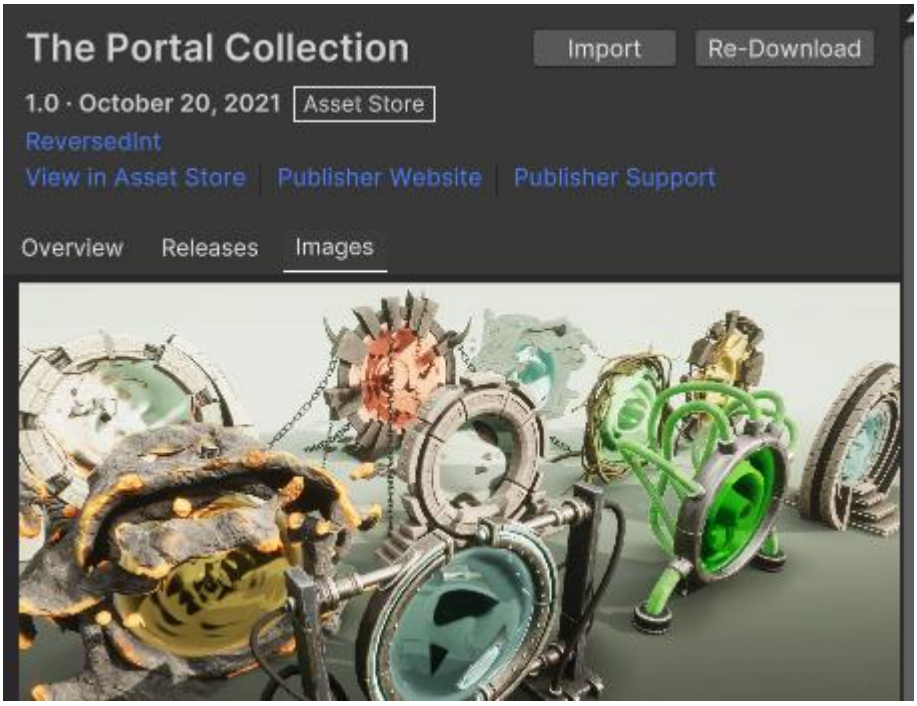

Figure 5.13 The Portal Collection

8. UX Flat Icons

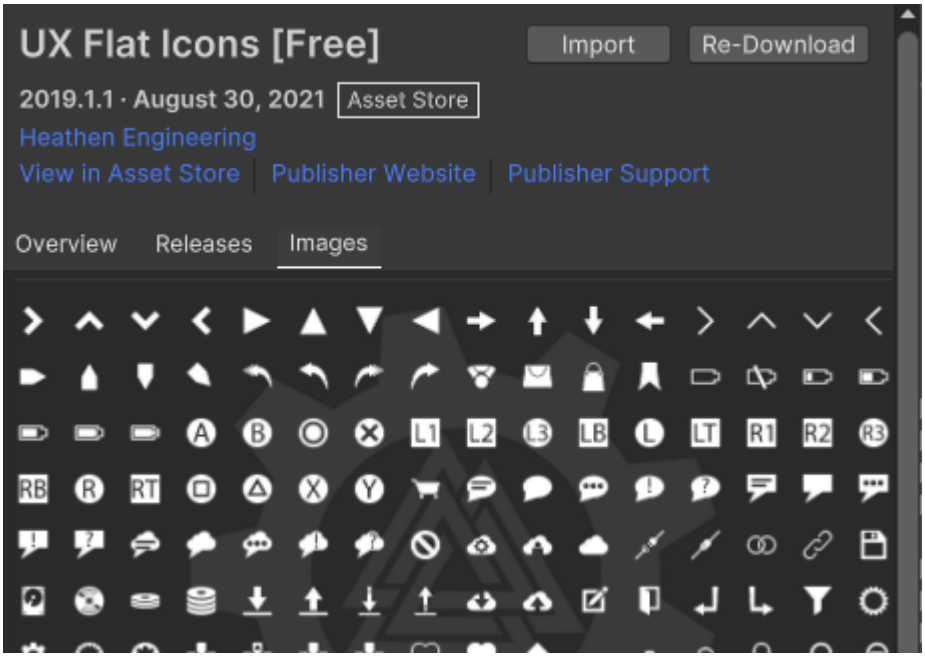

Figure 5.14 UX Flat Icons

5.4 System Operation

Main Menu

Upon launching the game, a main menu is displayed. There are three options: Start, Info, and Quit. The first led the player to stage panel and the info option shows the game details and tips. The user can exit the game with Quit button.

Figure 5.15 Main Menu

In the stage selection menu, the user can view the stage description and their completed achievements on each stage.

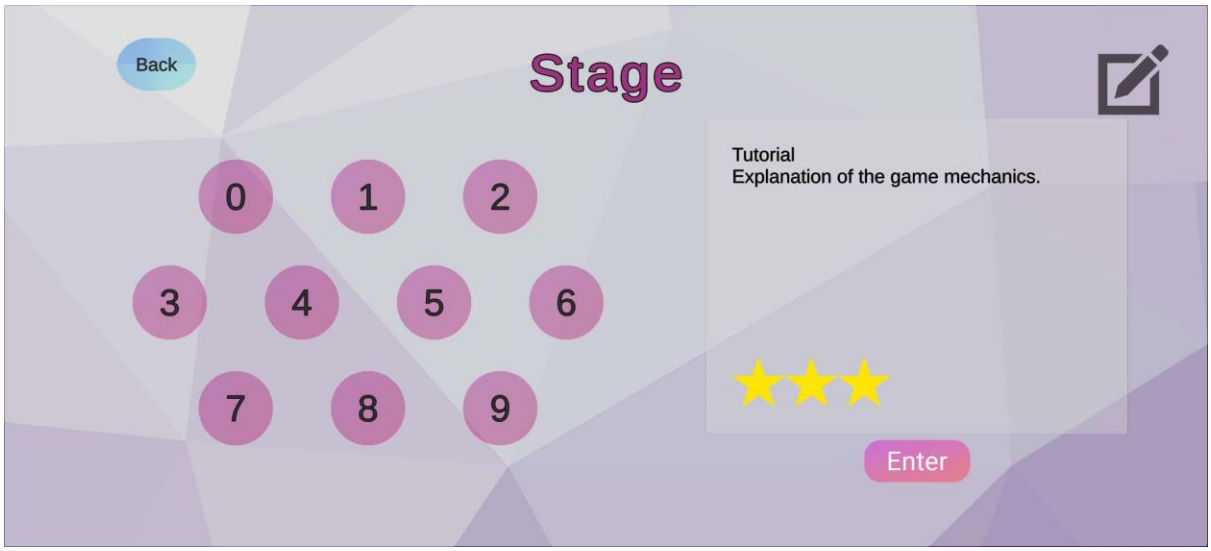

Figure 5.16 Stage Selection

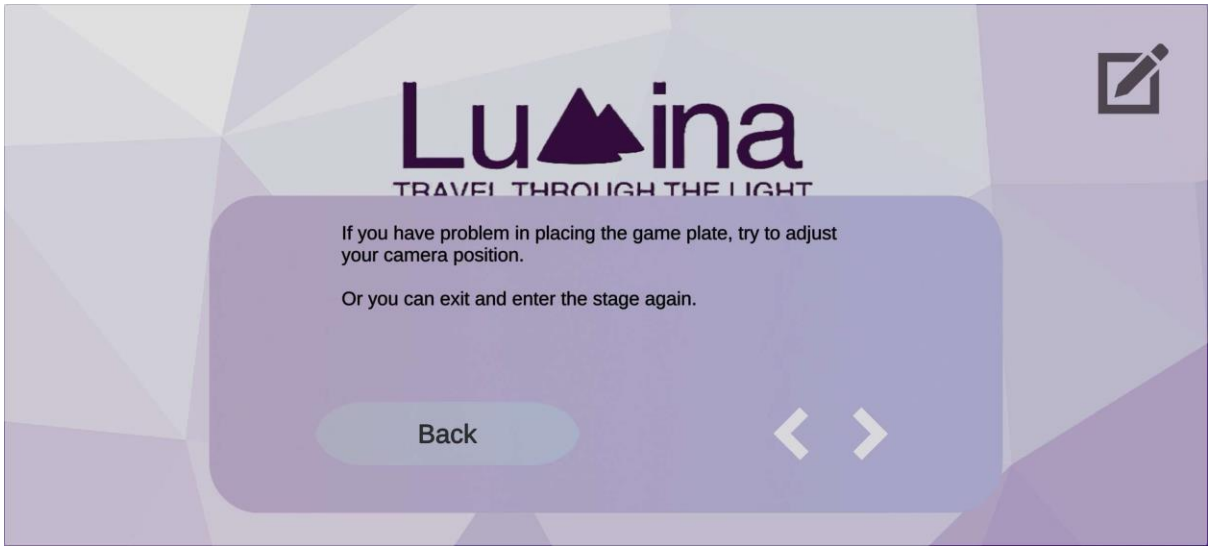

Figure 5.17 Info Panel

Game Scene

After selecting a stage, the user will enter the game scene. First, the user will need to place the game plate using the indicator and confirm the location by pressing on place button. Once the game plate is placed, the light beam with show up and the user can interact with the game elements. In addition, the rotate buttons on the sides enable user to rotate the game plate.

