FACULDADE DE ENGENHARIA DA UNIVERSIDADE DO PORTO

Inducing Flow in Board Games Through Augmented Audio

André Emanuel Afonso Gustavo de Sousa

Mestrado Mutimédia

Supervisor: João Jacob

Second Supervisor: Eduardo Magalhães

November 4, 2020

Inducing Flow in Board Games Through Augmented Audio

André Emanuel Afonso Gustavo de Sousa

Mestrado Mutimédia

November 4, 2020

Abstract

Games provide high levels of enjoyment and fun. The flow state is an optimal state of absorption in an activity that leads to enjoyment and fun. Modern board games provide good gaming experiences however it is possible to use various resources to further enhance the experience.

The purpose of this study was to discover if Augmented Audio can be used to induce flow during a board game playthrough and what is its impact in the user experience.

A augmented audio prototype was developed in order to try to answer this question using the board game "Rising Sun". The concept was to augment the user's sound environment with sounds related to their in-game actions. The data collection was gathered with 10 participants over the course of 3 days.

The results shown that augmented audio had a positive impact on the player's flow state while they were playing the board game.

Resumo

Os jogos são uma fonte de satisfação e de diversão. O estado de flow pode ser definido como um estado extremo de absorpção numa actividade que quando terminada leva a um estado intenso de satisfação. Os jogos de tabuleiro modernos fornecem boas experiências de jogo, no entanto é possível usar outros recursos para melhorar a experiência.

O propósito deste estudo é descobrir se o Áudio Aumentado pode induzir flow durante uma partida de um jogo de tabuleiro e qual é o impacto na experiência do utilizador.

O conceito desenvolvido é enaltecer o som natural ambiente com sons virtuais relacionados às acções de jogo. A avaliação dos resultados foi feita com 10 participantes durante 3 dias.

Os resultados demonstraram que o audio aumentado pode ter um impact positivo no estado de flow durante o jogo.

Acknowledgements

I would like to thank my supervisors João Jacob and Eduardo Magalhães that support me helped me and support me all the way and guided me during the quarantine periode.

A special thanks to Associção-Quebra dados for allowing me to use their space and for the incredible availability.

I would also like to give a special thanks to Maialen Palazot, Martinho Mota, and Hugo Caseira for the tireless support in the most difficult times. To my father that always supported my decisions. To Robert Thor Gordon for his much-appreciated help in revising the thesis.

Finally to all my friends that with their presence and help participated in this journey.

André Sousa

Contents

List of Figures

List of Tables

Abbreviations

API	Application Programming Interface
AR	Augmented Reality
ARA	Augmented Reality Audio
BGG	Board Game Geek
CAGR	Compound annual growth rate
CCG	Collectible Card Games
CMON	Cool mini or not
DAW	Digital Audio Workstation
DDA	Dynamical Difficult Adjustment
FOV	Field of view
FUMA	Furse-Malham
GDW	Game Designers Workshop
HMD	Head-Mounted Displays
HRTF	Head-related transfer function
ILD	Interaural Level Difference
ITD	Interaural Time Difference
MR	Mixed Reality
OST	optical see-through
RPG	Role Playing Game
SDC	Simulation Design Corporation
SDK	Software Development Kit
SPI	Simulation Publication Incorporated
VR	Virtual Reality
VST	Video see-through

Chapter 1

Introduction

The board game industry has boomed over the last decade. This industry is growing at a Compound Annual Growth Rate (CAGR) of 8.7% and this so-called hobby is spreading across different countries. A board game renaissance is now occurring with new models of game design and aesthetics. These new designs are focused on exploring new mechanics. They give the player agency, challenge them with problem-solving, and engage him with the game (*Playing Cards Board Games Market Size Worth $21.56 Billion by 2025: Grand View Research, Inc.*, 2020). With the exploration of new game designs also came technology. Over the last years, board games have been increasingly supported by technology. For instance, *Mansions of Madness* or *Lord of the Rings Journeys for Middle Earth* are both guided by apps that give support to the gameplay. They can record player or enemy stats as well as generate and randomize events and setups. Another advance in hybrid games came from the publisher *Cool Mini Or Not* (CMON) with the new system *Teburu* (figure, 1.1). This system uses sensors to track the player characters on the board, it then matches the corresponding game events with the position of the pieces and unlocks scenes and events related to the game history as well as triggers sound events when the player piece enter some areas. All this information is then sent to the player's smartphones via an app. This merge between board games and technology is the main focus of this dissertation, it aims to explore the possibilities of augmented audio in board games, a technology that is becoming available to the mass market. Although board game aesthetics have seen a big improvement in the last few years, audio content for board games is still very unexplored.

Figure 1.1: Teburu: System developed by Cool Mini or Not (*Teburu: A New Evolution in Board Games*, 2019)

1.1 Research Questions

Board games are evolving in terms of game mechanics and visual aesthetics however sound is still an unexplored area in board games. The current dissertation seeks to answer the following questions:

- Can we enhance the board game experience using augmented audio?

In order to further explore this question is possible to further divide this into more specific questions:

- Does augmented audio induce flow during a session of a board game?
- What is the impact of augmented audio in the user experience?
- What sound design strategies can be used for augmented audio in board games?

1.2 Document Structure

Chapter 1 provides the context where this dissertation is inserted, followed by defining the problem and the related research questions. Some key points are defined about the current state of the board game market.

Chapter 2 presents the literature review with the important work made in the area of boardgames, augmented reality, augmented audio, flow, and gaming flow. It starts with a brief history of the modern board games and their characteristics followed by Augmented Reality where the requirements are analyzed as well as some of the possible tracking methods and finally Augmented Audio were binaural audio and ambisonics format is presented. The chapter concludes with the research about flow and gaming flow.

Chapter 3 presents the proposed architecture for the prototype to use augmented audio in board games. It presents the project overview and the explanation about the game chosen. The planning for the development of the sound and detection as well the system architecture and the proposed methods for evaluation.

Chapter 4 covers all of the Development phase. It presents the implementation of the images with Vuforia, sound creation, implementation and the explanation on how the game engine works.

Chapter 5 is reserved for the validation of the prototype reviewing the results. At the end of the chapter is a section for results discussion.

Chapter 6 ends this dissertation with the conclusions and possible future work.

Chapter 2

State of the Art Review

This chapter covers the evolution of board games and the game system elements, followed by a brief history of Augmented Reality and their technologies, and ends with the flow and gaming flow theories.

2.1 A Brief History of Board Games

The study of **Modern Board Games** is a relatively unexplored field of research. Most of the existing literature is related to video games. Research for analog games are usually about abstract classical games, and Role-Playing Games (RPG). Sources like Stewart Woods book *Eurogames: The Design, Culture, and Play of Modern European Board Games* and online communities proved to be a valuable resource for the study of **Modern Board Games**.

Board games are associated with analog games. They are recognized by many people as games that are played on top of a board with analog components and are seen, in some cases, as an archaic form when compared with modern videogames. The oldest board game found is called *Senet*, and dates back to 2686 B.C., during the third dynasty of Egypt (Piccione, 2007). This term "board game" is also commonly related to mass market games like *Monopoly*, *Trivial Pursuit* and *Risk*.

From 2686 B.C until 1872 A.D a huge array of games were developed, including *Chess*, *Checkers*, *Dominoes*, *GO* and others. Other types of board games started to emerge in the early 20th century. *The landlord's Game* was the starting point for mass market family games. The *Parker Brothers* company bought its patent in 1935 and named it *Monopoly*, making it one of the most successful mass-market games ever. During the first half of the 20th century, the major American board game companies commercialized mainly mass-market family games (Belousov, 2019).

War games thrived in a niche market after the 1950s, mainly published by American companies like *Avalon Hill* and *SPI*. They usually focused on war and simulated conflict, they used very complex systems of tables and boards and elements of luck to dictate the result of actions.

It would not be until the 1960's that some American, British, and German companies developed a new line of adult and family strategy games that would deeply influence the design of modern board games. In 1962, the American company *3M* commissioned a development team led by the game designers *Alex Randolph* and *Sid Sackson* to create adult strategy games. In his book Woods cited the game designer *Shapiro* about the evolution of board games: "All of the games published prior to this, and many more to follow, could be considered first generation board games. These first generation games followed a rigid format where turns alternated in a strict pattern, there was little player interaction, a minimal number of choices per turn and, with rare exceptions, no real need for players to remain at the table when it was not their turn to play". Among the first games created by this second generation of game designers were Sackson's *Acquire*, Randolph's *Twixt*, and Onanian's *Facts in five*.

During the decade of 1970 and 1980, the popularity of board games grew, especially in the United Kingdom. This period saw the creation of important magazines like *Games and Puzzles* and the organization of the first game convention in Birmingham in 1976. During this period smaller companies in America and the UK released innovative adult games outside of the established mass-market and wargaming. In 1974, Designer *Francis Tresham* released *1829*, a game based on the construction of railroads using development and stock holding. In that same year, game designer *James St. Laurent's* released *Crude: The oil game*, which featured a unique mechanic wherein all the players benefit from a single dice roll. Sci-fi and fantasy themes also gained popularity during the 1970s. The most important game from this period is *Cosmic Encounter*. It is a game of area control (players use pieces to control different areas on the board) with a sci-fi theme where each player controls an alien race. The most remarkable aspects of this game were the asymmetry in player powers from each race and the diplomatic actions between players. Woods cites Shapiro on the importance of Cosmic Encounter: "The impact of Cosmic Encounter simply cannot be ignored. The original concept it introduced has permeated every genre of gaming from war and card games to video games. It is a single, simple idea: every player is allowed to break a rule in a unique manner. With Cosmic Encounter every player began with an identical set up and a card that allowed them to "break" one of the rules of the game. This was revolutionary". *Dune*, developed by *Avalon Hill*, took the asymmetry developed in Cosmic Encounter to the extreme, with each player having specific rules and mechanisms (Woods, 2012).

During the 1980-1995 period, important new mechanics emerged and new categories of games were developed. The design team behind *Dune* released *Borderlands* in 1982 which introduced the first player rotation. *Civilization* is a famous board game developed by the game designer *Hartland Trefoil* which later gave origin to the acclaimed video game series of the same name. It is the first game to use a "technology tree" (a sequence of possible upgrades) representing the various civilizations' development. *Civilization* was reprinted by *Avalon Hill* in 1981 and has acquired great renown within the board game community. Role-playing games were also developed during the 1980s with an emphasis on narrative and acting and found immense success. Publishers and designers sought a way to adapt some RPG's elements to create a hybrid between RPG's and board games. *Talisman*, published in 1984 by the publisher *Games Workshop*, incorporated the

exploration and narrative of RPG's with the traditional mechanic of roll and move. In 1984 the company also published *Railway Rivals*, considered as the first modern railway game. The objective of railway games is to foster the creation of railroads and the movement of goods as efficiently as possible. They differ from *Tresham's 18XX series* based on acquiring wealth using already established railroads. During this period german game designers were perfecting the German design later known as *Eurogames*.

In the 1990s Collectible Card Games dominated the market following the release of *Magic: The Gathering*, while at the same time *Eurogames* also started to gain popularity. During this period in 1995 one of the most important and influential games for the future generations was released: *Die Siedler Von Catan* from the German designer *Klaus Teuber*. The game featured all the main elements which define *Eurogames*: manageable and predictable playing times, simple rulesets, avoidance of direct conflict, high production values, and lack of player elimination. The influence of *Eurogames* can be found in modern board games, with which they share many characteristics (figure, 2.1). Modern board games often feature crossovers between existing categories of games, leading to a variety of mechanics that involve social interaction between players, blurring the boundary between playing and social experience, and leading to high levels of engagement (Woods, 2012).

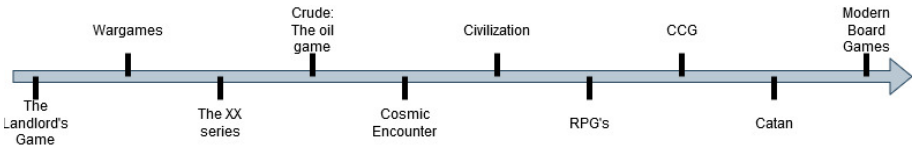

Figure 2.1: Board Games timeline from the beginning of XX century to the present

2.1.1 Board Games Categories

The evolution of board games led to the creation of different categories of games, organized by aesthetics and mechanics. Board games are divided into three main categories: Classical, mass-market, and hobby games (Woods, 2012).

2.1.1.1 Classical Games

Classical games tend not to have "ownership" mechanics. They are mainly historical games. Most of them are defined as abstract games since the theme is not identified. There exist four subcategories of Classical games (figure, 2.2):

- Race games, where players try to be the first to reach a specific point in a board.
- Space games where players manipulate the pieces to make them align or to make connections.
- Chase Games where the objective is for one player to catch the other.

- Displacement games where both players have symmetric setups and they should eliminate each other, the most well-known example being *chess*.

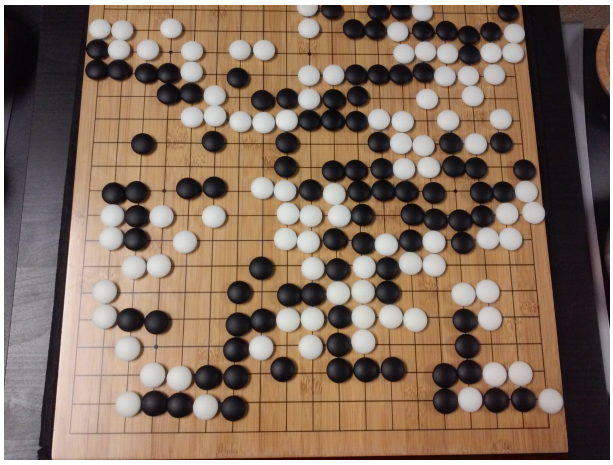

Figure 2.2: Classical Game "Go" (Mey, n.d.)

2.1.1.2 Mass-Market Games

Mass-market games are the ones that people from outside the hobby often associate with the activity. These games are sold in the majority of the big retailers and exist in three main groups :

- Family games, which developed during the XX century, had simpler, luck-driven mechanics and were not as rule intensive. Some notable mentions are *Monopoly* and *Clue*.
- Party games, which became famous during the ‘80s with *Trivial Pursuit*, these games focus on social behaviors and performance, they do not offer deep strategies.
- Licensed games, which focus on aesthetics or reskin of previous games since they are licensed products of famous TV shows. Crossovers over all three subcategories are common.

2.1.1.3 Hobby Games

Since the 1950’s a parallel board game market has emerged, focused on delivering different experiences from the mass-market. In his book *The Oxford History of Board Games*, *David Parlett* gives the following definition of modern board games (Parlett, 1999): "These may be characterized as games of skill and strategy appealing to players broadly describable as adults, serious, educated, intelligent. Many of these share the associated features of classic games, from which category they are only excluded by their appeal to a specialist section of the market". The definition of hobby games was coined by the community of board game players. They are designed for enthusiasts of gaming and target a mature public. The gaming writer *Greg Aleknevicus* describes four main subcategories of hobby games: Wargames, role-playing games, collectible card games, and eurogames (Woods, 2012).

2.1.1.4 Wargames

Wargames are a type of strategy game whose theme is to simulate real conflicts. The first wargames were developed for the army. They started to draw public interest in the 1950s, when the American *Charles S. Roberts* designed what is considered to be the first modern wargame named *Tactics* in 1954. They were published largely by American companies, the most notable being *Avalon Hill*. Wargames grew in popularity during the mid-XX century. According to Dunnigan, with the growth of the genre in America, other companies started to pop up following the steps of Avalon Hill: Simulation Publication Incorporated (SPI), Game Designer's Workshop (GDW), and Simulation Design Corporation (SDC) for instance. These companies proliferated during the 1970s mainly by publishing wargames (Woods, 2012).

The defining features of wargames from this time were:

- one versus one player setup
- the use of hexagonal grids each representing different types of terrain
- cardboard tokens to represent army units that have combat value and abilities
- probability tables and dice to determine the outcomes of combats.

Wargames were targeting a niche public, being quite difficult games to learn with very complex rulebooks and long playing times.

Diplomacy designed by *Alan Calhamer* in 1959 introduced new concepts to the category. It is a multiplayer game that uses in game players' relations to define the strategy. The combat is simplified by counting who has more units in an area, removing the element of chance. Conquête du Monde developed by Albert Lamorisse in 1957 is also a very simplified wargame. The battles are resolved with dice rolls, and each result of 5 or 6 kills an enemy unit. The rights for the game were later bought by Parker and Brothers who renamed it Risk (Gordon, 2013).

In 1977 *Avalon Hill* published the best selling wargame *Squad Leader* (figure, 2.3). The game allowed a variety of setups and terrains. The interest in Wargames decreased with the appearance of RPG games as well as with the increased popularity of personal computers, which could handle the high complexity of wargames including the bookkeeping and the rules. As *Dunnigan* describes (Dunnigan, 2000): "One can make the case that wargame sales are better than ever if one simply changes the definition of a wargame. That's what the market has done in response to market demands. But that's like saying that historical fiction should be reflagged as history books because few people will buy and read real history books anymore. No, the problem is that historical wargames were always a small market because they emphasized information and analysis at the expense of entertainment. Any gamer who was not a wargamer immediately saw that. Now that computers have made it possible for many more people to play wargames, you should not be surprised that most of them want to be entertained, not put through a training course." With digital competition, publishers turned to simplified approaches. *Warhammer*, developed by the publisher *Games Workshop*, became a phenomenon thanks to the success of the fantasy theme, very strong

lore, simpler rules, and enhanced aesthetics with miniatures. The use of miniatures has become common practice for wargames and some modern board games (Woods, 2012).