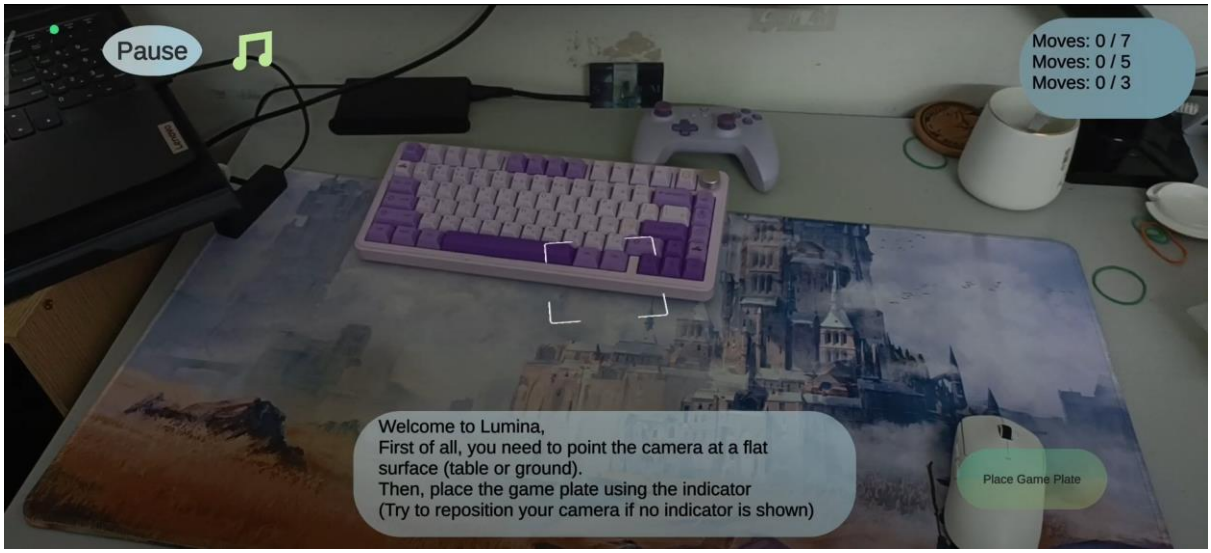

Figure 5.17 Game Plate Placement 1

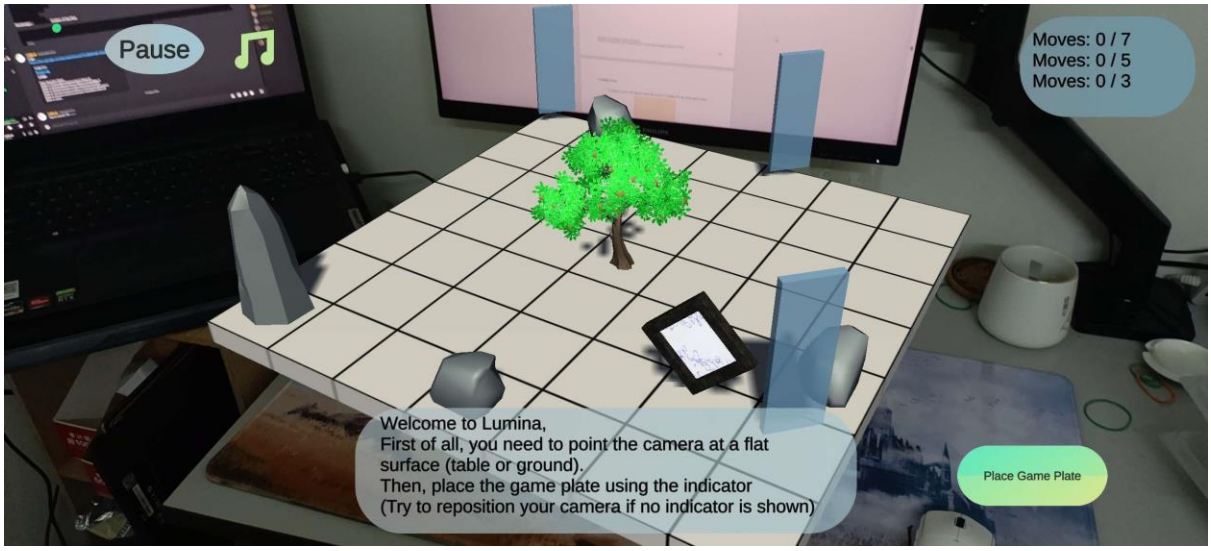

Figure 5.18 Game Plate Placement 2

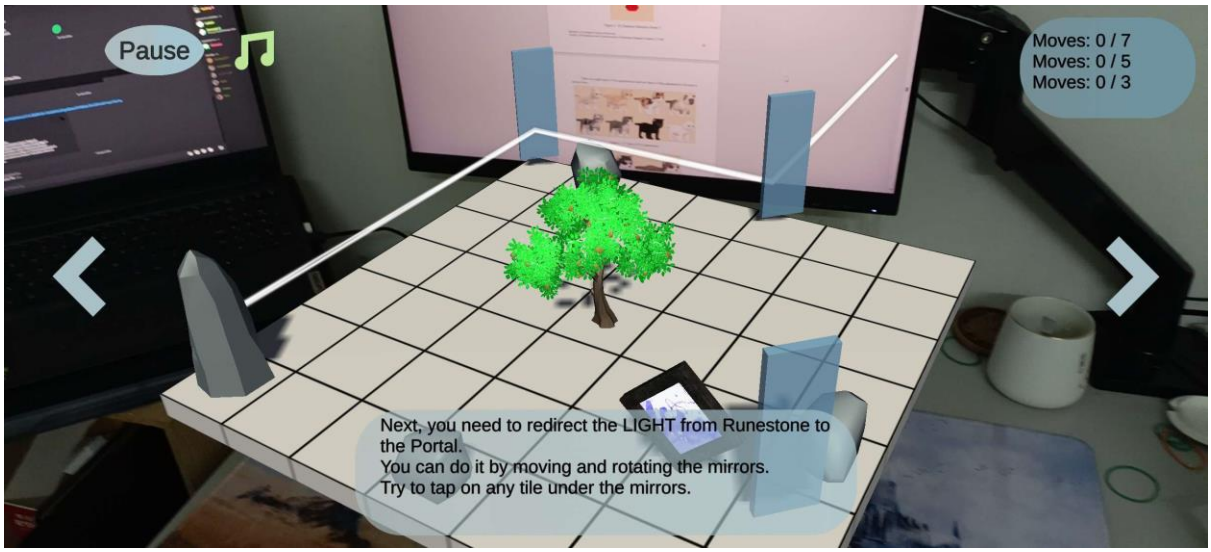

Figure 5.19 Game Plate Placement 3

Next, the user needs to redirect the light beam to the portal by manipulating the mirrors. The user selects the tile below the mirror and the system will highlight the selected tile and moveable areas. The rotate mirror buttons are displayed at bottom left corner. Also, the top right corner shows the requirements for achievements.

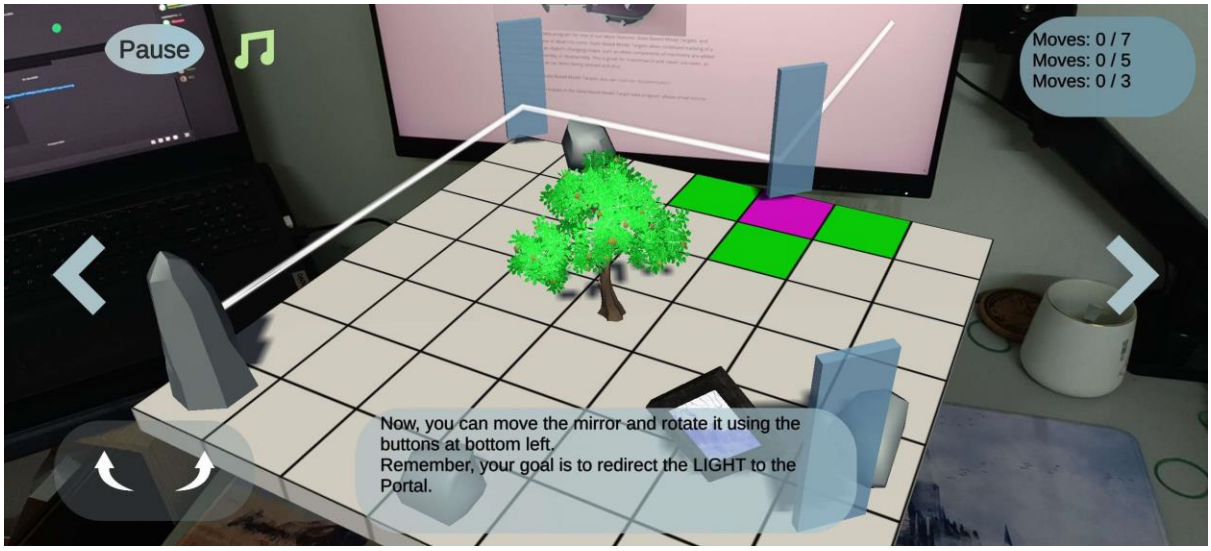

Figure 5.20 Mirror Manipulation

After the user successfully redirects the light beam to the end point, which is the portal, the user wins the stage.