Figure 2.3: Wargame: Squad Leader (Brooks, 2015)

2.1.1.5 Role-Playing Games

Gary Gygax and *Jeff Perren* are considered the founders of the Role Playing Games (RPG's) genre, owing to their creation of *Dungeons and Dragons* (figure, 2.4). Gygax developed a medieval miniatures game based on a rule system created by Perren. Later *Dave Arneson* added new concepts to the game like an ongoing campaign in a medieval setting and introducing the concept of magic. The first and the most recognizable trait of the genre is consisting in an ongoing Campaign where each player portrays a character in a collaborative game. The second trait is the individual's control and personalization over the character, the third is control of special powers, like magic, and the final trait is being a collaborative adventure. After reviewing these ideas Gygax and Perren developed the ruleset of the phenomenon named *Dungeons and Dragons*. In RPG games each player controls one character, these characters gain traits and abilities which they use during the campaign. The game can be played with few components, the essential ones being pens, papers, dice, and ruleset. The presence of a dungeon master (a person that leads the group through the campaign and describes events) is necessary. This player is responsible for the bookkeeping and for unfolding the game events. The game is mainly based on narrative and player choices. RPG's campaigns are normally played over many play sessions. During a session, players follow the narrative, where they are faced with various challenges which require them to use their traits, habilities and dice rolls in order to progress. The use of the dice to solve combat has its roots in

wargaming. The ruleset defines the relationship with the world and how to deal with objects and enemies. Modern RPGs tend to emphasize the theatrical elements of the game and the players' freedom of action (Woods, 2012).

Personal computers allowed for digitized versions of analog RPGs, but the core characteristic of these games is the socialization and interpretation aspects (Belousov, 2019). According to *Costikyan* (Davidson & Costikyan, 2011): "Paper RPGs, unlike electronic ones, are social affairs; players get together periodically to play and spend at least as much time roleplaying for their friends as they do try to maximize their character's effectiveness in a purely structural context. It is common for a group of friends to get together for years, playing the same characters in the game gameworld with the same game master. In the process, they establish long character histories, flesh out the world background, and so on. For long term players, the stories they create can be as emotionally powerful and personally meaningful as anything you find in a novel or a movie perhaps more so because the players are personally involved in their creation." The popularity of tabletop RPGs suffered a decline in 1993 with the arrival of Collectible Card Games (CCG) (Woods, 2012).

Figure 2.4: A session of Dungeon and Dragons (Luigi, 2005)

2.1.1.6 Collectible Card Games

Collectible Card Games (CCG) are based on collecting and trading of cards to build the player's deck. They tend to be strategic "one versus one" games (Turkay, Adinolf, & Tirthali, 2012).

During the year 1993, game designers *Richard Garfield* and *Peter Adkison*, owner of the company *Wizards of the Coast*, worked on Garfield's prototype. It was a two-player game meant to be

portable, based on collecting and trading baseball cards that could be expanded with new card sets. The cards were divided into different levels of rarity (i.e. Common, Uncommon, Rare, and Mythic rare). Later that year it was published as *Magic the Gathering*. Woods cites *Applecline* to describe the success of Magic the Gathering: “There is no way to overstate how much CCGs changed the RPG industry back in 1993 and 1994. Gamers were lining up at stores on release day, purchasing the new sets by the 100 dollars case. There was so much money in the fad that new game stores popped up just to get in on the booming industry. Print runs kept increasing, but pre-orders were locked in months ahead of each release, and Wizards couldn’t afford to print much above them, so retailers and distributors were constantly limited in their purchases, as their desires typically had grown by release date.” The introduction of expansions utilizing small purchasable "boosters" (figure, 2.5) added new contents to the game, allowing for numerous strategies (Woods, 2012).

The growth and success of *Magic the Gathering* led to the creation of specialized magazines and tournaments with monetary prizes. More publishers tried to release their version of CCG to compete with Magic The Gathering but the only serious competition came with the Pokemon card game released in 1999, targeting a younger audience.

Many CCGs also developed digital versions which made them more accessible to anyone who owned a personal computer. CCG’s that were out of print gained new life as their digital versions began to pop up.

Another type of collectible component were miniatures. They were a parallel market that had grown with the influence of miniatures wargames, especially from the publisher *Game Design Workshop* (Woods, 2012).

Figure 2.5: Magic the gathering expansion packs (Rupert, 2008)

2.1.1.7 Eurogames

The *Eurogame* genre is, as its name implies, based on a game design style from Europe, mainly Germany. The social impact that war had in Germany influenced their gaming culture. In his book, Woods cites game designer *Knizia* about the gaming culture in Germany: "Germany is extremely critical towards war games. That comes from the history and the experiences of the Second World War. The majority of people, the family game culture, doesn't really like to play war games. It's modern fairy tales they want to play" (Woods, 2012). Germany was long reputed for its production of excellent quality wooden toys, Boardgames from Germany had their pieces made of wood. After the Second World War, with the recovery of the German market, the country regained its title as the world capital of toys. Between 1970-1995, German board game designers and publishers were releasing many innovative games when compared with the rest of the world. One of the most important companies which inspired the German design was the American company 3M. The line of strategy games for adults they developed had a common feature with eurogames: there was no direct conflict either in theme or mechanics. Most of the mechanics focused on individual development, comparative achievement, and social interaction. According to game designer *Franz-Benno Delonge*: "If you want to move away from the idea of confrontation, which is classically at the core of nearly every game, then you have to come up with something really new as an alternative" (Woods, 2012).

The spread of German games came from hobbyists and magazines. The Internet also helped to convey information about these games, but the largest contributor came with the popularity from inside the hobby and the release of **Catan** (figure, 2.6). By the end of the century, German games gained the new title of Eurogames and more game designers from European countries followed its style. Their unique features influenced new board games throughout the world. The first generation of Eurogames tended to be accessible games with a small degree of complexity in its strategies. They avoided direct conflict, mitigated and de-emphasized the role of chance, offered predictable playing times, and high standards for components and presentation. In most cases, Eurogames favor mechanics over the theme. The continuous development of this style of game design opened the way for more complex games. *Puerto Rico* was a complex game praised by the community and an award winner of the *Deutscher Spiele Preis*. It introduced an innovative mechanic where a player could choose a global action for the other players.

Modern board games from all around the world are largely influenced by Eurogames. It is now possible to find Eurogames with a strong theme and that involve direct conflict. Modern eurogames also tend to do a better job of harmonizing their themes and mechanics (Woods, 2012).

Figure 2.6: The board game Catan (Yonghokim, 2019)

2.1.2 Elements and Mechanics in Modern Board Games

In his book, S. Woods uses Aki Järvinen's framework to analyze the game system. In the next section, the main ideas of Woods's and Järvinen's about game elements will be used to analyze the mechanics of modern board games. The main elements described by Järvinen are organized into three categories: systemic, behavioral, and compound elements (Järvinen, 2008).

2.1.2.1 Systemic Elements

The systemic elements described by Järvinen are the components and the environment. Components are all the elements in a game that a player can manipulate or interact with. In boardgames, the board, cards, meeples, currency, and tokens are all considered components. Some of these components can carry information and/or be moved during the game by the player (component-of-self), controlled by other players (components-of-others), or by the game system itself (components-of-system).

For Järvinen, the environment serves as a delimitation for the game system. The definitions of rules, spatial arrangement, events, agents, and objects of the game system all happen inside the context of the environment. The board is commonly used to establish the environment. There are three types of environments: no environment like dice and card games, an abstract environment like chess, and miniaturized representation of environments that use a board to represent a specific location or place. Game environments can be used as informational elements enabling the player to choose, trigger events, and create a specific atmosphere. The player's choices are constrained by the board which delivers important information in the ruleset. Events can be triggered when reaching a new area. In Gloomhaven, for example, when the player enters a new section of the board, new enemies and objectives can appear. In the majority of board games, the atmosphere is set using the illustrations on the box and board. The components can be miniatures with high details or stylized components like small wood pieces representing game elements like animals,

resources or characters for example. The ruleset can contain lore or the meaning of the game actions as pertains to the theme. According to Woods, the connection between high production, graphical presentation, theme, and components became a standard for modern board games. Both contribute to a deeper commitment to the game (Woods, 2012).

According to Järvinen, the four attributes in environments are (Järvinen, 2008):

- Part or whole: defines the relation between the present environment and other possible environments present in the game. The whole is the group of environments that defines the set of the game.
- State: defines if one environment or location is occupied or unoccupied.
- Scale: describes the size relationship between the environment and the component.
- Vectors: are indications that suggest or impose a direction in the movement.

Järvinen also groups game environments into three types:

- Boards or fields, which contain the game system inside of their limits. All the game interactions happen within these limits and the board can present information related to geometrical relations between the different components. Boards also feature information contained by the ruleset.
- Setups, where elements need to be organized in a certain way to communicate important information, even if they do not need an environment, as with card games
- Ecosystems, which represent bigger environments that can be divided into parts or levels, using normally simulated physics, vectors of movement, forces of nature, and others. This type of group is more common in computer games.

2.1.2.2 Compound Elements

According to Järvinen and Woods, compound elements create links between systemic and behavioral elements. For Järvinen, compound elements are the ruleset, mechanics, information, interface, and theme.

Games are made of rules insofar as they define the game behavior and can be applied to all the game elements. They can be transmitted to players through different elements such as the environment, but in board games, they are usually structured and compiled mainly in the ruleset. Järvinen states that players learn the rules from the rulebook and it is by the embodiment of the rules into game elements like theme, components, and board that players experience the rules as the behavior of the game. For both Järvinen and Parlett, the key to designing a game is to design the rules (Järvinen, 2008) (Parlett, 1999). Some rules are specific to the setup of the game, others explain how players can interact with the game system, clarify how the game works, define the behavior and boundaries of the environment as well as the goals of the game. Järvinen emphasizes

that rules are normally verbal or conceptual, but that the elements of the game can be visual, aural, or tangible and can pass on information. Although individual rules are not considered as a game element, the set of rules is an element by itself that defines the possibilities and behaviors inside a system or environment (Järvinen, 2008). An important aspect emphasized in modern board games is the accessibility of the ruleset (Woods, 2012). Common techniques used to show information on boards are the use of color schemes to represent actions, spaces on the board, different components, tables, directional arrows, and grids. These techniques help the player understand the rules visually.

As explained by Järvinen, mechanics function as an input for the game system to react. This input is given by the player manipulating the components, like playing a card, for example. Game mechanics work as questions and answers, with the system answering to the player's choices, though the possible mechanics are all defined in the ruleset. The majority of the games have a group of mechanics and when a player uses one or more, it influences the game state. The player's actions are directed to the goals of the game. The mechanics function around a goal, and this goal is what provides a sense of challenge. Sub goals can be defined during the game to reach a major goal. If the goal of the game is to finish with the most points, then acquiring a tile during the game that gives points would be counted as a sub-goal. As Järvinen describes: "In everyday experience, performing game mechanics are what playing a game is about, as they imply player action and performance – in other words: play. Therefore game mechanics are best described with verbs: Choosing, guessing, moving, aiming, shooting, collecting, kicking, trading, performing, bidding, etc. Thus the nature of a game mechanic, i.e. the action it conducts or simulates, might come to define the game experience for the player." According to his idea, mechanics are divided into three types (Järvinen, 2008):

- Primary, which is available to the player at all times.
- Sub-mechanics, which support the primary mechanics.
- Modifiers, which became available at specific times or conditionally.

Information elements in games display meaningful information about the game state and to all other elements in the game. Usually, the information in board games consists of the resources available, the player stats, and changes in rules. During the game, and in combination with the player's actions, information is produced and gained. Järvinen describes two types of information. Imperfect information, commonly used in board games, allows access to just a part of the total information. On the other hand, perfect information is when all the information is available like in chess, players can see and predict every possible movement. Both types of information can be used to produce states of engagement and curiosity. During games, information can be organized into four specific types (Järvinen, 2008):

- Events; the consequences of game mechanics.
- Agents; containing the player roles and attributes.

- Objects; related to components.
- System; how the game interacts according to the rules and according to the game state.

The theme in games is used to give a metaphorical level to the game experience, contextualizing the ruleset and the game elements that contribute to the player's experiences. For wargames, the theme represents the atmospheric and contextualization of the conflict simulation. Some games use themes on a deeper level than others. Even contemporary abstract games overlay the game with a thematic meaning. For example *Azul*, a drafting tile placement game uses Portuguese mosaics as the theme. Woods (Woods, 2012) and Järvinen (Järvinen, 2008) describe the importance of themes for mechanics in board games, they serve to put the game more readily understandable and place the player as the actors where their actions can be contextualized. Taking as an example *Rising Sun* where the main mechanic of the game is area control, each person represents a shogun (Japanese commander) belonging to a clan from mythological Japan that wants to become the next emperor. Players can commit *seppuku* (suicide Japanese ritual), take hostages, summon mythological creatures and hire mercenaries to gain points and conquer territories.

The last element is the interface. According to Järvinen, the interface is used for players producing input in the game. The player action through the interface can generate a visual, tactile, or aural response from the game system. Järvinen makes a distinction between direct and indirect access to the game system and elements. For him, analog components like cards, boards, tiles, tokens, pawns, and others can be accessed directly without the need for an interface. Indirect access normally presumes a digital form of the game that can only be accessed towards the interface. Although Järvinen analyses the interface in a more digital vs non-digital way, hybrid board games use both direct and indirect access because of their physical components as well as the interface where the digital information is stored. (Järvinen, 2008).

2.1.2.3 Behavioral Elements

Behavioral elements are related to the player and the context of the game. The first element described in the Järvinen framework is the player. Their actions and decisions influence the game system and generate meaning for the game. The behavior of the player is modulated by the game system and its elements (Järvinen, 2008). The level of difficulty can create a rewarding challenge for some players but can also generate anxiety for others, so the game should include ways to manage its difficulty (Chen, 2007). To maintain player involvement, modern board games apply solutions to deliver player performance feedback, avoid player elimination that can lead to bad feelings about the game, and also offer tools to recover from bad decisions, all of which are intended to help keep players engaged. Some examples include giving partial information about scores during the game or delaying the score until the end of the game to avoid knowing the winner beforehand. Another common example is to give the worst-performing player the ability to act first during an important event involving multiple players. These changes make it difficult to predict the winner until the game's end (Woods, 2012).

Players can establish emotional connections with games as shown by *Scoresby* and *Shelton* (Nah, Eschenbrenner, Zeng, Telaprolu, & Sepehr, 2014). These emotional bonds are derived from game mechanisms, themes, or other elements. Game designers can create a greater sense of involvement using a specific atmosphere, emotional disposition, or mood. For board games, this is established towards their theme and components and gameplay. Competitive games tend to generate different disposition than cooperative games.

The second element in the behavioral group is context, and according to Järvinen, this refers to the time and place where the game takes place, as both these factors have considerable repercussions for the game. Each game has a different history, target audience, coverage, culture, and others. The element that can emphasize the context of the game is the theme, allowing for the game to represent a specific setting or message. As Järvinen describes: "A relevant contextual factor is that the contexts influence players, the formation of their tastes, gaming habits, and so on. If the player element is about the player's behavior and relationship to games specifically, then contexts are something that expands to the players' personal histories and habits that affect, for instance, when, where, and with whom they play games" (Järvinen, 2008).

2.1.3 Board Games and Technology

As described by Woods, the advance of technology, the advent of the television and the internet had a significant impact on board games. Many complex wargames saw their digital version gain more success than their analog version (Woods, 2012). Many CCG were adapted for the digital format. However, some Board Games try to incorporate new media elements in their structure. The first game to do this was *Clue: The VCR game* in 1985, which used a VHS tape to play a series of sequences from the game while the players used cards trying to guess the murderer. Since then, more board games followed this attempt to mix media elements in an attempt to achieve a paratextuality between board games and licensed products, a characteristic that is common in video games. The use of multimedia technologies in board games also reflects an attempt to augment the play experience, with the current technologies available in the market (Booth, 2016). During the last decade, other board game systems were developed for support and bookkeeping. A game that had a huge impact on the board game community was "Mansions of Madness" (second edition) based on the works of H.P. Lovecraft. In this game, the players need to explore different places, investigate mysteries, and fight monsters. The game uses an app (app-driven game) that can be used in any mobile device to generate game content, manage setups of different scenarios, interact with the action of the board by text, audio, and player choices in the device. The game is in the top 100 games of all time according to BoardGameGeek (BGG). Systems apart from games are also being developed to support and refine the game experience, recently CMON announced TEBURU a board and dice with sensors that can be used with different games for bookkeeping, triggers during game events, to record progress during the campaign, and also trigger audio cues about game events. Another application that is trying to facilitate the experience to play board games is Dized, an app that teaches the rules while the players play the game.

The Internet also allowed for the development of communities related to the subject of gaming. BGG, the main platform related to board and table games, was founded in 2000 by *Scott Alden* and *Derk Solko*. The platform allows for any type of discussion around board games related themes. On the site, it is possible to find game designers discussing game features with members of the community, upcoming projects, rules clarification, tactics, and aspects of gaming culture (Belousov, 2019). Other important features of the platform are the rating catalog of over 101 000 games, the user's collection management, game-related files, as well as messaging and trading functionalities. The hobby games are the ones most discussed in the platform, particularly modern eurogames (Woods, 2012).

During the last decade, the funding of board games has normally been achieved via Kickstarter, a platform launched in 2008 by *Perry Chen, Yancey Strickler, and Charles Adler*. This was the turning point for the development of games. Indie developers and companies grabbed this opportunity to create and fund their projects. Some major companies use Kickstarter to reduce costs or risk in the development phase. Nowadays the majority of the games produced are presented and funded in Kickstarter (Belousov, 2019). Some games already raise capital in the values of millions. Some examples are Conan the Barbarian, Rising Sun, Tainted Grail, and Zombicide (*Most funded tabletop games*, n.d.).

The possibility for people to share content on the Internet also worked in benefits for board games. Youtube features different channels about board games, especially reviews, playthroughs, the announcements of new projects, podcasts and discussions. In 2013 a web series on youtube called TableTop created by the actor Will Wheaton reviewed games and invited celebrities to play board games. TableTop's success led Wheaton to develop a new series called Titan's Grave: The Ashes of Valcana, about RPGs. Other famous youtube channels about board games are The Dice Tower, Shut Up and Sit Down, No pun included (Belousov, 2019).

2.2 Augmented Reality

Technological advances in modern society have established an easy and accessible connection to the digital "world". Current computer graphics can produce a high degree of realism that makes possible and more accessible Virtual Environments also known as *Virtual Reality* (VR).

The concept of VR is to place the user in a virtual world and blind his perception of the real world, using peripherals. The most common are VR headsets and closed-back headphones. The user then experiences virtual images and sounds that constitute the virtual world.

During the last decades, the amount of information consumed has increased with the development and the democratization of mobile technology, but this information is still fully consumed in the "digital world". Even with mobile devices, the user is accessing information on apps or web pages that demand a constant change of focus between reality and the digital information on the device. *Augmented Reality* (AR) proposes a different approach to this problem being the opposite spectrum of VR. AR technology attempts to incorporate digital information into real-world experiences. As Schmalstieg and Hollerer claim, AR serves as an immediate and easy interface

to access computer-generated information that is displayed over real objects. It emphasizes the interaction between computer and human, being able to amplify all human senses (Schmalstieg & Hollerer, 2016). The definition of AR according to Azuma is (Azuma, 1997):

- The combination of real and virtual elements
- Interactivity
- 3D registration

Another important characteristic of AR is the establishment of local virtuality where people use technology to communicate in space, allowing them to have a sense of transportation from the real world to an augmented one (Benford, Greenhalgh, Reynard, Brown, & Koleva, 1998). In his core, AR is considered a collaborative technology.

Both AR and VR belong to the *mixed reality continuum* (MR) (figure, 2.7) coined by Milgram and Kishino: "MR includes systems in which the virtual aspects are dominant as well as those in which the physical reality is dominant. Within this range, augmented reality has more physical elements than virtual elements" (Costanza, Kunz, & Fjeld, 2009).

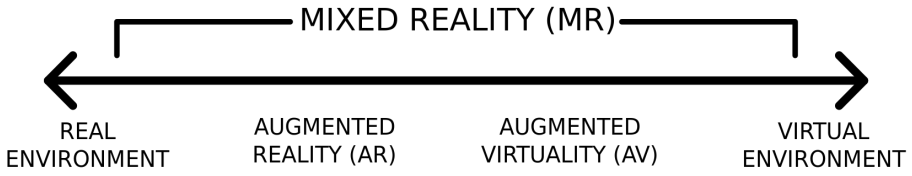

Figure 2.7: Mixed Reality continuum by Paul Milgram (Milgram, 2011)

The first AR prototypes appeared in the 1960s with Ivan Sutherland and his students at Harvard and Utah University. They developed a prototype that could display 3D graphics in a see-through display. Between the 1970s and 1980s, a group of research institutes investigated AR. This group included the United States Air force, Nasa, the Massachusetts Institute of Technology, and the University of North Carolina (Van Krevelen & Poelman, 2010). The term augmented Reality was coined by Caudell and Mizell in 1992. The introduction of mobile devices in the 1990s opened up new possibilities for mass-market AR, with PCs and mobile devices providing support for the graphical overlay and development tools for AR. Advances in augmented reality technology have opened up a range of applications in different fields, including personal information systems, industry, military, medicine, entertainment, office, education, and training.

While the field of virtual reality is maturing rapidly due to the increasing accessibility of the required technologies, the requirements of AR are more demanding, as AR must operate in real time in conjunction with real world events. The core components needed to build an AR system are tracking, registration, and visualization. It can also include a spatial model to store information about the real word which serves as a reference when tracking.

If the AR application is mobile it will also require a database and a fast network to communicate in real-time from system to user and user to user. The common framework for AR applications is shown on figure 2.8 (Schmalstieg & Hollerer, 2016):

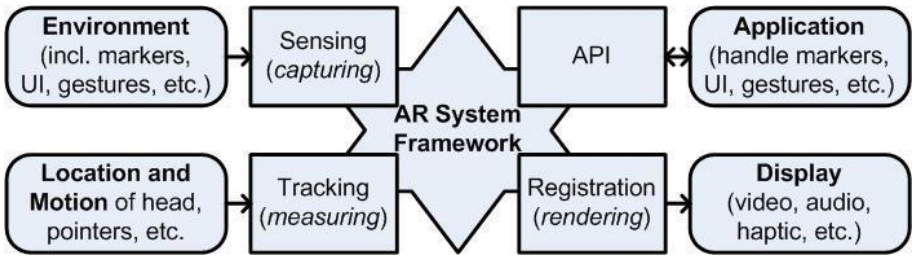

Figure 2.8: Augmented Reality development framework (Krevelen, n.d.)

2.2.1 Displays

AR requires displays that make it possible to visualize the real world in combination with virtual objects. In the majority of AR applications, displays must adapt to the human visual system. The common field of view of both eyes usually ranges between 200 and 220 degrees horizontally. Visual acuity is in the center between 0.5 and 1 degree (figure, 2.9). Focus is controlled by the eye and by head movements.

It is still not possible for an AR system to achieve the resolution of the human eye, however, the highest resolutions should be on the acuity point, the central vision. Brightness is a characteristic of visual perception giving the impression that a source is radiating light. It is controlled by the eye pupil and has a wide dynamic range from 10 to the exponent of 10. Since AR displays can face multiple viewing conditions they should be able to handle and control different levels of brightness. To give better results AR displays should be made for a binocular vision where both

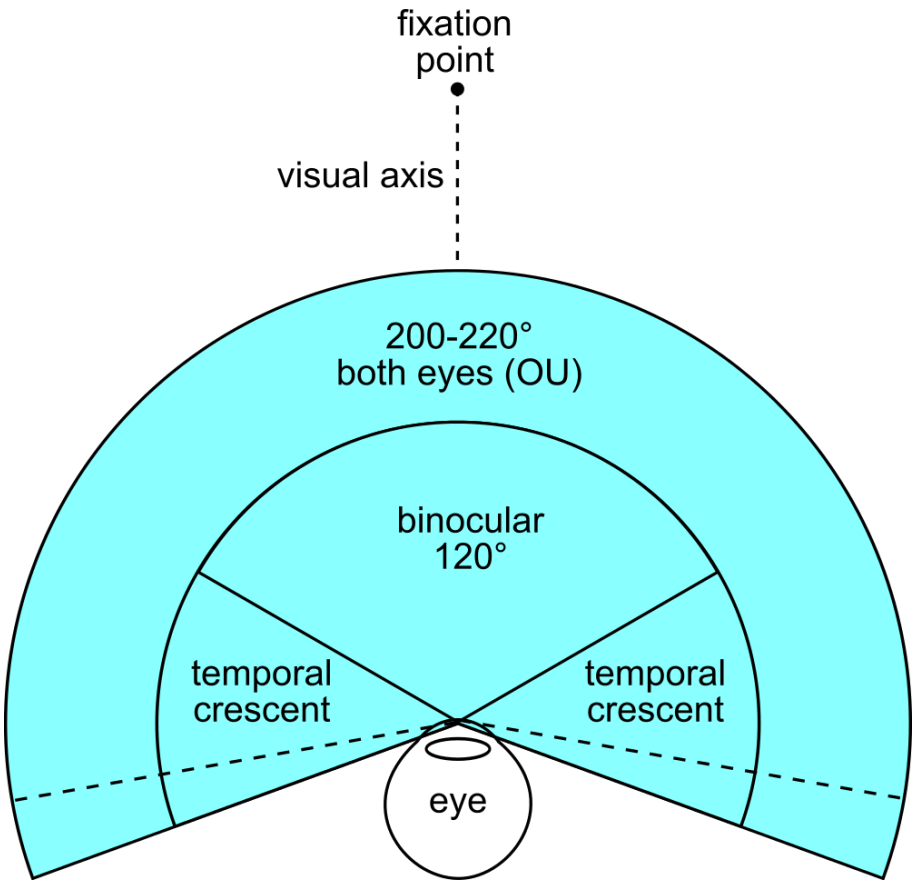

Figure 2.9: Human eye field of view (*field of view for both eye - human binocular vision*, 2014)

eyes perceive the object and the surroundings. Thanks to binocular vision, humans can have a better focal point, have a better sense of depth and a wider field of view. One major problem arises with AR displays due to the binocular vision, angular offset or perception outside the display.

The general purpose of AR should be to create life-like 3D augmentations in the real world that could be perceived as a different form or completely integrated with real physical objects. The most common forms to display vision AR are optical see-through (OST), Video see-through (VST), and spatial projection (Schmalstieg & Hollerer, 2016).

2.2.1.1 Optical See Through

Optical elements allow the passage of light. OST uses an optical element that is partially transmissive and reflective. The reflective part reflects the light source from a computer-generated display to the eyes. The transmissive part allows the user to see the real world. When the projected image is reflected in the mirror it overlays the real world image.

OSTs are commonly found in Head-Mounted Displays (HMD) (figure, 2.10).

The human visual system has a limited focus range but can perceive different distances. OST displays produce a fixed focus on virtual objects, regardless of the depth perceived. An associated problem is vergence (The inward or outward turning of one or both eyes that occurs when focusing

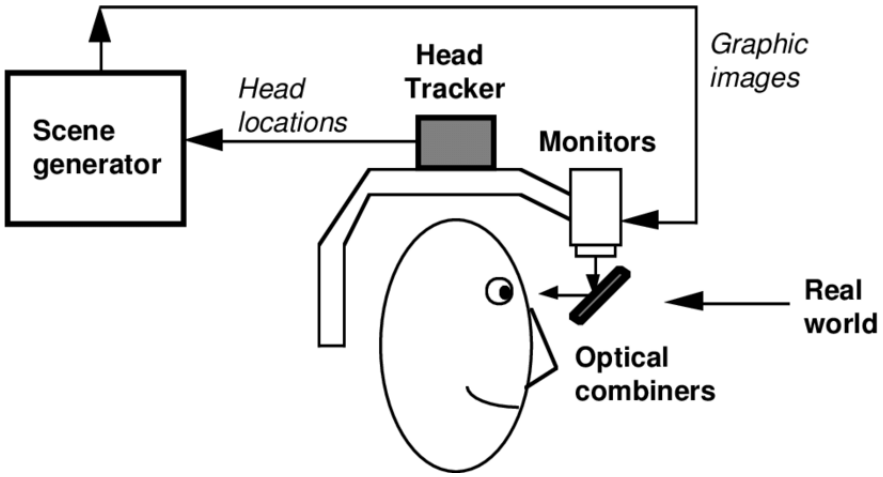

Figure 2.10: Optical see-through display example (Azuma, n.d.)

on an object.) which causes visual fatigue. This problem occurs in all stereoscopic displays with a fixed focal plane.

Another challenge for OST displays is the total occlusion of real world objects because it uses reflected light to generate semi-transparent augmentations.

As described in 2.2.1 it is difficult to achieve the resolution of the human eye, but if the resolution is sufficient to avoid artifacts, then it is generally sufficient for a good AR experience. In the case of OST, since the real world is perceived through a transparent material, the resolution is very high. Augmentations resolution in OST varies from one equipment to another. In the new Hololens 2 (figure, 2.12). the viewport resolution is 1440x936 pixels and the Tilt Five has 1280x720 pixels (figure, 2.11). Refresh rates in recent OST are higher than 60 Hz to avoid flickering (change in brightness during video cycles) and ghost images (replica of one image superimposed over the same image) (Schmalstieg & Hollerer, 2016).

Figure 2.11: Tilt Five - Optical display for augmented games (*Tilt Five*, n.d.)

Figure 2.12: Holo Lens 2 (*Holo Lens 2*, n.d.)

The Field of View (FOV) represents the maximum amount of information that can be shown to the user at once. A large FOV allows the user to perceive the augmentations without turning his head, while small FOVs can disrupt the user's immersion because he can perceive images outside of the display (angular offset). Modern OSTs normally have a wide field of view. While having a wide FOV is important, the natural alignment between virtual and real images needs to be precise. Some solutions like VST have easy ways to handle this problem. Others need calibration to avoid view offset (meaning that the position of the object is not correct). If view offset happens, incorrect information is passed to the user and the view is perceived as unnatural.

OST solutions are better suited for indoor use since they rely on reflected light. The use of this equipment outdoors creates problems related to high levels of natural brightness. Some techniques can be used to reduce natural light but they will affect the perception of the natural brightness of the environment, making the user perceive a darker environment. For professional solutions, OST is the most adequate. This equipment can be controlled only by the movement of the head and allows a broad perception of the surrounding world. It is also safer, which is a great boon for professional use. During precise operations or tasks, in case of system failure, it is always possible to see through the lenses (Schmalstieg & Hollerer, 2016).

2.2.1.2 Video See Through

Video see-through (VST) displays use a camera to record the real world and the computer graphic processor to combine video and the computer-generated images. When displaying content to the user, the virtual images are placed on top of the background image (the real world) can use different algorithms as the Z-buffer (figure, 2.13). The most common devices for using VST displays are smartphones or other devices with a built-in camera.

Many VST displays use Bi-ocular presentation, the use of one camera to present the same image to both eyes, image. But for this solution to achieve stereoscopy the device will need at least two cameras presenting different images to both eyes.

Once again, it is difficult to achieve a good solution for focusing, because any rendered image will have a fixed focus, causing eye strain. However, like the eyes, cameras also have dynamic focus to understand images in the real world at different distances (Schmalstieg & Hollerer, 2016).

The VST display provides one of the best solutions for object occlusion. It can use different algorithms such as the Z-buffer to understand by the brightness what is in front and behind the user. When placing the new virtual object, it can change the light intensity to place the object in the correct location.

Each year, advances are made in camera technologies that allow to reach higher resolutions. One important aspect that is taken into consideration is refresh rate. Since VST is normally mobile, the majority of new equipment supports refresh rates of 60 Hz to avoid any artifacts as pixelated lines.The FOV is characterized by the fact that the camera is normally large and is then compressed to be displayed on the screen. One common problem with VST is the view offset. If the camera is not centered, the user may have an incorrect sense of direction. For example, many mobile phones

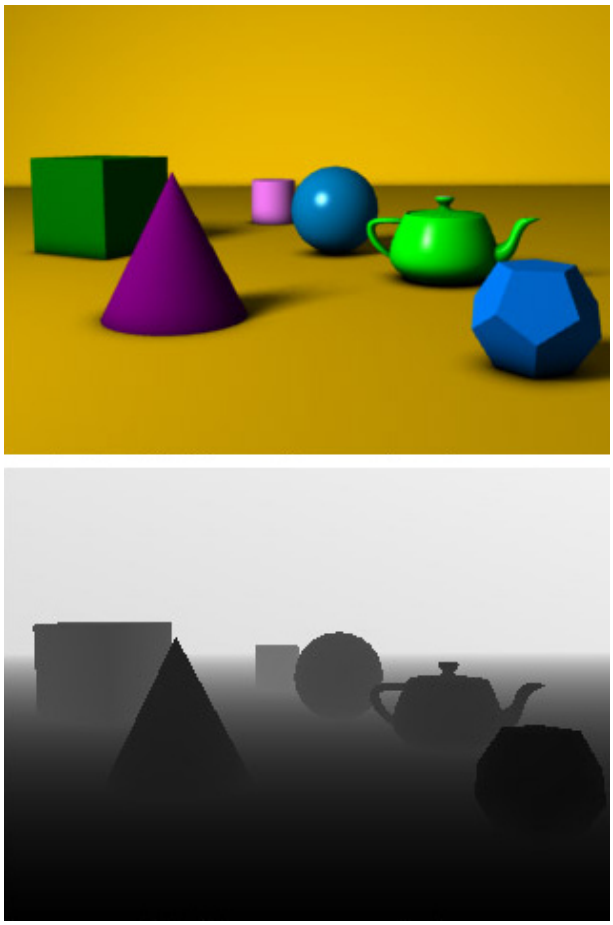

Figure 2.13: Z-buffer algorithm (*An image an the corresponding Z-buffer*, 2005)

have the cameras on top and when used on an HMD, the camera view is different from the user's (Schmalstieg & Hollerer, 2016).

Normally calibration is not needed in VST applications. However, in some cases, it can be used to correct pixel annotations. Every software and hardware present a delay in communicating with the necessary components. Some are extremely small and cannot be noticed while others are perceptible. VST offers a simple way to deal with delay problems, since the image is transmitted to the user as a video. The image can be delayed to avoid noticeable delays and match the correct position of the virtual object.

The major advantages of VST solutions are their accessibility and their expansion as a mass-market solution. They are cheap to implement and work well for outdoor use since the software can adjust the brightness. With the expansion of the smartphone market, more powerful cameras can be employed and the image quality of more features can be improved. However, VST also suffers from its dependance on electronic components, which are likely to switch off completely, leaving the screen black (Schmalstieg & Hollerer, 2016).

2.2.2 Calibration

Calibration is used to understand a specific scale or measurement that a device will use. It requires a comparison of measurement values between the sensor or instrument to be used and those of a reference device.

Some tracking devices in AR applications depend on a calibration , which is frequently done prior to operation. Measurements are done using discrete times where a sample is taken intermittently (Schmalstieg & Hollerer, 2016).

2.2.3 Registration

The overlay of objects depends on the registration capability of the AR system. When virtual and real objects are registered, they are aligned in a coordinate system that defines the spatial properties of the space. If registration happens correctly, the virtual and real objects are aligned, making it possible to superimpose them. Calibration is needed for static registration (user or camera not moving) and tracking is needed for dynamic registration (user or camera moving) (Schmalstieg & Hollerer, 2016).