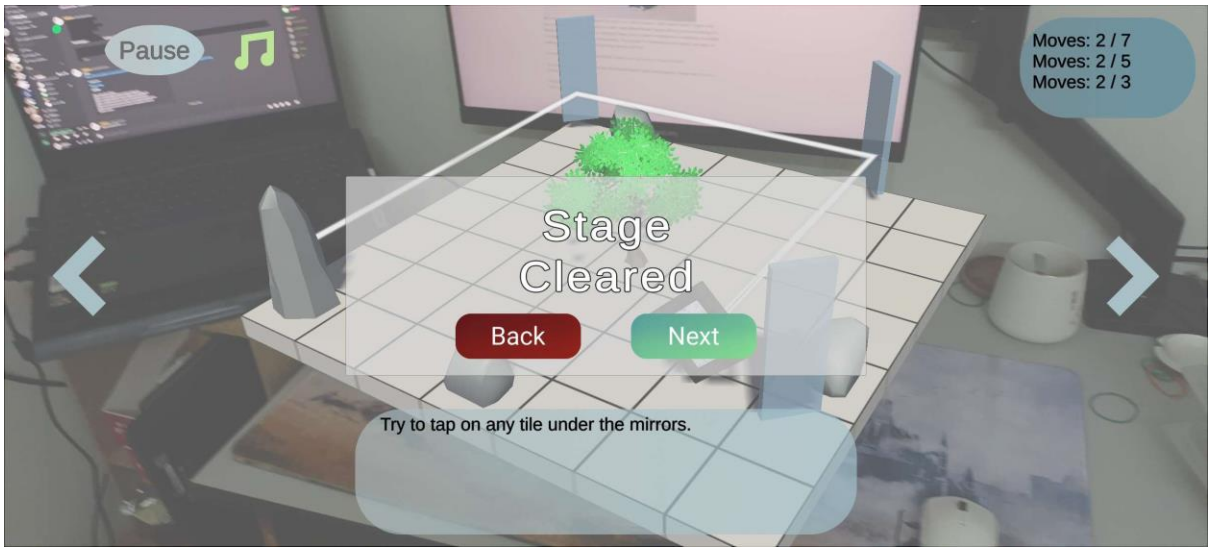

Figure 5.21 Stage Cleared

In the game scene, user can pause the game using the pause button. In the pause panel, the user can return to main menu.

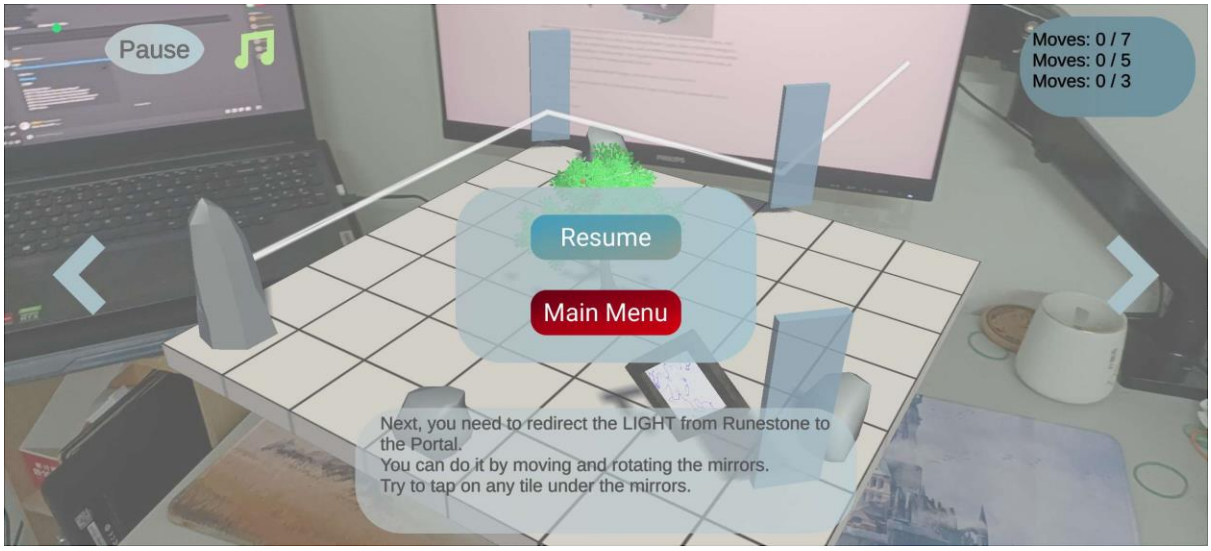

Figure 5.22 Pause Menu

5.5 Implementation Issues and Challenges

Complex Puzzle Design:

- Designing complex puzzles that effectively leverage light reflection mechanics presents a significant challenge. Balancing difficulty levels to cater to both novice and experienced players, while maintaining engagement and avoiding frustration, requires meticulous planning and testing.

User Interface Design:

- Developing an intuitive and user-friendly interface for interacting with AR elements poses its own set of challenges. Ensuring that controls for moving and rotating mirrors are intuitive and responsive, particularly on touchscreen devices, requires careful consideration and iteration. Also, the user interface flow must be well designed to ensure a smooth game play experience.

Performance Optimization:

- Optimizing the game's performance to run smoothly on a variety of mobile devices is essential. This includes minimizing latency, optimizing resource usage, and ensuring consistent frame rates to provide an enjoyable gaming experience across different hardware specifications. The codes especially those require update in every frame have to be optimized.

5.6 Concluding Remark

This project utilized a combination of carefully selected hardware and software to achieve a functional and engaging AR-based puzzle game. A laptop and an Android mobile phone were instrumental in the development and testing phases, ensuring that the game could run as desired. The Unity game engine, coupled with C# programming and the Vuforia AR framework, formed the backbone of the game's development, enabling the creation of complex AR interactions and a smooth user experience.

The setup and configuration of the project involved meticulous attention to detail, from setting up the Unity environment to importing necessary assets and configuring the Vuforia SDK. These steps were crucial in establishing a robust foundation for the game, allowing for seamless integration of various components, including the 3D Core template and essential assets like the LowPoly Environment and UI packs.

System operation involved a well-thought-out design of user interactions, from navigating the main menu to solving puzzles within the game scene. The game's core mechanic—redirecting a light beam to reach a portal—was carefully implemented to challenge players while providing intuitive controls for interacting with game elements. The inclusion of a stage selection menu, informative panels, and pause functionality contributed to a user-friendly interface, enhancing the overall gaming experience.

Throughout the implementation, several challenges were encountered, such as designing puzzles that balance difficulty and engagement, creating an intuitive user interface for AR interactions, and optimizing the game's performance across various devices. Addressing these challenges required continuous iteration and testing, ensuring that the final product met the desired quality standards.

Chapter 6 System Evaluation and Discussion

6.1 System Testing Setup

Main Menu

Table 6.1 Main Menu Testing Component

Testing Component	Description
Start Button	Test if the system shows stage selection panel.
Info Button	Test if the system shows info panel.
Quit Button	Test if it ends the application normally.
Stage Selection Panel	Test if the system shows stages correctly.
Stage Description Panel	Test if the panel shows the correct information.
Stage Start Button	Test if the system enters the selected game scene.
Info Panel	Test if the info panel works normally.

Game Plate Control

Table 6.2 Game Plate Control Testing Component

Testing Component	Description
Plane Detection	Test if the system can detect surface areas.
Game Plate Placement	Test if the system places the game plate.
Game Plate Rotation	Test if the system rotates the game plate.

Audio Control

Table 6.3 Audio Control Testing Component

Testing Component	Description
UI Sound Effect	Test if all the buttons have sound effects.
Game Sound Effect	Test if all the game interactions have sound effects.
Background Music	Test if the system plays or stops the background music.
BGM Toggle	Test if the system can toggle the background music.

Move Control

Table 6.4 Move Control Testing Component

Testing Component	**Description**
Tile Selection	Test if the system can recognize the selected tile.
Mirror Movement	Test if the mirror can be moved to another tile.
Mirror Rotation	Test if the mirror can be rotated.

Light Beam Control

Table 6.5 Light Beam Control Testing Component

Testing Component	**Description**
Light Beam Generation	Test if the system can generate light beam from starting point.
Light Beam Reflection	Test if the light beam can be reflected by mirrors.
Game Clear	Test if the user wins the game after redirected light beam to end point.

Player Data Control

Table 6.6 Player Data Control Testing Component

Testing Component	**Description**
Stage Progression	Test if the system saves the player's stage progression.
Achievement	Test if the system saves the player's completed achievement.
BGM preference	Test if the system saves the player's preference on background music.

6.2 Testing Results

Each of the module is examined to ensure they work as intended.