2.2.3.1 Tracking

Tracking has two main functions. The first one is to track the objects defined by the system. For example, many Development kits contain databases with targets, also known as target Images, which, when tracked, can prompt the system to take specific actions. (Maad, 2010). These images can also serve as reference points, so that after detection, the system will try to keep tracking the image. The second function of tracking is to make continuous measurements to know when a virtual object must be superimposed on a real object. Tracking in AR is done in a three-dimensional space normally with six-degrees of freedom but some sensors only manage to have three degrees of freedom. In six-degrees of freedom the user can move the camera 360 degrees. Each degree of freedom is measured independently. There are 3 degrees of freedom for position and 3 for orientation:

- Forward and backward
- Up and down
- Left and right
- Pitch
- Yaw
- Roll

There are two different ways of tracking: Globally and Locally (Maad, 2010). Local tracking is based on small scale coordinates than can be set by the user. Global coordinates have a much

larger scale, even if they do not measure the entire planet. The measurement of a city is already considered a global scale. Tracking can be done in two ways: absolute, where the coordinate system is established in advance, or relative, which establishes a dynamic coordinate system. The relative approach, however, is more challenging because of motion (Schmalstieg & Hollerer, 2016).

2.2.3.2 Model, View and Projective Transformations

To achieve a correct overlay, AR systems use a group of transformations that influence tracking behavior. The Model transformation analyses the coordinates between local 3D objects and those of the global 3D world to determine where virtual objects are placed in the real world. For non-static scenes a model transformation is always needed.

The view transformation is used to identify the relationships between the coordinates of the system camera and the coordinates of the global 3D world. This transformation is related to the user's movement. When only one camera is used, no calibration is required, as is the case with smartphones. For stereoscopic systems, a calibration is needed.

Projective transformation analyses the relation between the coordinates of the 3D camera and the coordinates of the 2D device, and defines the correct measurements to match the content to the unit of measurement of the device (Schmalstieg & Hollerer, 2016).

2.2.3.3 Tracking Methods

When tracking, different measures can be applied such as signal strength, signal direction, and time of flight,which allows for the measurement of distances and angles. AR systems can have more than one sensor, each one dedicated to a specific axis on a vector. When multiple sensors are used, they must be synchronized. The measures preferably should happen in a system with 6 degrees of freedom (DOF). Allowing to register virtual and real objects in a 3D space, however some equipment only work with 3DOF (Schmalstieg & Hollerer, 2016).

The coordinates used can be local or global. Local coordinates operate at a smaller scale, with the system taking measurements at different locations or objects in space, while global coordinates use georeferencing to cover much larger distances. Global coordinates use geographic information system (GIS) databases to locate virtual objects. Local coordinates tend to be more precise and accurate than global coordinates. Visual tracking markers or graphic symbols that are easily recognized by machines can be used as local coordinates. AR systems can have two types of measurements: absolute and relative. Relative measures are used for dynamic systems. This type of measurement calculates the difference between the current and the last measure. Absolute values are measures set in advance.

The sensors can be arranged in two different ways: outside-in where the sensors are fixed in the environment, and inside-out, where the sensors are mounted into a mobile system (Schmalstieg & Hollerer, 2016).

2.2.4 Computer Vision for AR

Computer vision is a group of techniques used by computers to perform tasks related to human vision and cognition procedures. For humans, visual procedures are inherent and can be perceived as low-level tasks, while cognitive procedures are high-level tasks. Some examples of low-level tasks include extracting brightness, color, range and perception of objects. These low-level tasks are unconscious for humans. When combined with high-level tasks, they represent significant challenges for a computer (Dana & Brown Christopher, 1982).

Computer vision for AR must work in real time and the algorithms developed must work in conjunction with the sensors of each system to ensure correct recording and tracking. Some solutions have been implemented to develop efficient and responsive AR systems, such as marker tracking, multi-camera infrared tracking, natural feature tracking, incremental tracking, and simultaneous localization and mapping. This dissertation, will briefly focus on marker tracking and make a small approach about natural feature tracking by detection(Schmalstieg & Hollerer, 2016).

2.2.4.1 Marker Tracking

Fiducial Markers are very common in AR applications, especially in mass-market or simple applications (figure, 2.14). These are also the cheapest way to build AR applications and do not require a high quality camera. A fiducial marker is an object or image that serves as a reference or measurement point (Piumsomboon, Clark, & Billinghurst, 2011). The camera can detect the four corners of the marker to calculate the position where the augmentation should take place. It can also detect the pattern of the fiducial marker that refers to a particular virtual image to be displayed. The pipeline for fiducial marker detection is the following (Schmalstieg & Hollerer, 2016):

- 1.Capture the fiducial marker with a camera
- 2.Search the application database for the marker shape
- 3.Dimension and coordinates estimation
- 4.Coordinates refinement
- 5.Virtual image renderization related to the camera position

2.2.4.2 Natural Feature Tracking

Compared to the previous tracking method, natural feature tracking does not add any external markers to the environment. Instead, it looks for points of interest in a specific object (figure, 2.15). This tracking method is commonly used in mobile devices and requires only one camera. It can use more than one, but this will increase the cost and computer demand. Using only one camera, it will try to find the 2D correspondences of the selected object in the 3D environment.

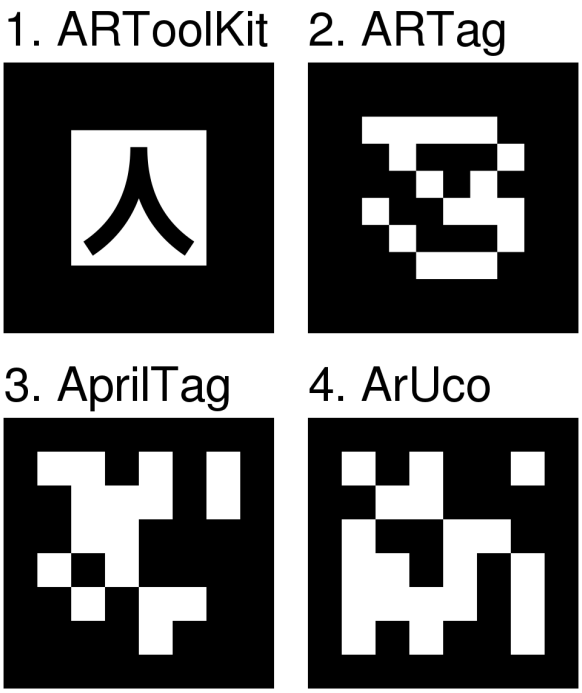

Figure 2.14: Fiducial markers (*Comparison of several fiducial markers for computer vision by CMG Lee*, n.d.)

This method works well in runtime because the system will always try to find the respective points of interest. The points of interest are represented by descriptors, which correspond to data structures on the image and can be read quickly to be detected. (Schmalstieg & Hollerer, 2016).

Sparse tracking selects a small but sufficient number of points of interest. Sparse correspondence is used for the majority of applications since it is easier to produce and can be more efficient in its processing. One advantage of this approach is that each point of interest is treated independently. If one or more points are not tracked, the system can still recognize the image if there are enough correct matches. An advantage of this tracking method is that it works well even when the camera is moving. If, for some external reason, the camera cannot find the object in one frame, it will not affect the next one. Another approach used for detection is dense tracking, however, this is not so common for the majority of applications. Dense tracking needs to find a correspondence for each pixel.

The tracking using detection does not need any previous information to be maintained, but it must know the models to track. The pipeline for the detection by natural features is:

- 1.Detection of interest point
- 2.Descriptor creation
- 3.Descriptor matching
- 4.Perspective-n-Point camera pose determination

- 5.Robust pose estimation

According to Shi and Tomasi (Jianbo & Tomasi, 1994), good detection features include: areas around the points of interest should be visually distinct, good texture, high contrast, color intensity changes occurring in the neighborhood area.

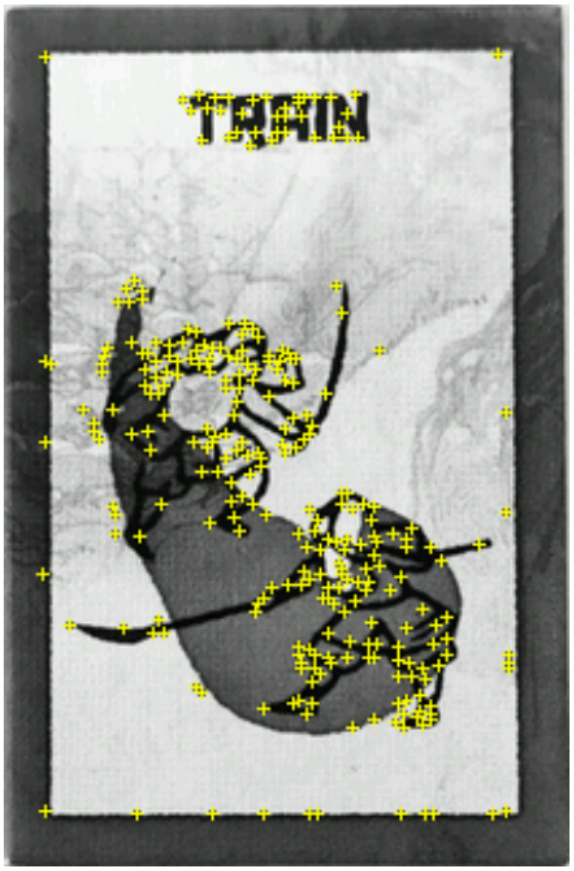

Figure 2.15: Points of interest detected in a political mandate in the game Rising Sun

2.3 Augmented Reality Audio

Augmented Reality Audio (ARA) shares the same basic concept as augmented reality, populating reality with virtual elements. There are different approaches explaining how ARA works. Vasquez and Alverez (Vazquez-Alvarez, Oakley, & Brewster, 2012) argue that ARA consists of a superimposed virtual soundscape in a real environment, while Tikander (Tikander, Karjalainen, & Riikonen, 2008) affirms that ARA enhances the real environmental sound with virtual aural objects. In the first case, researchers like Mariette (Mariette, 2007) have developed systems to create synthetic soundscapes to simulate the natural sound of the corresponding place according to the position of the user and the orientation of his head. In her research, she has focused on mobile devices capable of using binaural audio to completely replace the natural surround sound. The synthetic soundscape provides users with spatial information, allowing them to locate the objects that could trigger the sound. Her definition of these types of systems is "personal location sensitive-spatial audio". Other research using the same approach of ARA has applied synthetic soundscapes to museum visits. EC(HO) is a project that conceptualizes a responsive and adaptive system for user localization, making constant predictions about the user's interactions in the museum. When the user is in front of a specific piece, sounds are triggered according to previous analyses on the user choices and the piece that is being observed (Hatala, Kalantari, Wakkary, & Newby, 2004).

Another project based on the same principle as EC(HO) is LISTEN, a wireless 3D hearing system that tracked participants in different areas of the museum. The participants listen to the dynamic ambiences, sound effects and speeches about the exhibition through headphones according to the route they take and the room they are in. (Eckel, 2001).

The second approach to ARA focuses on enhancing the sound of the natural environment with digital sounds instead of replacing it with synthetic sounds. Ramo and Valimaki describe the ARA system with the following purpose (Rämö & Välimäki, 2012): "Augmented reality audio (ARA) combines virtual sound sources with the real sonic environment of the user. An ARA system can be realized with a headset containing binaural microphones. Ideally, the ARA headset should be acoustically transparent, that is, it should not cause audible modification to the surrounding sound. A practical implementation of an ARA mixer requires a low- latency headphone reproduction system with additional equalization to compensate for the attenuation and the modified ear canal resonances caused by the headphones." Recent commercial solutions have appeared on the market, launched by Sennheiser with Ambeo smart headphones (Orbit, n.d.) and by Bose with Bose Frames sunglasses. Both are based on the concept of enhancing the real-world sound environment. The Ambeo Smart headset uses microphones on the headphones to deliver the pseudo-acoustics of the natural sound mixed with the digital content. Bose Frames have taken a different approach by not using any in-ear approach. Bose frames have a small speaker on each side of the glasses that reproduces the digital content, while the natural environment remains perfectly perceived by the "naked" ear (Bauer et al., 2019).

Possible applications for this technology include binaural telephony, binaural audio meetings,

information services, object browsing, virtual tour guides, audio memos, contact management, audio-based games, and music creation (Rämö & Välimäki, 2012).

2.3.1 Binaural Audio

Binaural audio is a recording and reproducing technique used to emulate the way humans perceive sound. It is reproduced in two channels, one corresponding to the left ear and the other to the right ear, providing spatial information about objects. To reproduce binaural audio, a pair of calibrated headphones using HRTF functions should be used, as described in section 2.3.2. Binaural recording are made using a dummy head with two microphones inside the ears (figure, 2.16). Recording using a dummy head alters the perception of sound due to the reflection and scattering with the dummy head and the shape of the ears, providing clues about the position of the sound sources. The four common setups for binaural recording are(Zhang, Samarasinghe, Chen, & Abhayapala, 2017):

- Microphones inserted in the ears of the human listeners
- Microphones in the dummy head with torso, head, and ears
- Microphones in the dummy head with head and ears
- Microphones in the simulator with only ears.

Many VR and AR applications use binaural listening to create immersive audio ambiances for visual applications (Hong, He, Lam, Gupta, & Gan, 2017).

2.3.2 Head-Related Transfer Function

Humans can detect different sound characteristics such as timber, loudness, pitch, and spatial information. The head-related transfer function is a function that calculates how humans perceive sounds in their surroundings. When humans perceive sounds, they perceive direct, reflected or scattered propagations of objects and of the anatomic human system (head, torso, and pinnae). The way sound reaches the ears is what allows spatial information. Two important measures are made regarding sound, interaural time difference (ITD) and interaural level difference (ILD). ITD calculates the time difference between the moment a sound reaches the left ear and the right ear, enabling the brain to process the location of the sound. For example, if the sound source is placed on the left of the user's then the left ear will receive the direct sound and early reflections first than the right ear. ILD calculates the difference in sound level for each ear, and both the head and the torso act as an attenuator for sounds coming from different angles, making ILD also suitable for spatial information. In summary, to understand the position of a sound source it is necessary to know the sound level and the direction and distance to the listener's head (Hong et al., 2017).

As with binaural recording, HRTF measurements are made in the same way, using a dummy head with high-fidelity microphones in each ear. Binaural recordings are suited to reproduce

Figure 2.16: Neumann Ku 100 used for binaural recording (*Georg Neumann Ku 100 Dummy Head*, 2011)

statical spatial audio content. HRTF allows convolving a mono signal into binaural hearing. This is commonly used in AR and VR. Dynamic reproduction involves the use of computer vision techniques as described in section 2.2.4 to reproduce content based on the user's movement and head direction.

One of the common problems with HRTF is that for precise reproduction of spatial audio content measurements must be specific to the person who will be listening. In general spatial audio content, uses average human measurements, which may present different results for different users (Xie, 2013).

2.3.3 Ambisonics

Surround techniques place audio sources in a 3D spectrum around the listener, sometimes depending on the number and position of speakers they can work with vertically. The best known forms of surround technique are from Dolby, in the form of channel-based and, more recently, object-based techniques. To reproduce channel-based surround correctly a pre-established speaker array is required. The sound sources will be attributed to each channel according to the mixture. Objected-base surround defines sounds as objects and, instead of attributing a sound to a specific channel, gives instructions on where to place the sound. This allows the use of different formats and numbers of speaker arrays. However, due to the multitude of objects, it is preferable to use larger speaker arrays. (Fonseca, n.d.).

Ambisonics was developed during the 1970s and its popularity increased during the last decade due to AR and VR applications. The concept of ambisonics is to create a sphere of sound that can

be reproduced in any system, defined by the patterns of recording and reproduction. Ambisonics present different formats. The A-Format is the recording pattern used in tetrahedral microphones (figure,2.18) each capsule records the audio signal from a specific direction. This format must then be encoded in B-Format, the standard ambisonics format. In ambisonics, orders mean the number of channels for recording and reproduction. The first-order uses 4 channels, each one containing the audio from a specific coordinate (figure, 2.17) (Hong et al., 2017):

- W; omnidirectional having audio from all directions
- X; representing the sound from front and back
- Y; representing the sound from left and right
- Z; representing the sound from up and down.

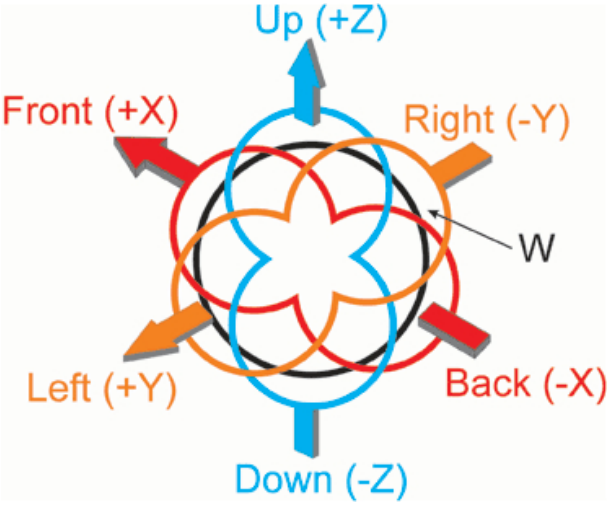

Figure 2.17: B-format (*The four B-format signals convey everything there is to know about the amplitude and direction of acoustic signals arriving at the microphone.*, 2001)

Each new ambisonics order increases the spatial resolution but also the number of audio channels and coordinates. For example, the third-order ambisonics uses sixteenth channels. Other important aspects contained in ambisonics are the component order, (i.e. the order of each audio channel). The most common order by today's standards is ACN, although FUMA can still be used. The last aspect to take into consideration is the normalization parameter that refers to the gain of each channel, the current most common use being SN3D. Ambix is a file format that contains the following parameters: B-Format ACN, SN3D (Fonseca, n.d.).

Encoders can be used to transform mono and stereo signals into first-order or higher-order ambisonic signals. The contrary can also be done by using a decoder transforming an ambisonic file into stereo, binaural, surround channel-based, and others. The main advantage of ambisonics is to be able to reproduce 3D environments in different systems (Hong et al., 2017).

Figure 2.18: Rode ambisonics tetrahedral microphone with 4 channels (*RØDE NT-SF1*, n.d.)

2.4 Flow

The theory of flow was developed by Csikszentmihalyi from 1975 to 2000, when trying to understand why people pursue certain activities or desire to repeat them, also seen as autotelic activities. Csikszentmihalyi interviewed different people about their activities and all reported a similar subjective experience about the activities they enjoy. They stated an intense concentration and involvement in the activity which caused them to forget about external and internal stimuli like time, fatigue, hunger. Csikszentmihalyi describes the sensation as: " The defining feature of flow is intense experiential involvement in a moment-to-moment activity. Attention is fully invested in the task at hand, and the person functions at his or her fullest capacity. ". This intense involvement in the activity generates subjective characteristics that people commonly report (Csikszentmihalyi, 2014):

- Merging of action and awareness
- The sense of control
- Altered sense of time

Even though the flow state can be experienced in any activity it does not commonly occur in daily situations. Some activities are more propitious to flow like games and sports. The activity should have certain conditions that help the person to enter the flow state:

- Balance between perceived challenges and perceived skills
- Clear set of goals

- Clear and immediate feedback

The theory of flow has many relations with motivation factors. Intrinsic motivation presumes a pre-established motive to do a certain task. Flow and motivation are related but contrary to establishing a predetermined goal flow experiences are primarily based on the interaction between the experience and the person. This means that the results produced by the experience happen moment-to-moment. Therefore if an activity consistently presents opportunities where the individual can take action with their current skills a state of flow can be induced. As the level of engagement with the activity increases, the goals of the activity become clearer, presenting a possibility to enter the flow state. During the activity, the balance between the skills and the challenge's demands is dynamic, with each new challenge demanding a new solution. However, if at any point the challenges become too difficult the person starts to experience anxiety, and if they become too easy the person experiences boredom (Csikszentmihalyi, 2014). According to Csikszentmihalyi another concept present in flow theory is emergent motivation (Csikszentmihalyi, 2014). When someone starts one activity the goals may not be clear and the activity itself may not be enjoyable. Emergent motivation means that motivation can be discovered during the duration of the activity, making it enjoyable through the process of engagement. This normally happens when the skills needed for the activity increase over time and allow the person to take up new challenges.

When flow is experienced typically the person persists in the activity and returns to it due to the experience delivered. Persisting in the activity will, in turn, develop the set of skills related to it. Since flow is a positive experience this may also result in the development of higher self-esteem. (Csikszentmihalyi, 2014).

2.4.1 Subjective Flow Characteristics

As described in the present section the three common subjective characteristics present in the flow experience are the merging of action and awareness, sense of control, and altered sense of time (Csikszentmihalyi, 2014).

During everyday life, the consciousness presents a form for understanding feelings like fear and desire. Consciousness is what creates awareness about the surrounding environments and personal behaviors. Concentration is divided into various tasks. During flow experiences concentration is fully directed to the task, creating a disconnection from the surroundings and the self.

Some activities present very demanding challenges and, in some cases, are dangerous, like rock climbing for example. When in the flow state a person gains a sense of control about the experience, allowing them to minimize the chance for error. This sense of control can also be understood as a lack of anxiety since the perceived challenges are matched with the perceived skills.

During enjoyable activities, time seems to go faster, as during unenjoyable activities it seems to slow down (James, 1890). When fully engaged in one activity the passage of time disappears

because the concentration is fully focused on moment-to-moment activity, making it enjoyable (Csikszentmihalyi, 2014).

2.4.2 Flow Conditions

The three conditions necessary for flow to occur. First the necessity to have *clear goals*, which allows us to understand the objective and the path to take to reach those goals. Examples include climbing a mountain, scoring more points in a game, understanding a book, discussing a specific topic in conversion, and others. It gives a purpose to the task. Games commonly present the main goal to players and direct them towards that goal.

Secondly there needs to be a *balance between the perceived challenges and the perceived skills*. Different tasks require different skills to be done. When faced with a task the perception of whether it is doable or not is dependent on the perception of the skills available. Maintaining a constant balance is the key to be in flow (Csikszentmihalyi, 2014). This balance is very well researched, especially in game design. Dynamical Difficulty Adjustment (DDA) is a concept developed by Chen based on the original theory of flow. It implies that games should be able to adjust their difficulty during the game, falling to maintain the player in the flow zone can generate boredom if skills are higher than challenges or anxiety if skills are lower than the challenges. Games can implement these changes using methods to give tools to transform difficult challenges into easier ones or changing the difficulty levels (Chen, 2007).

Finally, since flow happens at a high level of cognitive effort, constant feedback is necessary to help to understand how well the person is performing. Negative feedback is natural to appear due to the high level of challenges but does necessarily break the experience. Instead, it can help correct the performance. The feedback should be immediate as flow happens in moment-to-moment (Csikszentmihalyi, 2014).

2.4.3 Flow Measurements

Although being subjective and unselfconscious, solutions for measuring flow have been implemented since the initial studies developed by Csikszentmihalyi. Common methods used are interviews, paper-and-pencil measures, and the Experience Sampling Method. Interviews were the original method to understand the flow experience and what the participants felt. In these interviews, detailed descriptions about the experience can be gathered from the participants.

Questionnaires are used to measure the dimensions of flow, allowing us to understand what was the level of the characteristics of the experience. Some examples of questions are “I get involved”, “I get direct clues as to how well I am doing”. Since flow has been fairly researched other areas developed flow questionnaires to specific activities like the Game Experience Questionnaire, Immersive Tendencies Questionnaire, and others.

The Experience Sampling Method consists in delivering to the participants of the study paging devices that at different times of the day will send a signal to the participants to answer a questionnaire about the current activity that they were doing (Csikszentmihalyi, 2014).

2.5 Gaming Flow

Gaming flow is a group of concepts and theories based on the original flow theory from Csikszentmihalyi. Sweetser and Wyeth conceptualized a model to evaluate enjoyment in games *GameFlow*. Enjoyment according to Sweetser and Wyeth occurs when a person is fully engaged in the game losing their spatial and temporal awareness. When in a state of flow players play games without expecting any external reward like fame or money. These characteristics are described in their GameFlow Model where they adapt the eight elements of flow for video games, not all the components are necessary to enter the flow state (Sweetser & Wyeth, 2005):

- The Game: is the task that can be completed
- Concentration: is the ability to focus on the task
- Challenge/player skills: are the balance between perceived skills and challenges
- Control: is the sense of controlling their actions minimizing the error
- Clear goals: are the clear goals that a task should have
- Feedback: is clear and unambiguous feedback
- Immersion: is the deep and effortless involvement, the merging of action and awareness
- Social interaction: although does not belong to flow theory has an impact on games

Games are made of multiple layers of stimulus that should be able to grab the player's concentration. The virtual worlds of the games commonly provided enough content for the player to be focused on during long periods. To maintain concentration, games should avoid meaningless tasks.

Challenges in games should be adaptive while the player learns the game and deliver the player meaningful choices on how to approach the game according to their skill level. Dynamic Difficulty Adjustment (DDA) defines a relationship between the skills and the challenges of the player during the game, is the intention of games to maintain the player in the flow zone (Chen, 2007). The enjoyment of games came from the conquering of the game challenges. The development of the player's skills happens increasingly during the length of the game but they should be supported by interesting tutorials or elements of the game world (figure, 2.19).

When players are fully engaged with the game they tend to have a sense of control, a meaning to their actions. In video-games allowing the player character to move around or moving armies in a strategy game establishes a sense of control.

The goals of the game are commonly established in the first minutes but each level or mission should have specific goals. This is what gives the player a sense of direction in games.

Doing actions in games generate consequences and answers from the game system, for example, in a rhythm game the player receives constant and immediate feedback if he is staying on the

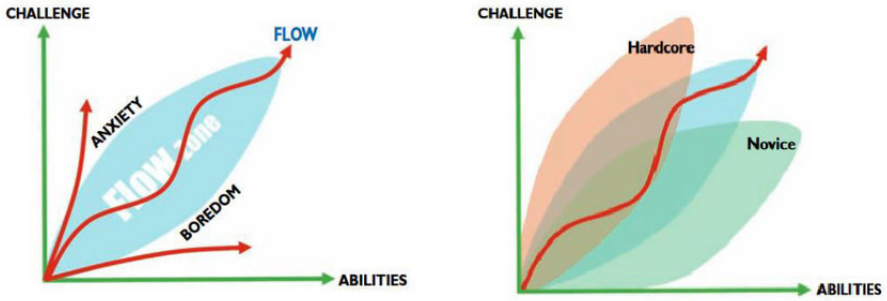

Figure 2.19: Graphic representing the flow zone and the different flow zones for different players (Beseda, 2016)

rhythm or not. The game can use colors or other elements to pass the necessary feedback on how the player is performing. Feedback determinants distance and progress towards the objectives. Sound and visuals can be used to deliver feedback to the player. In a fight scene if the player gets damaged sound cues can be used to alert the player of the damage taken.

Immersion is a relatively broad term used in many contexts. According to Calleja, the term immersion in games can be divided into immersion as absorption to as being fully engaged in the activity, or immersion as transportation the feeling of being in a virtual environment (Calleja, 2011). For this specific context, immersion as absorption and transportation will be used. Games demand the full attention of players, hence the need for absorbing them into the full experience. The challenges, if well balanced do not give space for external distractions. An emotional relation with the game can happen increasing immersion. If the game has content that resonates with the player like visuals, audio and narrative they can impact players' feelings (Chen, 2007).

The social element covered in the GameFlow model does not correlate with any flow component. According to Sweetser and Wyeth games should have the opportunity for players to interact. Playing against other players has a positive impact in flow (Nah et al., 2014). The social interaction can disrupt the virtual environment making players aware of their surroundings but it proved to be a very strong element for game enjoyment (Sweetser & Wyeth, 2005). In boardgames the social element is one of the most important elements according to Woods (Woods, 2012).

Cowley summarizes why games provide an easier way to experience flow: "Games give immediate access to their inherent potential for optimal experience, and that potential is facilitated by the structured nature of further game-play. Thus there is a common correlation between simply completing computer games and getting "in the flow" (Cowley, Charles, Black, & Hickey, 2008).

2.5.1 Preconditions for Flow in Games

Preconditions for flow in games are a group of characteristics that can be related with personality, game characteristics and interactions between players' and game. The next points will expose some preconditions that can induce flow. The characteristics mentioned in the next sections were empirical papers synthesized in *Flow in gaming: Literature synthesis and framework development* (Nah et al., 2014).

2.5.2 Antecedents of Flow

Some conditions can have a positive or negative impact on flow. Antecedents that generate positive effects tend to allow an easier access to the flow state. Many of the antecedents are correlated with personality traits. Research in the field of flow is extensive and several antecedents were found to have a possible impact on flow.

Players' gender can influence flow with boys experiencing more flow in interactive social environments than girls. Having prior knowledge of the game can be a predictor for flow experiences. Self-efficacy is another trait that positively affects flow. Self-efficacy is the confidence that a person has to complete a task. On the other hand, competitive anxiety has a negative effect on flow being able to block the person from enjoying the game. This can happen when competition is seen as a negative factor. Gaming attitude mainly came from previous game experiences and relates with positive experiences in games, it was shown to be an antecedent for the flow state. Autotelic personalities as described Csikszentmihalyi (Csikszentmihalyi, 2014) are explorative and tend to engage in activities for its own sake. These types of personalities have a greater disposition to experience flow. The education level can contribute to flow in collaborative educational games (Nah et al., 2014).

2.5.2.1 Game and System Characteristics

Certain characteristics of the game can act as precursors for flow. The response of the system to the actions of the player should create a seemingly experience avoiding any disruption. A major requirement in games is a fast response to player actions. If the system is unable to answer the player's actions quickly, flow cannot be achieved. As stated by Csikszentmihalyi flow is a moment-to-moment activity that requires immediate and constant feedback (Csikszentmihalyi, 2014). System usability takes an important role in a game. If the interaction with the game is cumbersome or complicated it will create a constant disruption flow state cannot be achieved. Another aspect correlated with system usability is the user interface, in any way the user interface should interfere with the experience. Higher levels of engagement have been found with human opponents that can easily lead to flow experiences than with computer opponents. The game content can affect flow (graphics, audio, narrative, characters), especially for inexperienced players. Also, the quality of the content and their appeal can significantly impact flow (Nah et al., 2014).

2.5.2.2 User and Game Characteristics

The interactions between the game and the players are defined as user and game characteristics. As already mentioned a balance between perceived skills and challenge is necessary for the flow state. It was also found that challenging games produce higher levels of flow than games that try to perfectly match skills and challenges. The relation between skills and challenges with game experience proved to influence flow in less experienced players making them feel a higher degree of flow in less demanding challenges.

Well designed interfaces and perceived ease of use can work as an antecedent for flow. As described earlier the interaction between players proves to influence skill, challenge, and attention which all contribute to flow. The game should create emotion, motivation, and engagement in players, these three characteristics have a great influence on less-experienced players. Emotion can create a connection with game elements as the character or the world. Motivation is reached because of the emotional connections with the game and engagement is obtained towards emotional bounds and motivation. However, it was found that experienced players can connect with the game a priori(Nah et al., 2014).

2.5.3 Flow Outcomes

The outcomes of flow represent the post-experience after experiencing the flow state. The outcome affects the perspective of the user about the game. A common behavior after experience flow in games is the intention to play. Flow experiences represent a positive feeling, opening the possibility for future interest in playing the same game again or creating a general interest in playing games. The flow experience has an impact on the exploratory behavior of players'. Meaning they develop an attitude to search for new games just for the sake of curiosity. It also proved that flow experiences increase the will to share facts or opinions about the game (Nah et al., 2014). The positive experience of flow can also produce enjoyment and satisfaction in games. According to Hsu satisfaction in games is "the extent to which users believe the available game meets playing requirements" (Nah et al., 2014).

2.6 Incorporation

Incorporation is a concept created by Gordon Calleja that describes the state of a player in the virtual world. According to Calleja: "the absorption of a virtual environment into consciousness, yielding a sense of habitation, which is supported by the systemically upheld embodiment of the player in a single location, as represented by the avatar." This definition presumes that the virtual world is based and organized in the real-world model. The concept of incorporation clarifies the dynamics and the relations between the game environment and the player avatar. This concept tries to clarify a state where the player is engaged with the game environment previously defined as presence or immersion. Incorporation goes further and explains the relation of daily routines with the organization of the game world. When the complexity and sophistication increase in the virtual world the connections with daily life become easier to make. To create a sense of dwelling virtual environments Calleja purposed two levels of incorporation. First, the virtual environment is incorporated into the players' minds as part of their surroundings where they can interact. Secondly, the player is incorporated into a location in the virtual environment at any single point in time. This creates a disposition to the virtual environment and at the same time to the other players. Multiple elements can affect incorporation giving the player a stronger connection with the virtual environment such as movement, shared involvement with other players, narrative, visuals, audio, goals and rules of the game. Contrary to the concept of immersion, as immersing the player in the

virtual environment using photorealistic graphics and other technologies, incorporation can benefit from outside world stimulus to intensify the experience. For example, the reaction of another player about the game in the same space can affect the experience positively (Calleja, 2011).

Chapter 3

Proposed architecture for audio augmentation

After the analysis of the related work in chapter 2, the current chapter will now analyze and define the conceptual and planning phases for the audio augmentation system to be used with the board game Rising Sun. The chapter intends to explain the methods used in the development of the system as well the plan for testing the system to evaluate the research questions present in section 1.1. This chapter will start with an overview of the project, the reasons, and the characteristics of board game choice, the sound design plan, the AR detection system, and the methods used for evaluation.

3.1 Project Overview

In order to understand if it is possible to induce flow while playing board games using ARA, a prototype was designed to implement an augmented system in the board game Rising Sun. As stated in the previous chapter the majority of the literature focuses on flow in video games, however this study aimed to understand how audio could be applied specifically to board games to enhance the playing experience.

As shown by Woods board games are very engaging social experiences, for this reason, the objective was to create a system that was able to maintain the natural characteristics of board games while avoiding any disruptions during the experience that could negatively affect the flow state of the players. Therefore, the system should be simple to interact with and also be continuous, making it possible to work even if any detection problem occurs.

To induce flow two approaches were taken into consideration, the audio feedback of players' actions and an audio environment that represents the theme of the game. For the hardware conceptualization, the choice was to develop the system according to the idea of enhancing the natural

environment instead of synthesizing it. Initially, there was an attempt to contact Sennheiser asking permission to use their AMBEO SDK and Smart headset. The Smart Headset is a pair of headphones with built-in microphones like the ones described in section 2.3. The AMBEO SDK allows for 3D audio content and applications to be used with the Smart Headset. The final solution needed to be changed mostly due to the current global pandemic since it was not possible to contact Sennheiser to get access to their equipment. Later during the final planning phase, a new direction needed to be taken having the ARA concept in mind.

The choice of the game was a very important step and therefore needed to bewell thought out since it affected the entire development process. The literature suggested that modern board games have better game design features an proportionate a better playing experience than the mass-market games, as analyzed and described in section 2.1. With this in mind, the game chosen needed to have a good amount of player interaction, be accessible by having a good game design recognized by the community, as well as important visual features that benefit AR tracking. The final choice for the game was **Rising Sun**, a strategy board game published by CMON Limited in 2018.

The final element that needed to be defined before beginning the implementation was which software would be used to create and implement the prototype. In the end, the choice was using REAPER for sound creation, FMOD, and Google Resonance for sound implementation and spatial audio, Vuforia SDK for AR development and tracking, and Unity as the game engine that integrates everything and runs in the final build during the gameplay (figure, 3.1).