Main Menu

Table 6.7 Main Menu Testing Results

Testing Component	Expected Result	Result
Start Button	The system shows the stage selection panel.	Pass
Info Button	The system shows info panel.	Pass
Quit Button	The system ends.	Pass
Stage Selection Panel	The system shows stages correctly.	Pass
Stage Description Panel	The panel shows the correct information.	Pass
Stage Start Button	The system enters the selected game scene.	Pass
Info Panel	The info panel works normally.	Pass

Game Plate Control

Table 6.8 Game Plate Control Testing Results

Testing Component	Expected Result	Result
Plane Detection	The system can detect surface areas.	Pass
Game Plate Placement	The system places the game plate.	Pass
Game Plate Rotation	The system rotates the game plate.	Pass

Audio Control

Table 6.9 Audio Control Testing Results

Testing Component	Expected Result	Result
UI Sound Effect	All the buttons have sound effects.	Pass
Game Sound Effect	All the game interactions have sound effects.	Pass
Background Music	The system plays or stops the background music.	Pass
BGM Toggle – Off	The system can turn off the background music.	Pass
BGM Toggle – On	The system can turn on the background music.	Pass

Move Control

Table 6.10 Move Control Testing Results

Testing Component	**Expected Result**	**Result**
Tile Selection	The system can recognize and highlight the selected tile.	Pass
Mirror Movement – Moveable Area	The system highlights the moveable areas.	Pass
Mirror Movement – Move	The mirror can be moved to another tile.	Pass
Mirror Movement – Invalid Move	The system cancels the tile selection.	Pass
Mirror Rotation	The mirror can be rotated.	Pass

Light Beam Control

Table 6.11 Light Beam Control Testing Results

Testing Component	**Expected Result**	**Result**
Light Beam Generation	The system can generate light beam from starting point.	Pass
Light Beam Reflection	The light beam can be reflected by mirrors.	Pass
Light Beam Reflection – Block	The light beam can be blocked by other game objects.	Pass
Game Clear	The user wins the game after redirected light beam to end point.	Pass

Player Data Control

Table 6.12 Player Data Control Testing Results

Testing Component	**Expected Result**	**Result**
Stage Progression	The system saves the player's stage progression.	Pass
Achievement	The system saves the player's completed achievement.	Pass
BGM preference	The system saves the player's preference on background music.	Pass

6.3 User Playtest

A playtest was conducted as part of this project to gather feedback from players and improve the game to better align with audience expectations. The playtest consisted of two stages. In the first stage, a beta version of the game was released to players, who were asked to play and complete a survey afterward [15]. The feedback and data collected from this stage were analyzed to refine the game. Following these refinements, a new version of the game was distributed in the second stage to evaluate the effectiveness of the improvements made.

The survey used during the playtest was divided into three sections:

- **Demographic:** This section investigated players' age group, gender, and experience with puzzle or augmented reality (AR) games.
- **Game Experience Questionnaire (GEQ):** The survey employed a well-established model to evaluate user gameplay experience [16]. The GEQ assessed the game experience based on scores in seven components: Immersion, Flow, Competence, Positive and Negative Affect, Tension, and Challenge. To maintain simplicity, only the in-game version of the GEQ was used, which included 14 questions with two questions corresponding to each component.
- **Puzzle Design:** This section explored players' thoughts on the design of the puzzles, focusing on aspects such as clarity, difficulty progression, and overall engagement.

6.3.1 Stage 1

In the first stage, the playtest involved six participants, with a demographic spread across different age groups, genders, and varying levels of experience with puzzle and AR games. The testers included three males and three females, with ages ranging from 16 to 35. Half of the participants had experience with puzzle games, while only two had experience with AR-based games. This diverse group of testers provided a broad spectrum of feedback that could address various user experiences.

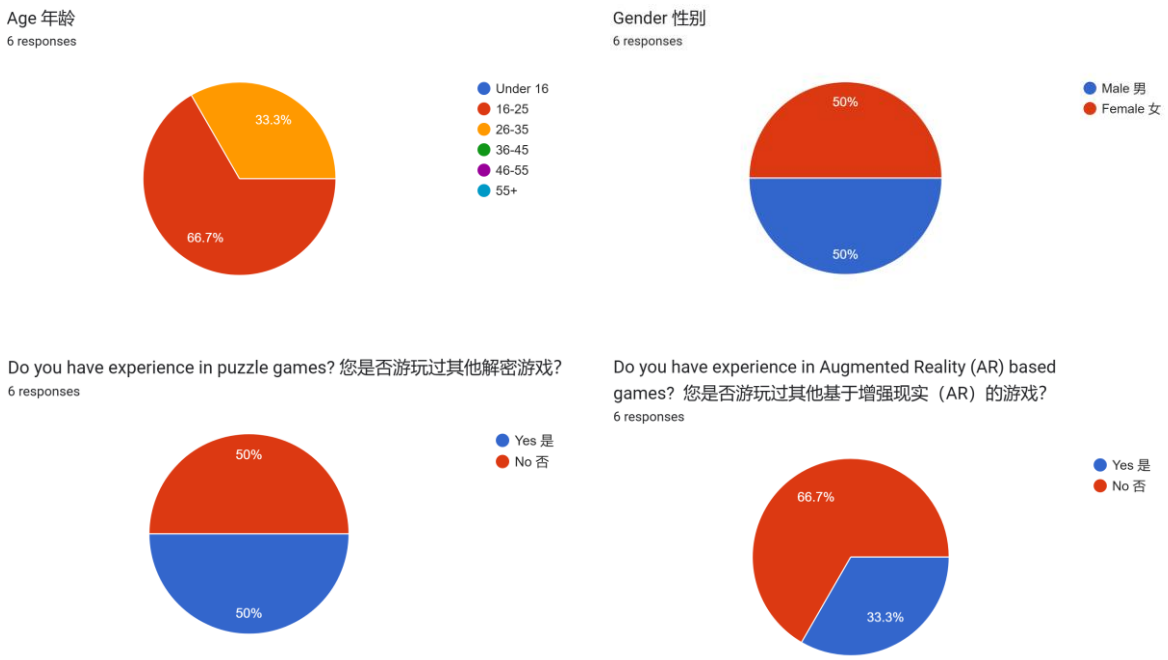

Figure 6.1 Stage 1 - Demographic

The Game Experience Questionnaire (GEQ) results showed that the overall player competence score was moderate, with an average of 3.67. Scores for sensory and imaginative immersion were slightly lower at 3.58, suggesting that while players felt engaged, there was room for improvement in creating a more immersive experience. Flow, which measures how seamlessly players felt while playing, was also rated relatively low at 2.92, indicating that players may have encountered difficulties that interrupted their gameplay. Tension and challenge scores averaged 2.75 and 3.75, respectively, indicating that while the challenge level was satisfactory, the tension experienced was higher than desired. Players reported moderate levels of positive and negative affect, with scores of 3.42 and 2.5, respectively.

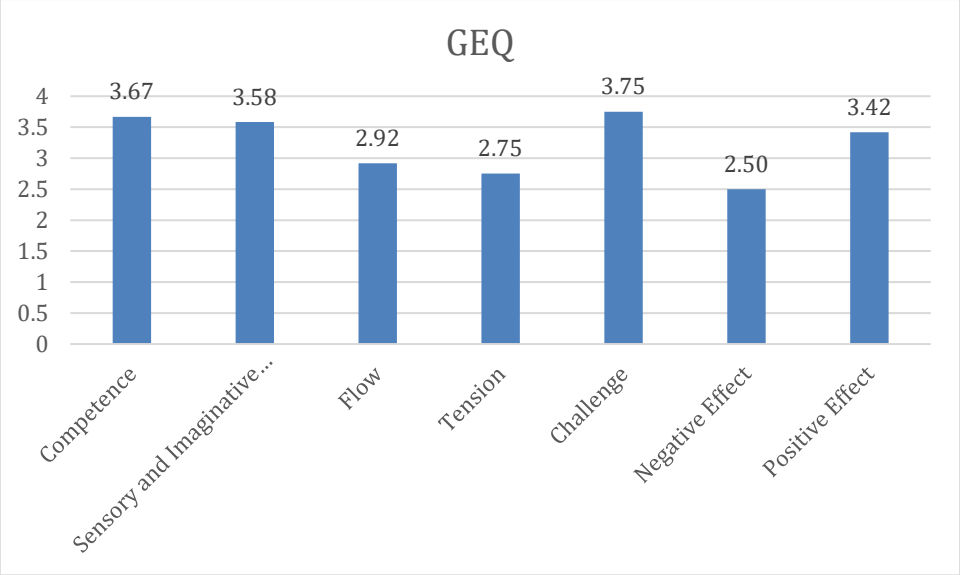

Figure 6.2 Stage 1 - GEQ

Feedback on puzzle design highlighted areas for improvement. The difficulty of puzzles was rated at 2.83, suggesting they were slightly easier than optimal for engaging gameplay. Players felt that the difficulty progression was adequate, with an average score of 2.83, and they generally understood new puzzle elements as they were introduced, scoring 3.17. However, there was feedback indicating a need for clearer instructions and smoother introduction of new elements. Overall, players found the puzzles to be moderately complex, with an average score of 3.0, and felt that the game provided adequate information to play, scoring 3.17. The introduction speed of new elements was rated at 2.83, suggesting that they were introduced at a manageable pace.

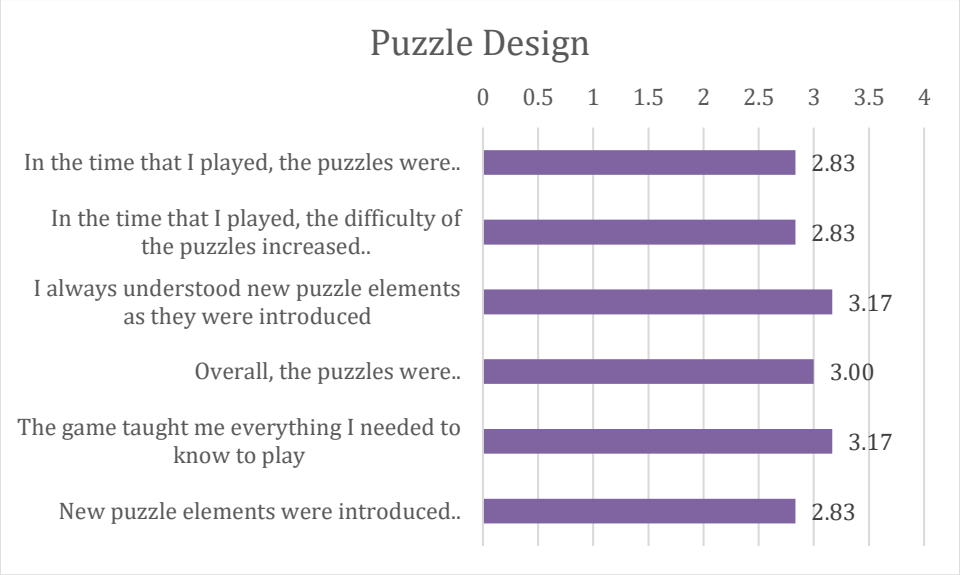

Figure 6.3 Stage 1 – Puzzle Design

6.3.2 Refinement

Based on the feedback from Stage 1, several refinements were implemented to enhance the gameplay experience.

First, the addition of background music was implemented to increase sensory and imaginative immersion, aiming to create a more engaging atmosphere and improve the flow of gameplay. The initial feedback indicated that while players found the game challenging, there was room to enhance the emotional experience, which could help elevate scores related to sensory engagement.

The graphical user interface (GUI) design was also enhanced. The survey results highlighted a need for a clearer and more intuitive interface, as some players reported difficulty in understanding the game's mechanics. An improved GUI was expected to help players navigate the game more easily, reducing tension and negative effects while fostering a smoother transition into more complex puzzle levels.

The tutorial was revised to include additional details, as feedback showed that some players did not fully understand new puzzle elements as they were introduced. This adjustment aimed to ensure that players felt more competent and less frustrated when encountering new game mechanics, which could contribute to a better flow and a more enjoyable game experience.

Lastly, a rotate game plate function was added to provide players with more control over their gameplay strategy. This feature was designed to address the feedback on puzzle

complexity and challenge, enabling players to interact more dynamically with the game environment and potentially increasing their overall satisfaction.

6.3.3 Stage 2

The second stage of the playtest involved five new participants, following the same demographic and experience range as the first stage. New participants are involved in this playtest because the participants in stage 1 already have the solutions for each of the puzzle, and this will affect the results of puzzle design.

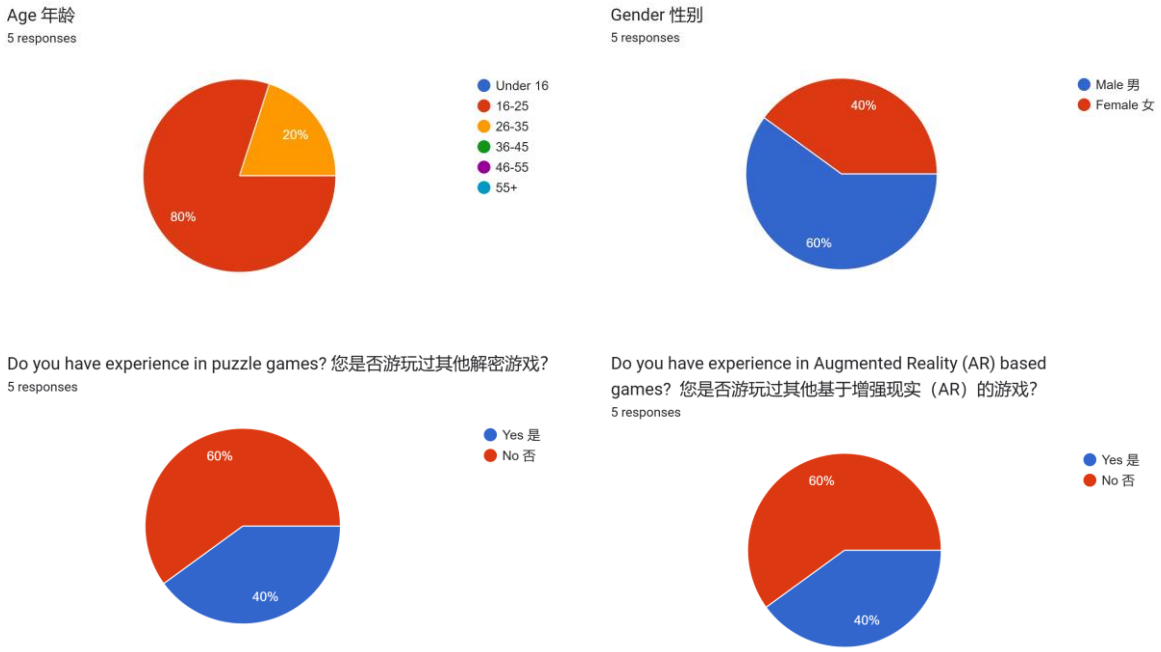

Figure 6.4 Stage 2 – Demographic

The GEQ scores demonstrated improvements across most categories. Player competence increased to an average score of 4.0, reflecting enhanced player understanding and engagement with the game mechanics. Sensory and imaginative immersion saw a slight improvement to 3.8, suggesting that the addition of background music and GUI enhancements contributed positively to the overall experience. The flow score increased modestly to 3.1, indicating that players felt more at ease during gameplay. Tension was reduced to 2.3, a significant improvement, suggesting that players experienced less frustration or anxiety. Positive affect

increased to 3.5, while negative affect decreased to 1.7, reflecting a more enjoyable experience overall.

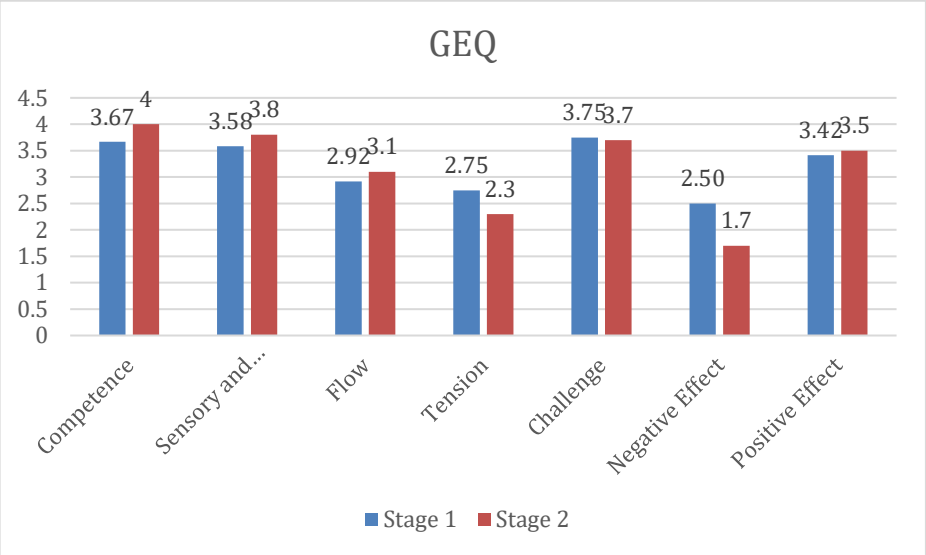

Figure 6.5 Stage 2 – GEQ

Feedback on puzzle design in Stage 2 also showed positive trends. Players rated the difficulty of the puzzles at 3.2, closer to the desired level, and felt that the difficulty progression was more appropriate, also scoring 3.2. Understanding of new puzzle elements improved to 3.6, indicating that the additional details in the tutorial were effective. Overall complexity was rated at 3.2, suggesting that players found the puzzles more appropriately challenging. Players agreed that the game taught them everything needed to play, with a score of 4.0. The speed at which new elements were introduced was rated at 2.8, suggesting that the pacing was satisfactory.