The final prototype tracks a specific area on the board where players play their actions and triggers audio cues related to the political mandate played over a continuous soundscape and the natural environment. The following flowchart shows the final prototype and how it works.

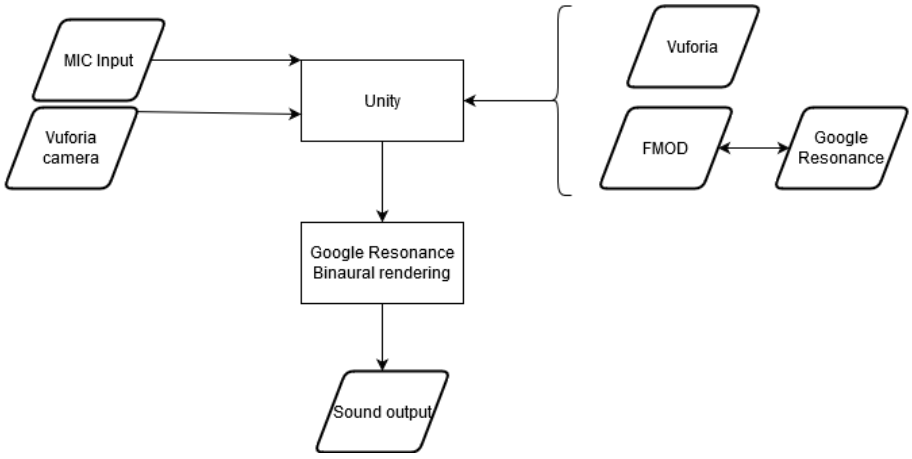

Figure 3.1: prototype overview

3.1.1 Rising Sun

As referenced in the previous section, a lot of thought was put into the choice of the game. Rising Sun is an area control strategy game for 3 to 5 players and features negotiation, different paths

to victory, variable player powers, and blind bidding. The game has 4 rounds which are known as seasons (Spring, Summer, Autumn, Winter). During each season seven actions are played and each player needs to perform each action played. At the end of the game, the player with the most points wins. The game has a very strong theme about feudal mythological Japan, this helped in the development of a coherent sound design for the game. The premise of the game is that each player is a shogun (military title to describe a war general in feudal Japan) that controls a clan, and wants to rebuild Japan. As referenced by Woods (Woods, 2012) modern board games tend to have complex gameplay with simplified rule systems and manuals. For new players, the game has a very informative and intuitive player aid that allows them to know what each action does. Another important aspect although not directly related to the game design was the fact that the game has good features for AR natural feature detection namely each of the action cards which are all very distinct. Because of this, instead of tracking the entire board it was possible to only monitor the season track where the actions are played to track each action, known as political mandates in the game.

Both the board and action pieces have good characteristics which is an important feature as described by Schmalstieg and Tomasi in section 2.2.3.1. Because of both the interesting and engaging game design and the easy to track features Rising Sun was chosen for the ARA prototype, allowing to compare how much augmented reality audio could impact the experience of a well design game.

Figure 3.2 shows the board of the game with the description of the different areas. The 6 different elements presented on the board are:

- 1.The honor track (where the players resolve ties)
- 2.The Kami sanctuaries (where players can collect bonus).
- 3.The season track (players place their actions here)
- 4.The territories of Japan (players place their figures here)
- 5.The battle track (shows the players the order of the battles)
- 6.The points track (shows the players the number of points that each has)

Figure 3.2: Rising Sun board (Guild, 2017)

Figure 3.3 shows the 5 types of political mandates (actions), from left to right:

- Recruit; allows the players to place figures on the map
- Marshall; allows the players to move figures on the map
- Train; allows the players to buy a card from the current season deck
- Harvest; allows players to collect the territory bonuses
- Betray; allow the player that plays this mandate to replace two figures on the map with two of their own.

Figure 3.3: Rising Sun political mandates (players actions) (*The political mandates of Rising Sun*, n.d.)

Figure 3.4 shows the player aid containing all the information related to player actions.

Figure 3.4: Rising Sun: player aid explaining the player actions (*Rising Sun player aid*, n.d.)

3.1.2 Sound Design

As stated in the research questions, it was important to investigate what sound design strategies can be used when applying ARA in board games. The first step was to analyze the game and understand which sounds would make sense to be played during gameplay. The areas taken into consideration were the following:

- The four rounds(seasons) of the game: (Spring, Summer, Autumn and Winter)
- The mythological monsters in the game
- The political mandates actions
- The era of feudal Japan
- Japanese musical instruments
- Japanese musical scales

The ideas for the sounds needed to be able to fit well with the surrounding natural environment that the users would experience, using the ARA headphones. To fully combine the two layers of sounds the google resonance plug-in was used enabling binaural hearing and mixing the digital sounds with the environment.

Regarding the key ideas for the game, the first step was started to define what approach to take regarding the seasons and the political mandates. The seasons should be a constant presence during the game that changed every time the season track was full. For the political mandates, they should function as audio cues about the action played and should fade out after it finishes. For designing the sound for both the soundscapes and the political mandates research was conducted about traditional Japanese instruments and Japanese scales. In the end, four instruments were chosen although only 3 were used, the *Koto* a plucked string instrument, the *Shamisen* also a

plucked string instrument, the *Shakuhachi* a wind instrument and the *Taiko* drums a percussion set of drums. The instruments were assigned to different actions and soundscapes according to their sound. The *Koto* was assigned to the soundscapes, the *Shamisen* to the harvest mandate, *Shakuhachi* to the recruit mandate, and the *Taiko* drums to the Marshall mandate. The Japanese scales are commonly 5 notes with different intervals between them. The ones used were the *Akebono*, *Hirajoshi*, *Iwato*, and *Insen*. Despite the use of musical instruments, music was avoided as the objective of this research was to determine the impact of sound design.

The soundscapes should have two important aspects into consideration, they should work as background thematic ambient without being too loud to interfere with the communication between players, and they should avoid repetition that could be detected by the players and create boredom or annoyance since the time can vary between seasons. The mandate tiles needed to play a short sounds that represent the player action, however since these were played multiple times throughout the game, there were multiple variations of each sound in order to avoid repetition. Using FMOD is possible to randomize sounds and properties using the in-built different instruments. Four of the political mandates makes all the players take the action, the betray mandate is the only one that benefits the player that played it. During the development, was tried to find a way to trigger the betray sound only to the other players but a way to do it was not found.

3.1.2.1 Audio Input

As already discussed in section 3.1 the initial concept of the project needed to be changed due to the global pandemic Covid-19. It was necessary to find a solution to replace the environment audio input. The first approach was to use Max/MSP and connect it to Unity to define the microphone input and also work as a spatializer. However, there were difficulties when trying to connect both programs. The connection needed to be made using network ports and no signal input was received from Unity to MAX/MSP. No possible solution or resource to solve the specific problem was found online. The second option was to route the microphone input towards FMOD, although search had been done in FMOD forums no successful solution or approach was found to solve this problem. Contact with FMOD support was also made and they shared a possible solution using a C++ script in the FMOD API examples but a solution could not be found to properly adapt the script to the prototype. The final option was to create a script in Unity to use the defined microphone and google resonance as the spatializer, although Unity is not the best solution to handle real-time audio due to the possibility of introducing latency. One advantage of this solution is the fact that Google Resonance is already fully integrated with Unity. To reliably test if augmented audio could allow fluid communication between players a H3-VR 360º microphone was connected to the computer using a USB cable and defined as the input sound card encoded into Ambix. A Focusrite 6i6 was used as the main output sound card with two headphones connected to it, allowing the players to ear their surroundings.

3.1.3 Detection

Due to choosing Unity as the game engine to support the entire prototype, it was decided to use Vuforia SDK as the integrated solution to handle the AR assets and tracking in real-time. Vuforia can record in its database 2D objects, 3D objects, and fiducial markers to be tracked during the execution of the program. The database that contains the targets was developed in the Vuforia developer portal and was later integrated into Unity as a package. Since the trackable objects were only the political mandates and the board, it was possible to use only 2D images that show the feature interest points in the images of the mandates. Another element that needed to be tracked was the game board, which is also a 2D plane image, these images are later identified in Unity as target images. The Vuforia developer portal was an excellent feature to rate the quality of the images for detection that goes from 0 to 5 stars and all the images had rates of 4 and 5.

3.1.4 System Architecture

The prototype was designed taking into consideration the places where board games are usually played: board game meetings, board game cafés and living rooms.

The pipeline of the system consists of FMOD which contains all the sounds and their spatial information being called by Unity and when a target image is recognized by Vuforia, Unity searches for the corresponding sound event in the FMOD project. The soundscape present in FMOD is initialized as soon as the program initiates. When one of the political mandates enters the camera vision Vuforia analyses the mandate and tracks it, if the political mandate enters one of seven spaces of the season track one of the seven spaces in the season track this initializes the sound instance corresponding to that mandate. If another mandate is played while another mandate sound is still playing all previous sounds related to mandates are stopped and the new one begins. When all the seven spaces are filled, the game advances to the next season and the system makes a transition for the next soundscape. The microphone input is immediately detected as soon as the program starts allowing fluid communication. The Unity mixer contains Google Resonance that routes all the signals to the user headphones for binaural listening (figure, 3.5).

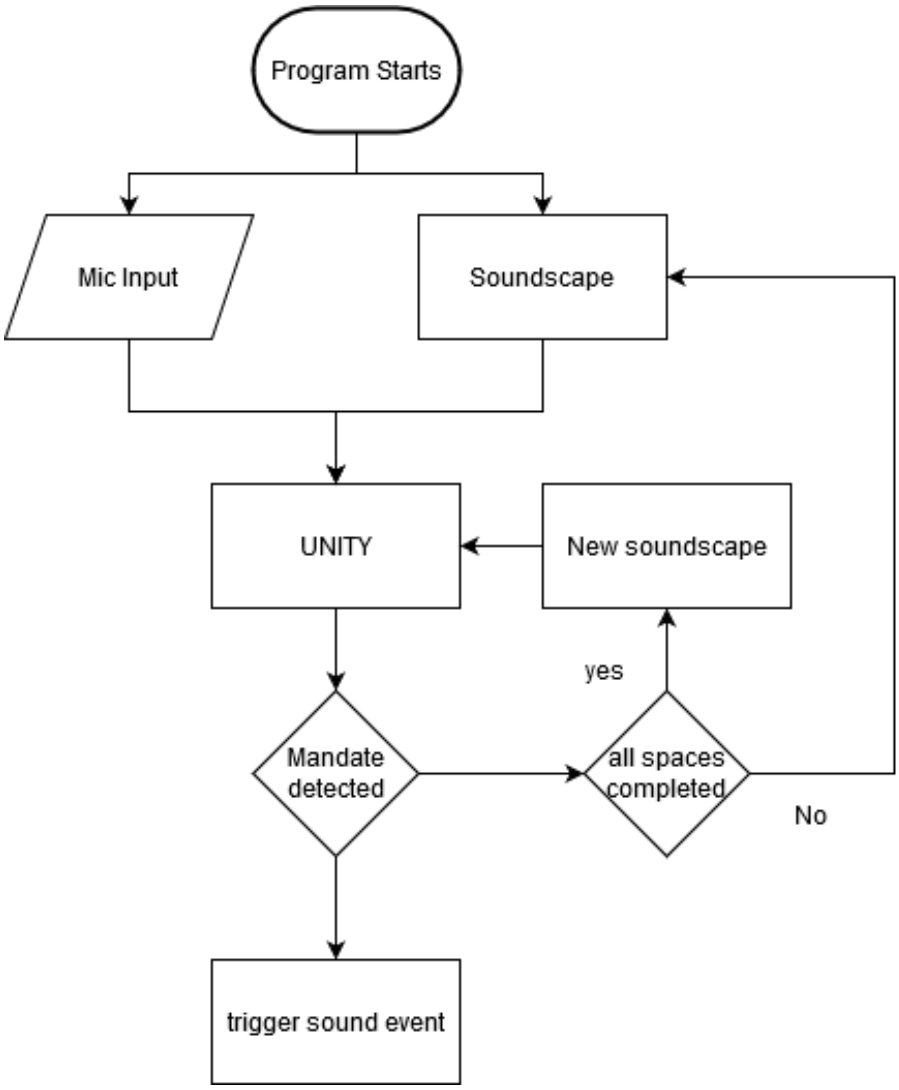

Figure 3.5: Program pipeline

3.1.5 Evaluation

The test of the prototype was intended to answer questions in the section. The focus was to understand if ARA could induce flow or work as a pre-condition for flow, since flow requires a high degree of concentration the system should not disrupt in any way in case of flow happens. Thus it was necessary to collect data to understand how participants felt about the system. Initially, a quantitative approach was defined using a questionnaire based on the "game experience questionnaire" and the "system usability questionnaire", to support these questionnaires biometric data would also be collected and each session would be recorded. Each participant should play the game two times, once with ARA and then again without it for the control test, the sessions were randomized for each participant to get results without this variable attached.

At the end of each session the participants should fill a questionnaire, both questionnaires had the same questions in order to be able to compare each play session. Aiming to achieve

scientific relevance in this study of a quantitative approach, the plan was to run the experience with at least 30 users. To gather these participants contacts were made with different groups and associations namely board game groups in Aveiro, Porto and Braga as well as the Quebra-dados association, and the generic email of the University of Porto. Was asked for the participants to have a basic understanding of the rules of the game to avoid delays during the gameplay. Due to the global pandemic special measures were taken to ensure the safety of the participants, a room was prepared with all the required safety material and all the sessions were scheduled to avoid big groups.

Chapter 4

Development

The developed prototype is an ARA system implemented in the board game Rising Sun that tracks the actions of the players and feeds them thematic sounds according to the actions played.

This chapter will analyze the procedures used to build the prototype in detail. It will analyze how the target images are defined and implemented in Unity, followed by the implementation of the FMOD project, and afterward will analyze how the sounds were made and the encoders and decoders used for spatial audio files and, lastly, will also cover the game engine.

4.1 Images Augmentation in Vuforia

The use of the Vuforia SDK was defined during the conceptual phase of the prototype. As explained in section 3.1, Vuforia is a software development kit for AR. To choose which game assets should be tracked, it is necessary to create and populate a database in the Vuforia developer portal (figure, 4.1). Each application has a unique license key that can be obtained from the Vuforia portal to be incorporated into Unity. This key gives access to the main features of the tool kit. It is in the developer portal that the database to be used is created. This database contains all the targets that should be identified by the camera. The targets chosen were the five political mandates and the season track of the board. All of them scored a rating 4 or 5 stars. An important aspect later discovered during the preliminary tests of the prototype was the fact that Vuforia cannot detect the same target image simultaneously. Since each political mandate has a copy, the solution was to find images that could easily represent the mandate and placed them inside the sleeve to cover the mandate image. The images used did not have very good results being normally 3 stars, but the system was able to detect the images anyway, with some needing a bit more time to be detected.

To connect the database with Unity the following steps were necessary:

- Install the Vuforia extension in Unity
- Export the database from the Vuforia developer portal as a package for Unity

- Drag and drop it in the Unity Project
- Deleting the Unity camera and replace it with the AR camera
- Copy the license key to the camera
- Choose the database

When the Vuforia extension is installed it adds new game objects to Unity to be used for AR applications. As already mentioned the game camera of Unity needs to be replaced with the Vuforia AR camera for target detection. Each political mandate is tracked using the Vuforia game object Target Image, each of these objects will access the "Rising Sun database" to define what image corresponds to it. Due to the pandemic situation, access to the required material for tests was difficult so the decision was made during the development to use the mobile phone camera to track the objects. The ultimate solution found that allowed the use of the camera in the project was to use the app *iriun webcam*, which allows any computer or mobile phone with the app connected to the same network to share the mobile phone camera. To help understand when the image is tracked a material object was placed as a child object to appear in the Unity screen when the image is detected.

To avoid any problems with the tracking, the real width of the political mandates and season track were defined being 0.04 cm for the mandates and 45 cm for the season track.

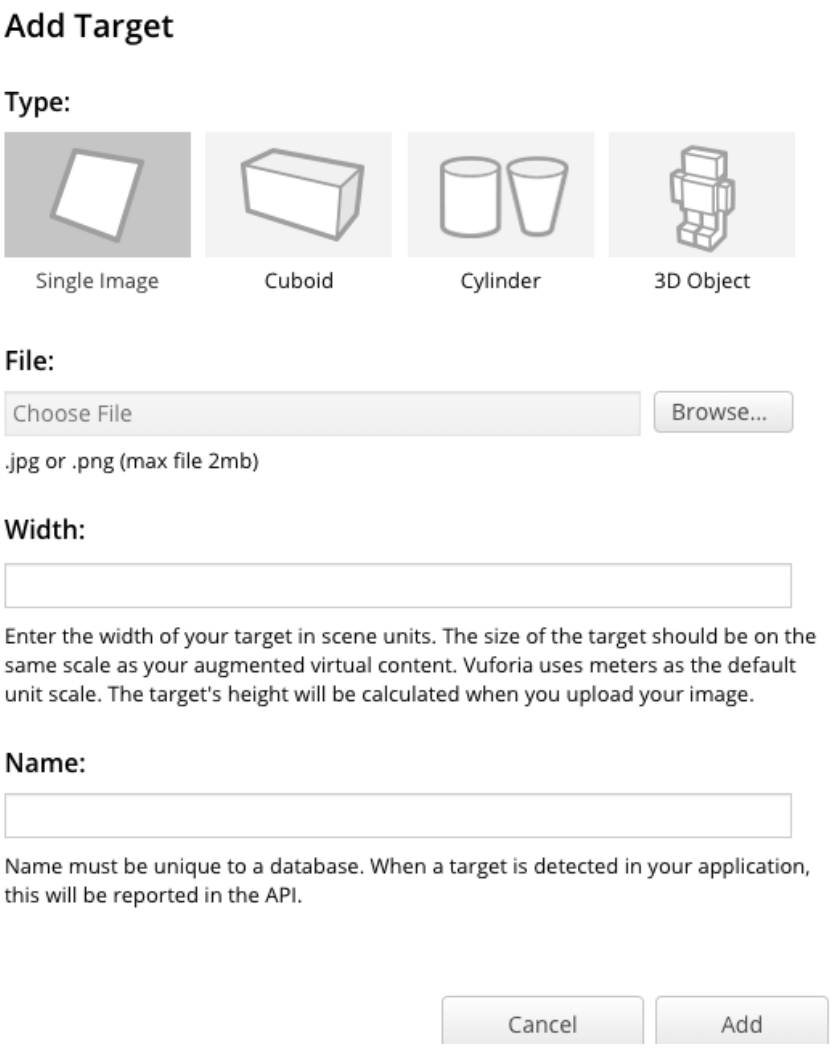

Figure 4.1: Vuforia portal to add target image

4.2 Sound Creation in Reaper

As described in section 3.1.2 a research was conducted to find congruence between the perceptual imagery and the sounds. The sounds for this project was developed in REAPER, a digital audio workstation. Since the project intended to use ambisonics the ATK-plug-ins were used to encode mono sources to ambisonics B-format. The master track also needed to have the ATK-binaural decoder and the FUMA to Ambix decoder (ACN-SN3D) since Google Resonance uses Ambix. The project was set for multichannel-audio. The instruments chosen during the planning phase were assigned to different mandates according to their sound properties. Kontakt 5 was used to play samples of the specified instruments.

The soundscapes were composed using various elements that represent each season, the spring had flowing rivers and the birds, the summer the crickets and the wood sticks snapping, the autumn

had the wind blowing and finally for the Winter there was a taiko rhythm to create a build up to the end of the game and its winner. Since the Koto is considered one of the most prominent instruments in the Japanese culture it was chosen for the soundscapes (Johnson, 2004). These contained small musical phrases and chords that were randomly played throughout the soundscape in order to sound natural and avoid repetition.

When designing the sounds played during each of five the mandates, special care was taken in order to properly associate each action with the action the player was making. The taiko drums were used for the Marshall mandate because they can mark a march rhythm and since their sound is loud and with a long decay therefore making the player associate it with an army's movement. Other elements like steps and voices were added to further reinforce the desired effect.

The shakuhachi was used for the recruit mandate, using the Koro Koro technique this instrument produces a sound similar to a hunter's horn. It can be associated with the call of the monsters or the troops that fight for the players. Additionally a mixture of different types of steps from humans and giant steps representing the monsters of the game were added. Initially, there was an attempt to use the Shamisen in the harvest mandate reminding the player of an instrument that someone is playing in the fields, but in the end, it was removed since it could be confused with the Koto being both pluck instruments. To replace it a man chanting was used. Other elements like grass, dirt, tools noises were also present. For the Train mandate swords, voices, and coins sounds were used to give an idea of someone hiring mercenaries or buying something because this mandate action allows players to "buy" a card from the deck. Lastly, the Betrayal mandate was conceptualized as a sudden surprise move. To represent its quiet nature, the sound of a knife cutting and the sound of blood dropping on the floor made the aural context for this mandate.

4.3 FMOD

FMOD was the program used to make the integration of adaptive audio in games. This software's user interface is similar to a digital audio workstation (DAW). FMOD is divided into three sections: FMOD studio (a stand-alone program where the project is created to be implemented in Unity), FMOD runtime API (used to connect with FMOD Studio), and FMOD low-level API (this API gives instructions to UNITY regarding which sounds should be played and when).

For this prototype, FMOD studio was setup dividing the sounds into 2 folders: the mandates and the soundscapes. The folder of the mandates contains five FMOD events each one representing one political mandate (Betray, Marshall, Harvest, Train and Recruit). Initially, the soundscape folder contained 4 events each one representing a soundscape (spring, summer, autumn, and winter). Later during the development phase, all the sounds were combined into just one event. The reasoning for this will be explained later in detail in section 4.3.6. In FMOD's mixer two group buses were added, one that routed all the mandate events and another that routed all the soundscapes. Both of the buses output routed directly to the master bus output.

In the version 2.00.08 FMOD contains Google Resonance already as a built-in plugin. To set google resonance as the decoder plug-in in FMOD it's necessary to place the resonance audio

listener in the master bus, this plugin enables binaural spatialization of sound sources created with the other two google plug-ins: Resonance Audio Source (Mono files) and Resonance Audio soundfield (ambisonics files). The soundscapes contain the Resonance Audio soundfield in the master event track to decode the ambisonic files. The political mandates have the resonance audio source in the event master track to position the mono sources for binaural listening.

4.3.1 Betray

The sounds contained inside of the betray event create a sound sequence that leads to an assassination as implicit by the game action. It was composed by four tracks, three of these tracks have an event instrument that represents a specific sequence of the sound. One of the tracks contains a scatter instrument containing droplets sounds. The scatter instrument allows for multiple sounds being triggered at different times. It was used to represent multiple blood droplets hitting the ground. The table 4.1 shows the FMOD instruments and the corresponding sounds:

Table 4.1: Betray Event

FMOD instrument	**Sounds**
Event Instrument	Steps approaching
Event Instrument(Multi-instruments)	Knife sounds
scatter instrument	Blood Drops
Event Instrument	Steps running fade-out

The sounds in the event are all mono thus Google Resonance Audio Source was added to the event master track for sound spatialization.

4.3.2 Harvest

The approach taken when creating the Harvest mandate consisted in trying to represent the ambience in the fields. The Harvest event in FMOD is made of five tracks, four contain multi-instruments to allow for sound randomization. One of the multi-instruments hosts two event instruments each one containing a specific type of terrain sounds (mud and dirt). The last track contains an event instrument with two multi-instruments one containing tools sounds and other voices. The man chanting is a four channels ambisonic file used to give the listener the sensation of coming from all directions, the Google resonance Soundfield was added directly into the track. All the other sounds were mono and to spatialize them the Google resonance Audio Source was placed in the event master track (table, 4.2).

Table 4.2: Harvest Event

FMOD instrument	**Sounds**
Multi-instrument	Japanese Gong
Multi-instrument	Men Chanting (Ambisonics)
Multi-instrument	Event mud terrain Event dirt terrain
Multi-instrument	Birds
Event instrument	voices and tools

4.3.3 Marshall

The Marshall event contains layers of sounds to represent multiple units marching. All the Sounds were placed inside an event instrument. Inside the event instrument are six tracks. Four of the tracks have multi-instruments with different taiko phrases. The further the instruments are in the timeline the louder the sound, recreating the sensation of an army approaching. To add more variation two Scatterer instruments for footsteps in different terrains and weapons were added inside the event instrument. The final track has an event instrument with two multi-instruments containing a sound effect recorded on an empty room to simulate the earth-shaking by the mythological monsters in the game. For spatialization, the Google Resonance audio source was placed in the event master track (table, 4.3).

Table 4.3: Marshall Event

FMOD instrument	**Sounds**
Event-instrument	Giant steps
Single-instrument	Taiko Drums
Multi-instrument	Taiko Drums
Event-instrument	Steps and swords
Multi-instrument	Voices
Event-instrument	Taiko

4.3.4 Recruit

The recruit mandate was kept very simple. The idea was to use the sound of shakuhachi to be recognized as a summon. The event has three tracks, all having multi-instruments. Two of the tracks have variations of the Koro Koro technique and one of the tracks has multiple voices screaming with a crescendo effect. The shakuhachi files are first-order Ambisonic to add the effect of surrounding the user. The voices are mono, coming from a specific point in space. For the shakuhachi, Google Resonance Audio field was introduced in the corresponding tracks and for the mono sources the Google Resonance Audio Source was placed on the event master track (table, 4.4).

Table 4.4: Recruit Event

FMOD instrument	**Sounds**
Multi-instrument	shakuhachi (Ambisonics)
Multi-instrument	Screams (Mono)
Multi-instrument	shakuhachi (Ambisonics)

4.3.5 Train

The Train mandate has seven tracks, two using multiple single instruments, four using scatterer instruments, and one using a Multi-instrument. The single instruments have the sounds for the bag of coins, each instrument has defined a probability for playing the sound. The scatterer instruments have multiple swords sounds and voices with different intervals for triggering sounds, possibly giving the impression of a training place. The Multi-instrument has the sound of a sword dropping to indicate that the train is finished. All the sources used were mono sources and spatialized with the Google Resonance Audio Source (table, 4.5).

Table 4.5: Train Event

FMOD instrument	**Sounds**
Single Instruments	Bag of coins
Single Instruments	Coins
Scatterer instrument	Swords clang
Scatterer instrument	Swords clunk
Scatterer instrument	Swords sharpening
Scatterer instrument	Vocals
Multi-instrument	sword falling

4.3.6 Soundscapes

Contrary to the political mandates each soundscape needed to be a continuous loop that needed to be played until a new season started. Initially, each soundscape was designed as a separated FMOD

event but due to how the script evaluated if the new soundscape should be played, a constant re-triggering was happening. This will be further explained in the section. To solve this problem only one event was used containing all the soundscapes. Three of the soundscapes were organized into event instruments (Spring, Summer, Autumn). Each one consisted of first-order Ambisonics files in Multi, Single and Scatterer instruments. One important element was kept playing constantly to identify the season, river in spring, birds, and crickets in summer and rain and wind in Autumn. Other elements will appear at different times and with different probabilities. For the Winter season was only used a multi-instrument with a Taiko phrase to announce the end of the game. To be able to change the loops in the timeline a local parameter was added to the soundscapes event. The parameter value varies from 0 to 1, each transition marker contains a specific value from 0 to 1 that will make the playback advanced for the corresponding destination marker. All the tracks have the Google Resonance Soundfield to decode de Ambisonic files.

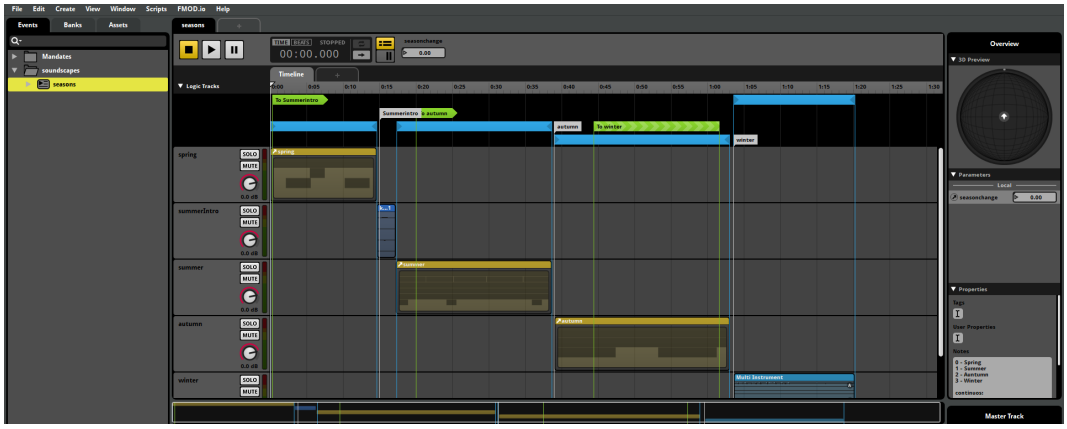

Figure 4.2: FMOD project with the soundscapes event

4.4 Game Engine and Sound Implementation in Unity

This section describes how the game engine works and what communications are made between Unity, FMOD, and Vuforia. It explains how Unity uses the Vuforia SDK which is receiving the webcam's video feed. The program initiates the soundscape event of the FMOD project and tracks the season track where 7 colliders are implemented into each of the spaces where the mandates are played. To set Unity for delivering binaural output, the Google resonance plugin is defined as the spatializer decoder and as the Unity mixer output.

4.4.1 Vuforia Setting

The unity project contains twelve game objects related to Vuforia SDK. The game object with the Target Image belongs to the Vuforia library and one image from the Vuforia database is assigned to it to being able to be tracked by the camera. The target Image that contains the season track has seven children objects, each of them is a collider representing each of the seven available spaces.

For each of the colliders, a Tag is defined to be used as a variable to track how many spaces are occupied at any given time. The colliders are set as triggers so they do not retain any physics property, only triggering when a mandate collides with the space.

For the Target Images that have the political mandates, a rigid body and a collider were also added without being a trigger to activate the collision with the spaces. The tags of the mandates are used to communicate with FMOD what sound instance should be triggered. Additionally two scripts were added to the political mandates : the “raycool” and the “collision” scripts. The “raycool” script is where the main functions related to the collisions are, this script detects if any collision is happening and detects what mandate is causing the collision using the Game object tags. The collision script is called when a collision is found and identifies the object tag, for playing the FMOD event.

4.4.2 Fmod Settings

To trigger the FMOD events some functions were made inside of “raycool” and “collision” scripts. To control the number of sounds that can be triggered the system accesses the bus track in the mixer containing the political mandates and each time an action is played all the events in that bus should stop before triggering the new event. The instances that call the sounds for each of the mandates are located in the collision script. As described in the section when a card enters the space a new instruction is called to search in the collision script for the same tag as the object that enters the space, creating an instance of the event to start playing.

The script for the soundscapes is located in a game object called “soundscapes”. This script initializes the soundscapes event in FMOD. When all the spaces are filled the “CounterChange” will change the value of the counter that will be analyzed by the “ParameterChange” which will change the parameter value in FMOD, activating the transition regions in the FMOD timeline to initiate the next season. Initially, there were four soundscapes in different events but due to the pipeline of the system the new soundscape was always being retriggered every time the “Counter-Change” method was called.

4.4.3 Hardware Connections

The system has three peripheral connections: the Logitech webcam 720P, the Focusrite 6i6 external sound card, and the Zoom H3-VR microphone. The webcam is connected by USB and is defined as the input webcam in the Unity AR camera. The Focusrite 6i6 was the main sound output of the system defined in the system preferences. Both headphones were connected to the headphones out in the Focusrite, allowing the users to regulate the general volume. The audio input of the system was defined as the zoom microphone in the computer preferences. When connected via USB the microphone gives different options to be set as an audio interface, for this project it was set as an ambisonics microphone in B-format. For Unity to use the defined input, an audio source component and script were attached to a game object. The script gets the elements from the audio source component attached to the game object and uses the built-in Microphone class in

Unity to tell the audio source that the clip playing will be the current Microphone. For continuous microphone input, the audio source needs to be set as a loop. The audio source goes through Unity's mixer where Google Resonance is defined to encode the B-format from the microphone to binaural listening. In the image 4.3, it is possible to see the pipeline between the peripherals.

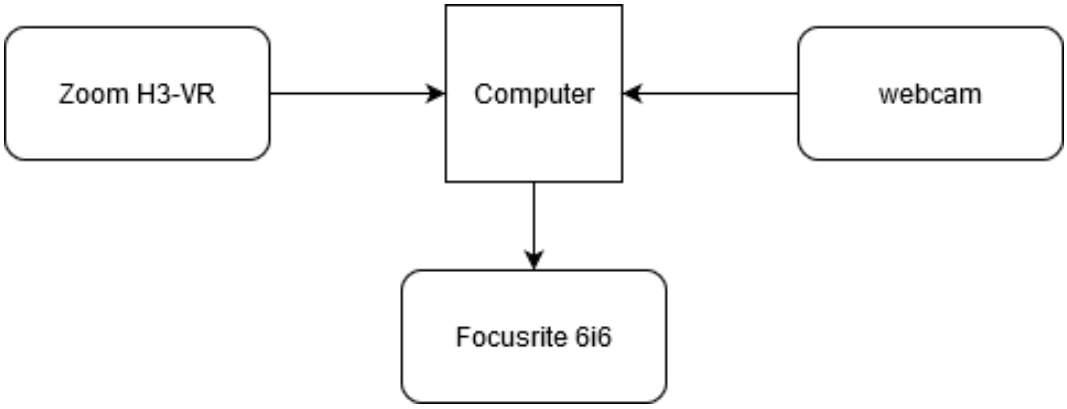

Figure 4.3: Flow chart showing the hardware connections

Chapter 5

Validation

The present chapter will cover the results obtained from the participants. The trial games occurred between the 8th and the 10th of August at FEUP's facilities and Quebra-dados association. This chapter will analyze the results by making a comparison between both questionnaires and the empirical observations. At the end of the chapter there will be a section discussing the results.

5.1 Experimental Design

The experience was designed to be conducted with 30 or more participants preferably with an equal number of men and women. To gather the participants, as it was described in chapter 3, contacts were made to different groups that play board games weekly and in the University. To have a good sample to compare the initial plan was to conduct the tests with these 30 participants over a span of eight days, between the 7th and 15th of August. However, due to the pandemic, it become difficult to gather participants. In the end, the final number of participants was 10 and the tests took place between the 8th and 10th of August. Each test had two participants as well as a researcher to facilitate the playthrough and answer any question the players had. The choice to allow only two participants at a time was to minimize any health risks associated with the gathering of large groups.

Each test was expected to last 3 hours, consisting in two full playthroughs of the game, one with the ARA and other without it. To avoid any bias or variables related to the order of play, each game was randomized, therefore some participants played with the augmented audio first while others started by playing without it.

All the sessions were recorded with the consensus of the participants (appendice, C), in order to be further analysed later. This was done by placing a video camera in the room, taking care to avoid placing the camera close to them. The main tool for analysis was the questionnaires in (appendice, B). Both A and B questionnaires contained the same questions. Questionnaire A was used for the augmented version while questionnaire B for the non augmented version.