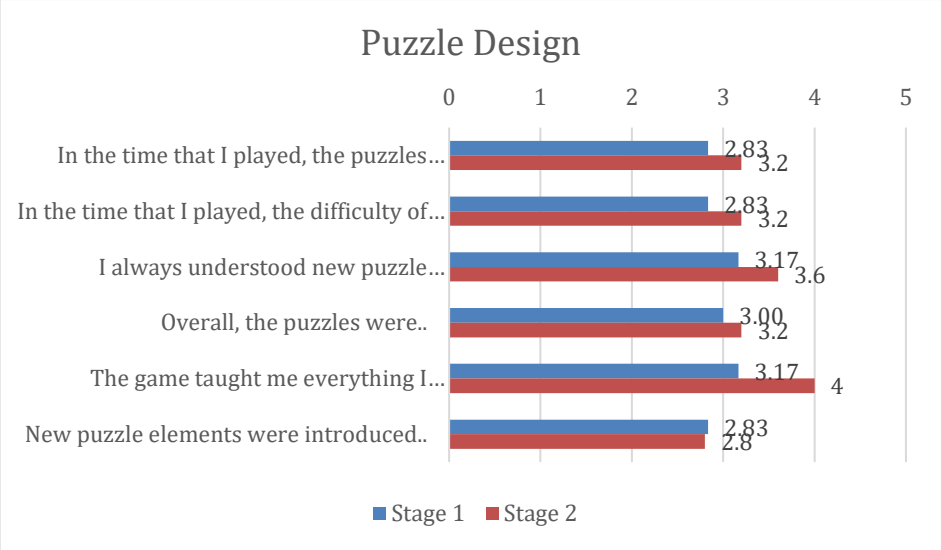

Figure 6.6 Stage 2 – Puzzle Design

6.4 Project Challenges

Throughout the development of this AR-based puzzle game, several challenges were encountered that required innovative solutions and iterative design approaches:

Complex Puzzle Design:

- One of the most significant challenges was designing puzzles that effectively utilized light reflection mechanics. Balancing the difficulty of these puzzles to cater to both novice and experienced players was a delicate task. Hence, the two stages playtest is conducted to collect the players' feedback. However, this challenge remains as another playtest is needed for additional stages in the future.

Vuforia Plane Detection Issues:

- A significant technical challenge arose with the plane detection function of the Vuforia AR framework. This function did not work reliably on some devices, particularly older models. To address this issue, the Vuforia SDK is updated to the latest version, which improved the functionality on several devices. However, despite these efforts, the issue persisted on certain older models.

User Feedback Incorporation:

- Gathering and effectively incorporating user feedback from playtests was essential for refining the game, but it also presented challenges. Balancing the diverse opinions and

preferences of players while staying true to the original vision of the game required careful consideration. It was important to prioritize changes that would enhance the overall gameplay experience without compromising the core mechanics and design principles.

6.5 Objectives Evaluation

The project set out with three key objectives, each aiming to leverage AR technology to create a unique and engaging puzzle game. The following evaluation assesses the extent to which these objectives were achieved:

1. *To design and develop a handheld AR-based puzzle game that leverages the capabilities of AR technology to overlay virtual puzzles onto the real-world environment.*

This objective has been successfully achieved. The game integrates virtual elements into the physical world, allowing players to interact with puzzles in their immediate surroundings. The use of AR not only enhances the immersion but also provides a seamless blend of virtual and real-world elements, fulfilling the core design goal.

2. *To introduce an AR-based puzzle game that incorporate light reflection mechanics as gameplay element.*

This objective has been fully realized through the implementation of puzzles that require players to manipulate mirrors and redirect light beams to reach a specific target. The light reflection mechanics were carefully integrated into the game, providing a unique and challenging gameplay experience that differentiates the game from traditional puzzle games. This mechanic has been pivotal in defining the game's core interaction and has been well-received in testing.

3. *To enhance the gameplay experience of players in a diverse range of challenging puzzles.*

The project successfully delivered on this objective by incorporating varying levels of difficulty and complexity in the puzzle design. Players are presented with puzzles that not only require logical thinking but also encourage experimentation with different strategies. The diversity in puzzle design ensures that the game remains engaging for a wide audience, catering to both novice and experienced players.

6.6 Concluding Remark

This project has successfully created an engaging AR-based puzzle game that meets its design and gameplay objectives. The system has successfully passed the testing in each module.

The user playtests were critical in shaping the final product. By conducting playtests in two stages, the project was able to gather valuable insights into player experiences and expectations. The feedback from the first playtest allowed for significant refinements, which were then validated through the second playtest. This iterative approach ensured that the game not only met technical and design goals but also resonated with the target audience.

The use of the Game Experience Questionnaire (GEQ) provided a structured way to evaluate the game's impact on players. By focusing on key components such as immersion, flow, and challenge, the GEQ highlighted the strengths of the game while also pointing out areas for improvement. The feedback gathered through this questionnaire confirmed that the game successfully engages players and delivers a satisfying puzzle experience.

Chapter 7 Conclusion and Recommendation

7.1 Conclusion

The development of the AR-based puzzle game has been a significant achievement, demonstrating the effective integration of augmented reality technology with engaging gameplay mechanics. The project successfully created a unique gaming experience by leveraging AR to overlay virtual puzzles onto the real-world environment. The core mechanic of light reflection, combined with intuitive controls and a user-friendly interface, provided a challenging and immersive experience for players.

The project has achieved several notable successes. Firstly, it effectively utilizes augmented reality technology by seamlessly blending virtual elements with the physical world, which enhances player immersion and interaction. This integration of AR technology has significantly contributed to creating an engaging and immersive gameplay experience.

Additionally, the project stands out for its innovative puzzle mechanics. By incorporating light reflection as a central gameplay element, the game differentiates itself from traditional puzzle games, offering a unique and distinctive experience to players. This creative approach has set the game apart and added depth to the gameplay.

Moreover, the project benefited from comprehensive testing and iteration. Rigorous testing processes and iterative improvements, informed by user feedback, ensured that the game met high technical and experiential standards. This commitment to refining the game based on user insights played a crucial role in its overall success.

Challenges encountered during development, such as balancing puzzle complexity and addressing Vuforia plane detection issues, were addressed through careful planning and continuous refinement. The iterative playtesting process provided valuable insights, allowing for adjustments that improved the overall gameplay experience.

Overall, the project has achieved its primary objectives of creating an engaging and innovative AR-based puzzle game. The combination of AR technology and well-designed gameplay mechanics has resulted in a product that successfully captivates players and offers a rewarding puzzle-solving experience.

7.2 Recommendation

Based on the project's outcomes and the challenges faced, several recommendations can be made to further enhance the game and its user experience.

First, addressing the persistent plane detection issues on certain devices should be a priority. Exploring alternative AR frameworks or additional optimization techniques could help improve compatibility and performance across a broader range of hardware.

Additionally, while the current puzzle designs effectively utilize light reflection mechanics, future updates could benefit from introducing new gameplay elements or mechanics to maintain player interest and engagement. For example, one of the play test participants said he hopes to see portals to swap the mirror location.

Finally, considering the potential for integrating social features or multiplayer options could add a new dimension to the game, fostering community engagement and extending its longevity. A real time ranking function can be added to motivate the players in achieving better performance in game.

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APPENDIX

Sample of Survey in Playtest

Lumina - Game Experience Survey

I am a student at the Faculty of Information and Communication Technology (FICT) from the University Tunku Abdul Rahman (UTAR). I am currently developing a mobile puzzle game based on Augmented Reality (AR) for my Final Year Project. The purpose of this survey is to understand users' gameplay experiences and thoughts about the game.

The survey is divided into three sections: Demographics, Game Experience Questionnaire (GEQ), and Puzzle Design. Completing this questionnaire should take approximately 5-10 minutes.

Your feedback is vital in aiding me to make informed decisions.
Please rest assured that your responses will remain confidential and your individual answers will not be revealed.

我是拉曼大学（UTAR）信息与通信技术学院（FICT）的一名学生，目前正在为我的毕业设计开发一款基于增强现实（AR）的手机益智游戏。此次调查的目的是了解用户对游戏的体验和看法。

问卷分为三部分：人口统计、游戏体验问卷（GEQ）和益智设计。完成这份问卷大约需要 5 到 10 分钟。

您的反馈对于我的决策至关重要。请放心，您的回答将严格保密，个人信息不会被公开。

* Indicates required question

Section 1: Demographic

This section is to have a little information about you.

1. Age 年龄 *

Mark only one oval.

- ◯ Under 16
- ◯ 16-25
- ◯ 26-35
- ◯ 36-45
- ◯ 46-55
- ◯ 55+

2. Gender 性别 *

Mark only one oval.

- ◯ Male 男
- ◯ Female 女

3. Do you have experience in puzzle games? *
您是否游玩过其他解密游戏?

Mark only one oval.

- ◯ Yes 是
- ◯ No 否

4. Do you have experience in Augmented Reality (AR) based games? *
您是否游玩过其他基于增强现实（AR）的游戏?

Mark only one oval.

- ◯ Yes 是
- ◯ No 否

Section 2: Game Experience Questionnaire (GEQ)

Please indicate how you felt while playing the game for each of the items.

5. I was interested in the game's story *
我认为这个游戏是有趣的

Mark only one oval.

	1	2	3	4	5	
Not at all 完全不同意	◯	◯	◯	◯	◯	Extremely 完全同意

6. I felt successful *
我很有成就感

Mark only one oval.

	1	2	3	4	5	
Not at all 完全不同意	◯	◯	◯	◯	◯	Extremely 完全同意

7. I felt bored *
我感到无聊

Mark only one oval.

	1	2	3	4	5	
Not at all 完全不同意	◯	◯	◯	◯	◯	Extremely 完全同意

8. I found it impressive *
我对这个游戏印象深刻

Mark only one oval.

	1	2	3	4	5	
Not at all 完全不同意	◯	◯	◯	◯	◯	Extremely 完全同意

9. I forgot everything around me *
玩游戏时我把别的事情都忘记了

Mark only one oval.

	1	2	3	4	5	
Not at all 完全不同意	◯	◯	◯	◯	◯	Extremely 完全同意

10. I felt frustrated *
我感到沮丧

Mark only one oval.

	1	2	3	4	5	
Not at all 完全不同意	◯	◯	◯	◯	◯	Extremely 完全同意

11. I found it tiresome *
我感到疲惫

Mark only one oval.

	1	2	3	4	5	
Not at all 完全不同意	◯	◯	◯	◯	◯	Extremely 完全同意

12. I felt irritable *
我感到焦躁

Mark only one oval.

	1	2	3	4	5	
Not at all 完全不同意	◯	◯	◯	◯	◯	Extremely 完全同意

13. I felt skilful *
我是有技巧的

Mark only one oval.

	1	2	3	4	5	
Not at all 完全不同意	◯	◯	◯	◯	◯	Extremely 完全同意

14. I felt completely absorbed *
我完全投入在游戏中

Mark only one oval.

	1	2	3	4	5	
Not at all 完全不同意	◯	◯	◯	◯	◯	Extremely 完全同意

15. I felt content *
我感到满足

Mark only one oval.

	1	2	3	4	5	
Not at all 完全不同意	◯	◯	◯	◯	◯	Extremely 完全同意

16. I felt challenged *
我觉得游戏有挑战性

Mark only one oval.

	1	2	3	4	5	
Not at all 完全不同意	◯	◯	◯	◯	◯	Extremely 完全同意

17. I had to put a lot of effort into it *
我必须付出很多努力

Mark only one oval.

	1	2	3	4	5	
Not at all 完全不同意	◯	◯	◯	◯	◯	Extremely 完全同意

18. I felt good *
我感觉很好

Mark only one oval.

	1	2	3	4	5	
Not at all 完全不同意	◯	◯	◯	◯	◯	Extremely 完全同意

Section 3: Puzzle Design

19. In the time that I played, the puzzles were.. *
在我玩游戏的时候，谜题是...

Mark only one oval.

	1	2	3	4	5	
Muc too easy 过于简单	◯	◯	◯	◯	◯	Much too hard 过于困难

20. In the time that I played, the difficulty of the puzzles increased.. *
在我玩游戏时，谜题的难度增加得...

Mark only one oval.

	1	2	3	4	5	
Muc too slow 太慢	◯	◯	◯	◯	◯	Much too fast 太快

21. I always understood new puzzle elements as they were introduced *
我总是能理解新引入的谜题元素

Mark only one oval.

	1	2	3	4	5	
Stro	◯	◯	◯	◯	◯	Strongly Agree 完全同意

Strongly Disagree 完全不同意

22. Overall, the puzzles were.. *
总体来说，谜题...

Mark only one oval.

	1	2	3	4	5	
Muc	◯	◯	◯	◯	◯	Much too complex 过于困难

Much too simple 过于简单

23. The game taught me everything I needed to know to play *
这款游戏教会了我玩游戏所需的一切

Mark only one oval.

	1	2	3	4	5	
Stro	◯	◯	◯	◯	◯	Strongly agree 完全同意

Strongly Disagree 完全不同意

24. New puzzle elements were introduced.. *
新的谜题元素引入得...

Mark only one oval.

	1	2	3	4	5	
Muc	◯	◯	◯	◯	◯	Much too quickly 太快

Much too slow 太慢

Thank you for your feedback. After considering the opinions of the participants, I will release the final version. Please stay tuned, and I hope you can participate in the game survey of the final version.
感谢您的反馈，在参考参与者的意见之后，我将会发布正式版。敬请期待，也希望您能参与正式版的游玩调查。

25. Do you interest in other new AR mobile games?
您是否对其他新的 AR 手机游戏感兴趣?

Mark only one oval.

	1	2	3	4	5	
Not at all 完全不同意	◯	◯	◯	◯	◯	Extremely 完全同意

26. If you have any other feedbacks, please write it here
如果您有任何其他反馈，请在此处写下

FINAL YEAR PROJECT WEEKLY REPORT

(Project II)

Trimester, Year: T2Y3	**Study week no.:** 4
Student Name & ID: Chiu Ken Boon 22ACB00361	
Supervisor: Dr. Ng Hui Fuang	
Project Title: LUMINA: A HANDHELD AR BASED PUZZLE GAME	

1. WORK DONE

- Puzzle design
- Audio and animation integration

2. WORK TO BE DONE

- Implement the puzzle into game scenes
- Prepare survey questions for playtest

3. PROBLEMS ENCOUNTERED

- Not sure if the difficulty of puzzles meet expectation

4. SELF EVALUATION OF THE PROGRESS

- Satisfied with the progress

Supervisor's signature

Student's signature

FINAL YEAR PROJECT WEEKLY REPORT

(Project II)

Trimester, Year: T2Y3	**Study week no.:** 6
Student Name & ID: Chiu Ken Boon 22ACB00361	
Supervisor: Dr. Ng Hui Fuang	
Project Title: LUMINA: A HANDHELD AR BASED PUZZLE GAME	

1. WORK DONE

- Implementation of all stages
- Survey questions for playtest

2. WORK TO BE DONE

- Conduct the first playtest

3. PROBLEMS ENCOUNTERED

- None

4. SELF EVALUATION OF THE PROGRESS

- Satisfied with the progress

Supervisor's signature

Student's signature

FINAL YEAR PROJECT WEEKLY REPORT

(Project II)

Trimester, Year: T2Y3	**Study week no.:** 8
Student Name & ID: Chiu Ken Boon 22ACB00361	
Supervisor: Dr. Ng Hui Fuang	
Project Title: LUMINA: A HANDHELD AR BASED PUZZLE GAME	

1. WORK DONE

- First playtest
- Collect feedback from playtest participants

2. WORK TO BE DONE

- Analyze the playtest
- Make improvement based on the playtest

3. PROBLEMS ENCOUNTERED

- None

4. SELF EVALUATION OF THE PROGRESS

- Satisfied with the progress

Supervisor's signature

Student's signature

FINAL YEAR PROJECT WEEKLY REPORT

(Project II)

Trimester, Year: T2Y3	**Study week no.:** 10
Student Name & ID: Chiu Ken Boon 22ACB00361	
Supervisor: Dr. Ng Hui Fuang	
Project Title: LUMINA: A HANDHELD AR BASED PUZZLE GAME	

1. WORK DONE

- Refinement on the application based on playtest analysis, including:
  - Add in background music (BGM)
  - Enhance GUI
  - Improve the game tutorial
  - Add in rotate game plate buttons

2. WORK TO BE DONE

- Conduct next playtest to evaluate the improvements made

3. PROBLEMS ENCOUNTERED

- The timeframe is short

4. SELF EVALUATION OF THE PROGRESS

- Satisfied with the progress

Supervisor's signature

Student's signature

FINAL YEAR PROJECT WEEKLY REPORT

(Project II)

Trimester, Year: T2Y3	**Study week no.:** 12
Student Name & ID: Chiu Ken Boon 22ACB00361	
Supervisor: Dr. Ng Hui Fuang	
Project Title: LUMINA: A HANDHELD AR BASED PUZZLE GAME	

1. WORK DONE

- Second playtest
- Analysis on second playtest results

2. WORK TO BE DONE

- Complete the report and prepare for presentation

3. PROBLEMS ENCOUNTERED

- None

4. SELF EVALUATION OF THE PROGRESS

- Satisfied with the progress

Supervisor's signature

Student's signature

POSTER

author: Chiu Ken Boon
supervisor: Dr. Ng Hui Fuang

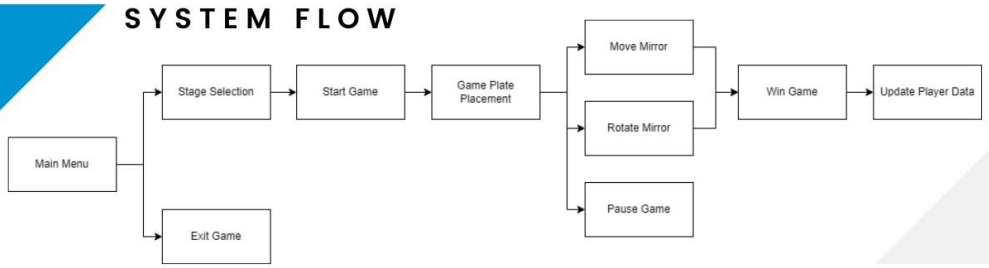
Lumina: A Handheld AR Based Puzzle Game

An AR-based puzzle game that skillfully incorporates the concept of light reflection, offering an immersive and intellectually captivating gaming venture.

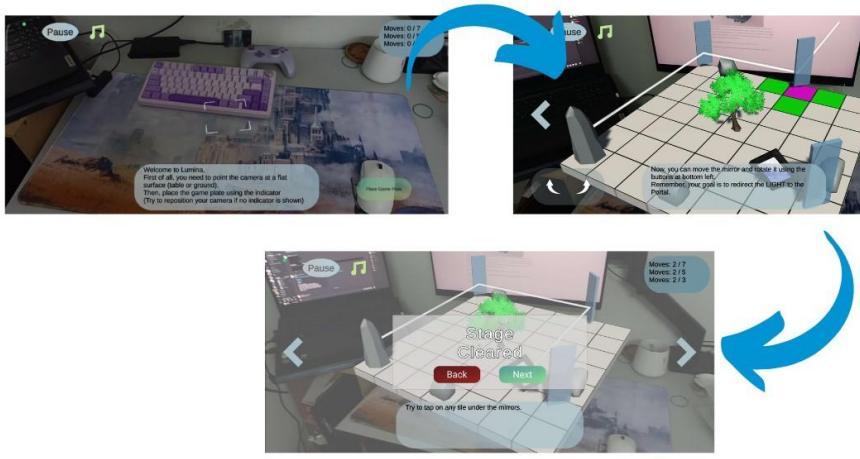
OBJECTIVES

- design and develop a handheld AR-based puzzle game that leverages the capabilities of AR technology
- introduce an AR-based puzzle game that incorporate light reflection mechanics as gameplay element
- enhance the gameplay experience of players in a diverse range of challenging puzzles

SYSTEM FLOW



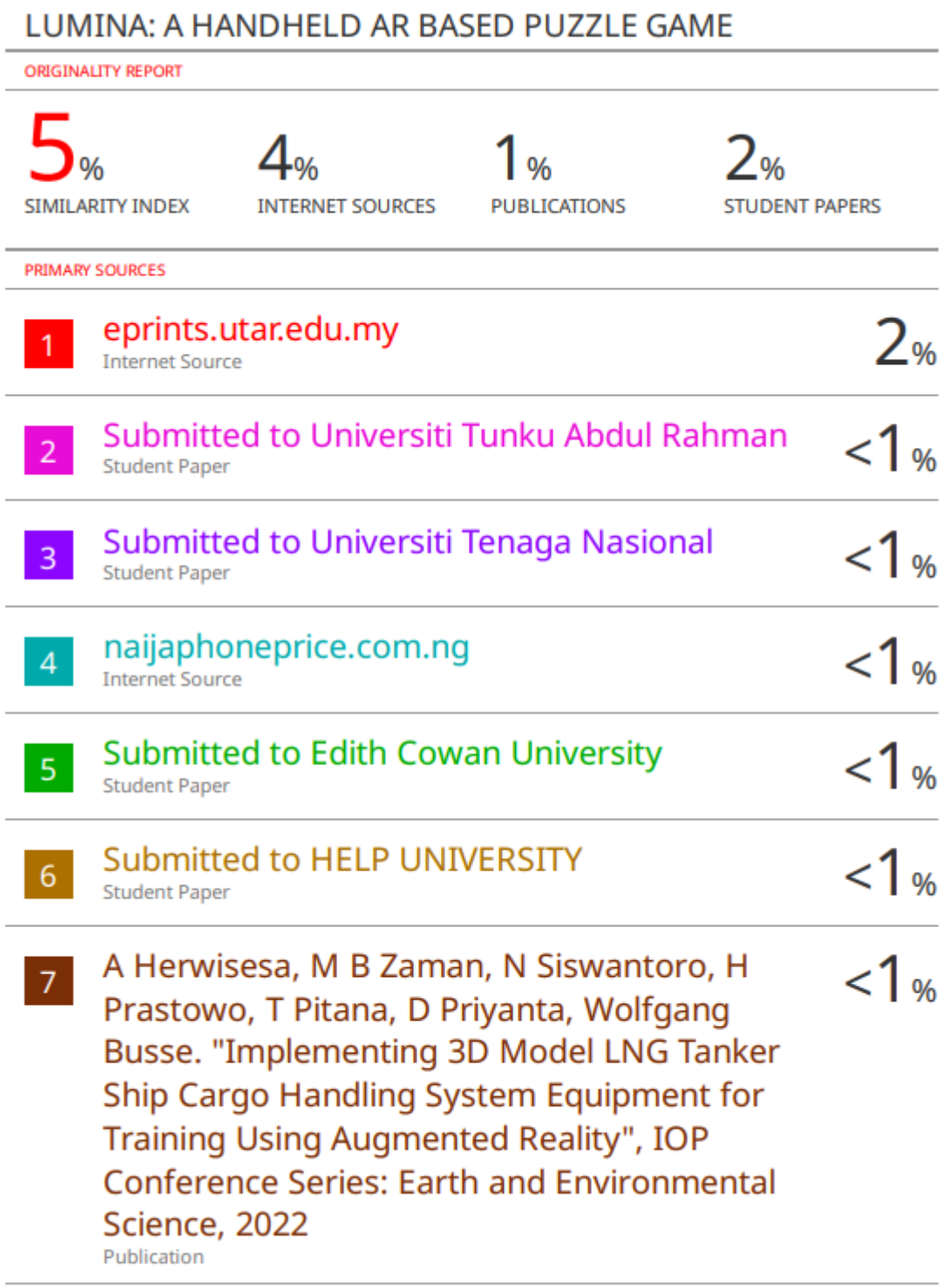
RESULT



CONCLUSION

By introducing light reflection mechanics as a core gameplay element, the project aimed to push the boundaries of traditional puzzle gaming and showcase the potential of AR technology in delivering captivating experiences. Overall, this project represents a step forward in redefining the possibilities of AR gaming and sets the stage for further innovation in the future.

PLAGIARISM CHECK RESULT



LUMINA: A HANDHELD AR BASED PUZZLE GAME

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Form Title: Supervisor's Comments on Originality Report Generated by Turnitin for Submission of Final Year Project Report (for Undergraduate Programmes)			
Form Number: FM-IAD-005	Rev No.: 0	Effective Date: 01/10/2013	Page No.: 1of 1

FACULTY OF INFORMATION AND COMMUNICATION TECHNOLOGY

Full Name(s) of Candidate(s)	Chiu Ken Boon
ID Number(s)	22ACB00361
Programme / Course	Bachelor of Computer Science (Honours)
Title of Final Year Project	LUMINA: A HANDHELD AR BASED PUZZLE GAME

Similarity	**Supervisor's Comments (Compulsory if parameters of originality exceed the limits approved by UTAR)**
Overall similarity index: 5 % **Similarity by source** Internet Sources: 4 % Publications: 1 % Student Papers: 2 %	
Number of individual sources listed of more than 3% similarity: 0	
Parameters of originality required, and limits approved by UTAR are as Follows: **(i) Overall similarity index is 20% and below, and** **(ii) Matching of individual sources listed must be less than 3% each, and** **(iii) Matching texts in continuous block must not exceed 8 words** ***Note: Parameters (i) – (ii) shall exclude quotes, bibliography and text matches which are less than 8 words.***	

Note: Supervisor/Candidate(s) is/are required to provide softcopy of full set of the originality report to Faculty/Institute

Based on the above results, I hereby declare that I am satisfied with the originality of the Final Year Project Report submitted by my student(s) as named above.

_____ _____

Signature of Supervisor Signature of Co-Supervisor

Name: Ng Hui Fuang Name: _____

Date: 10/9/2024 Date: _____

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FACULTY OF INFORMATION & COMMUNICATION TECHNOLOGY
(KAMPAR CAMPUS)

CHECKLIST FOR FYP2 THESIS SUBMISSION

Student Id	22ACB00361
Student Name	Chiu Ken Boon
Supervisor Name	Dr. Ng Hui Fuang

TICK (√)	DOCUMENT ITEMS Your report must include all the items below. Put a tick on the left column after you have checked your report with respect to the corresponding item.
√	Title Page
√	Signed Report Status Declaration Form
√	Signed FYP Thesis Submission Form
√	Signed form of the Declaration of Originality
√	Acknowledgement
√	Abstract
√	Table of Contents
√	List of Figures (if applicable)
√	List of Tables (if applicable)
	List of Symbols (if applicable)
√	List of Abbreviations (if applicable)
√	Chapters / Content
√	Bibliography (or References)
√	All references in bibliography are cited in the thesis, especially in the chapter of literature review
√	Appendices (if applicable)
√	Weekly Log
√	Poster
√	Signed Turnitin Report (Plagiarism Check Result - Form Number: FM-IAD-005)
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*Include this form (checklist) in the thesis (Bind together as the last page)

I, the author, have checked and confirmed all the items listed in the table are included in my report.

(Signature of Student)
Date: 9 September 2024