The experience was made in FEUP at Room I323, all the equipment used in the game described in chapter 4.4.3 can be seen in figure 5.1. Due to problems with FEUP's security, the test on the 9th of August needed to be done at in Quebra-Dados association.

Figure 5.1: Participants during the break between sessions

5.2 Protocol

The participants were informed during the registration that each session consisted of 2 games of Rising Sun with a questionnaire that needed to be filled at the end of each game. After accepting to take part in the experience the participants received a video in their email address containing the rules of the game. Additionally, before the first game, any possible doubts remaining about the rules were clarified. These two steps ensure that the players had a firm grasp on how to play Rising Sun thus allowing for a smooth playthrough without many interruptions that could break the flow of the game. Participants were instructed to use headphones throughout the entire experience. The game features different decks and clans that can offer variability in the gameplay but to maintain the experience consistent, the same deck (The mountain deck) and the same clans (Koi clan, turtle clan, and dragonfly clan) were always used. The participants could choose between two of the available clans (the Dragonfly and the Turtle clans) while the researcher always played with the Koi Clan.

At the end of each game the data was collected using the respective questionnaires which were available for players to fill on a computer. The first part of the questionnaire had questions related to gender, education, time spent playing board games, and experience with AR. The second part of

the questionnaire contained the game experience questions regarding flow, social questions, sensory and imaginative immersion, in-game positive and negative feelings, post-game positive and negative feelings as well difficulty to return to reality. All the statements could be answered using a 5 item Likert scale with the following answers: not at all, slightly, moderate, fairly, extremely. The last section of the questionnaire had some statements from the system usability scale questionnaire to evaluate the impact of the system on the user experience using also a 5 item Likert scale with the following answers: strongly disagree, disagree, neutral, agree and strongly agree.

5.3 Participant Characteristics

Of the 10 participants who participated in the tests, nine were male and one was female (table, 5.1). The level of education of eight of the participants had higher education while one participant had basic education and another had completed high-school (table, 5.2). In this group 60% of participants played between 0 and 2 hours of board games weekly, and the remaining 40% was divided evenly between those who played 2 to 5 hours and those that played 5 to 10 hours (table, 5.3). Few had much experience with the test game Rising Sun, with 60% of the players saying that they had played 0 to 2 times, and 40% having played 3 to 5 times. The average experience with AR was none or very little (table, 5.4).

Table 5.1: Participants Genre

Genre	**Participants**
Male	*9*
Female	*1*

Table 5.2: Education Level

Education	**Participants**
Grade - 1 to 9	*1*
Grade - 10 to 12	*1*
College	*8*

Table 5.3: Time Playing

Time playing	**Participants**
0 to 2 hours	*6*
2 to 5 hours	*2*
5 to 10	*2*

Table 5.4: AR experience

AR experience	**Participants**
None	*6*
Very little	*3*
Some	*1*

5.4 Flow Questions

Six statements of the questionnaire were related to the state of flow during gameplay. In order to compare the results between the two sessions, Session A consists of the augmented audio tests while session B consists of the non-augmented tests.

The first question was if the participants were fully occupied with the game (figure, 5.2):

- The graphic below shows that 30% of the participants did not feel fully occupied with the game in session B
- The graphic below shows an increase of participants answering that they felt more occupied with the game in session A.

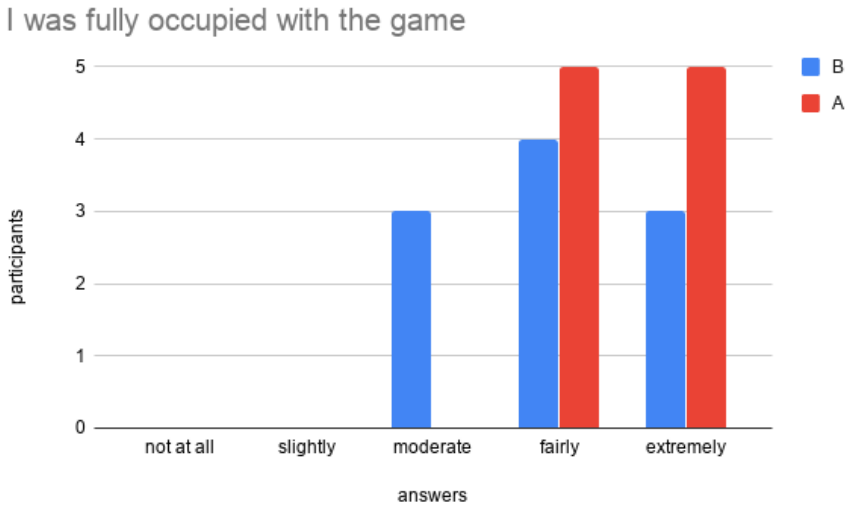

Figure 5.2: Results to the following statement: "I was fully occupied with the game"

To evaluate the merging of awareness the second statement answered was " I forgot everything around me" (figure, 5.3):

- In session B participants' answers stayed consistent in the middle of the scale with 60% answering "moderate" and the others 40% answering "fairly".
- In session A, participants' answers were more dispersed. 30% of the participants answered that they felt slightly more aware of the surroundings. 30% of the participants answered "extremely".

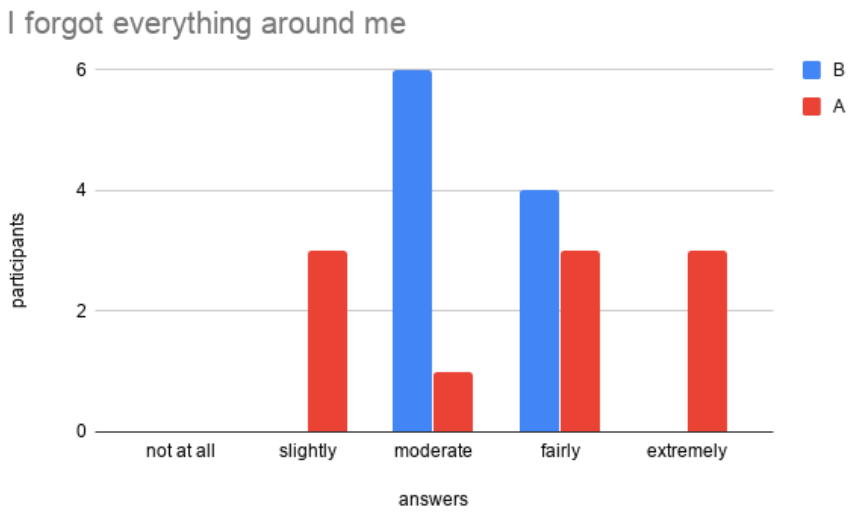

Figure 5.3: Results to the following statement: "I forgot everything around me"

Another essential subjective characteristic to analyze is the perception of time. The questionnaire contained the following statement: “I lost track of time” (figure, 5.4):

- In session B participants related that they have lost track of time considerably. With 70% answering fairly, 10% moderate, and 20% extremely.

- In session A some participants said that they felt more the sense of time but at the same time there was an increase in participants answering they completely lost track of time

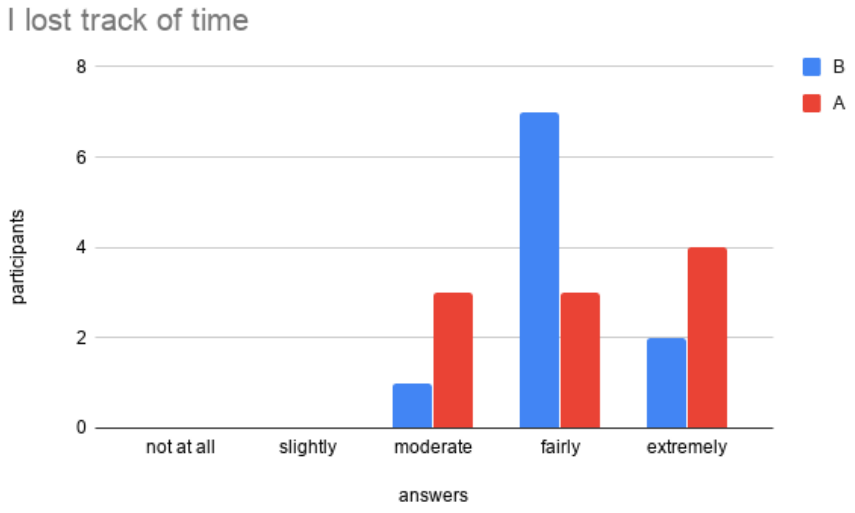

Figure 5.4: Results to the following statement: "I lost track of time"

Measuring the level of concentration in the activity in each session is an important indicator of the state of flow. The following statement intended to understand the concentration in the activity "I was deeply concentrated in the game" (figure, 5.5):

- The results on session B present a positive result, however, 30% of the participants answered that they were only moderately concentrated in the game.
- In session A the answers show a very positive result with 50% of the participants answering they were fairly concentrated in the game and the other 50% answering they were extremely concentrated in the game.

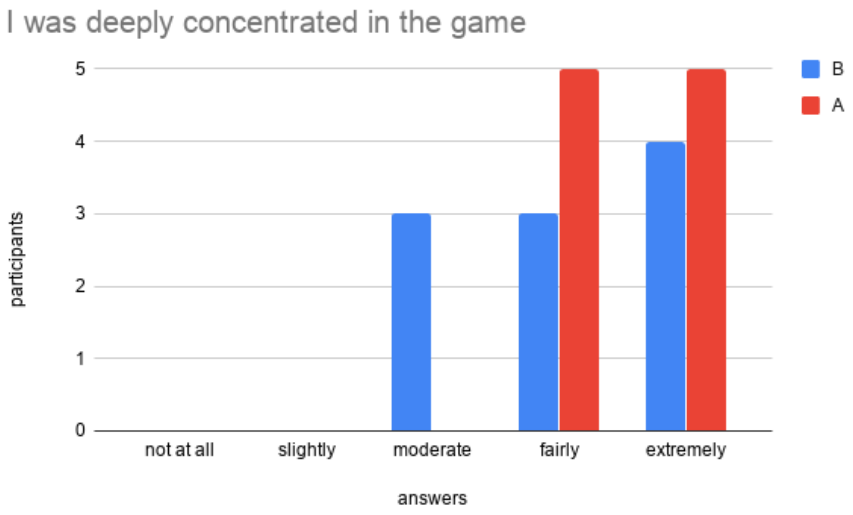

Figure 5.5: Results to the following statement: "I was deeply concentrated in the game"

To understand how immersed the players were in the game, the following statement was made: "I lost connection with the outside world (figure, 5.6):

- Both the session A and B presented small variants to this statement. In both statements, the majority of the participants stated to have some degree of disconnection, within both cases having one person that felt extremely disconnected.

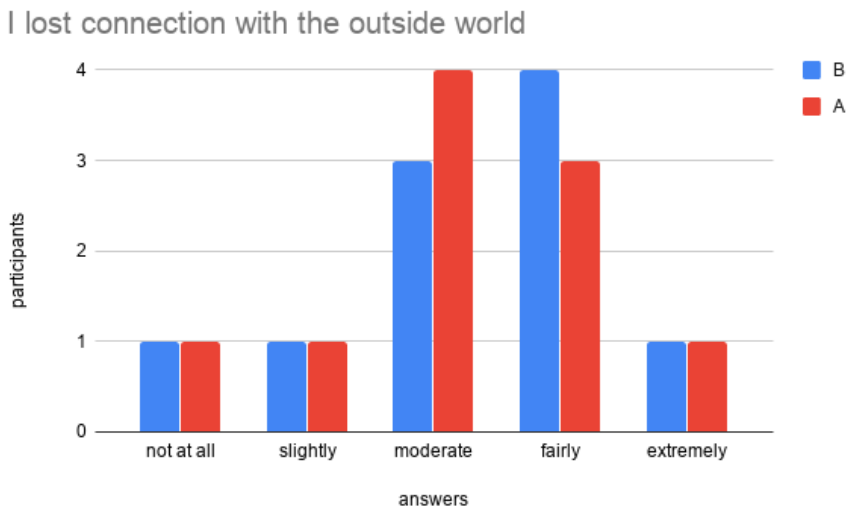

Figure 5.6: Results to the following statement: "I lost connection with the outside world"

The last statement for in-game flow was related to feeling absorbed in the game, “I felt completely absorbed” (figure, 5.7):

- In session B participants related to having different degrees of absorption, with one person answering slightly, 30% moderate, fairly 40%, and extremely 20%.
- In session A the results were very positive with 70% of the participants stating high degree of absorption and 30% feeling extremely absorbed.

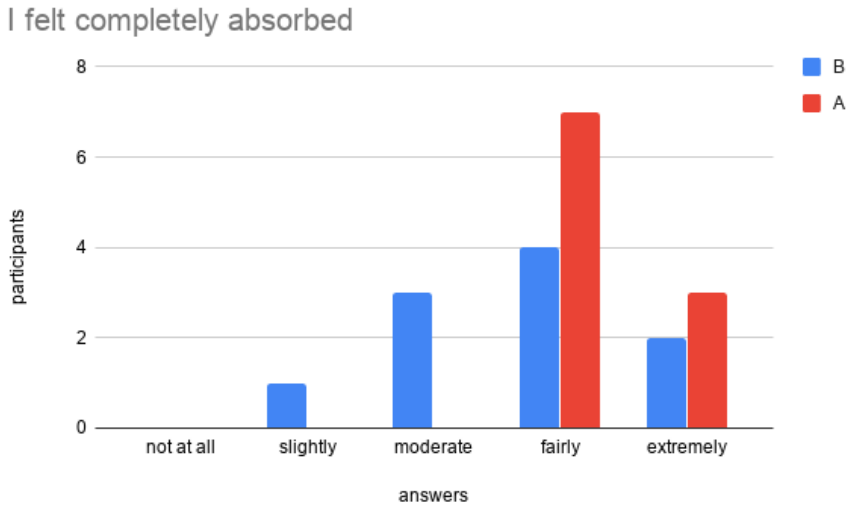

Figure 5.7: Results to the following statement: "I felt completely absorbed"

The flow in-game statements presents positive results for concentration, absorption, and activity fulfillment.

5.5 Social Questions

To evaluate the social interaction of the system the questionnaire has three statements to understand the social interactions of participants during the experience. The first statement was “I felt connected to the other(s)” (figure, 5.8):

- Session B had the participants positively connected in the game. With more than half of the participants answering positively.
- Session A had a small decrease of one participant answering that he was feeling slightly connected to other participants.

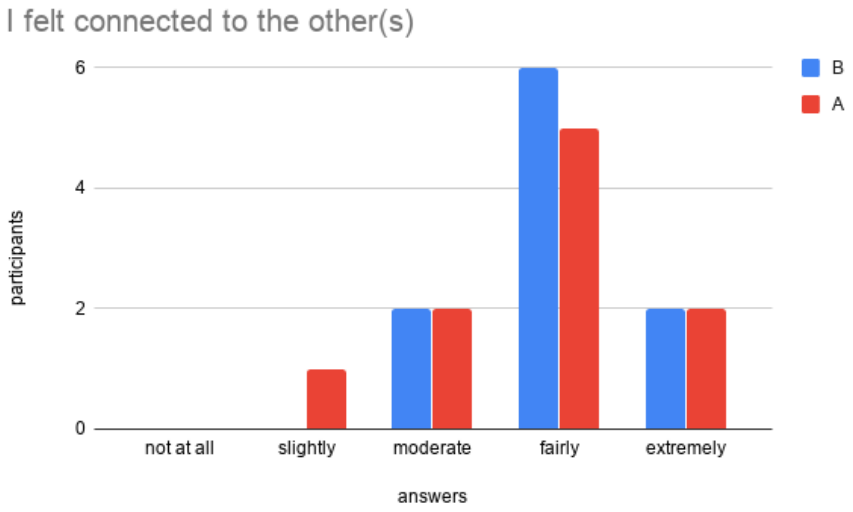

Figure 5.8: Results to the following statement: "I felt connected to the other(s)"

Evaluating the impact of other participants in the experience the following set of statements were made “I found it enjoyable to be with others” (figure, 5.9) and “ I was influenced by others moods" (figure, 5.10).

- Participants show positive results in enjoying being with others in both session B and session A with session A having an increment in participants finding it extremely enjoyable to be with others.
- Participants’ answers about the influence of other players are mixed, with answers filling all the possibilities, while in A participants reported mixed answers with half of the participants not feeling influenced and the other 50% feeling some high degree of influence.

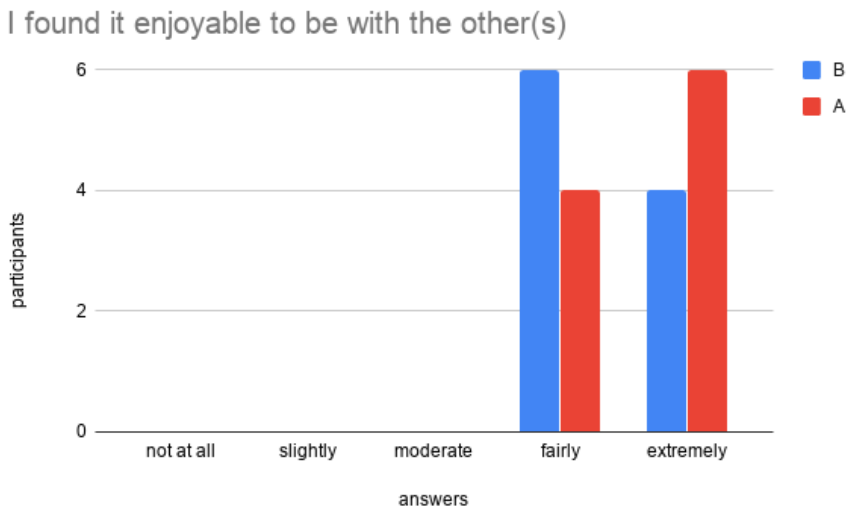

Figure 5.9: Results to the following statement: "I found it enjoyable to be with the other(s)"

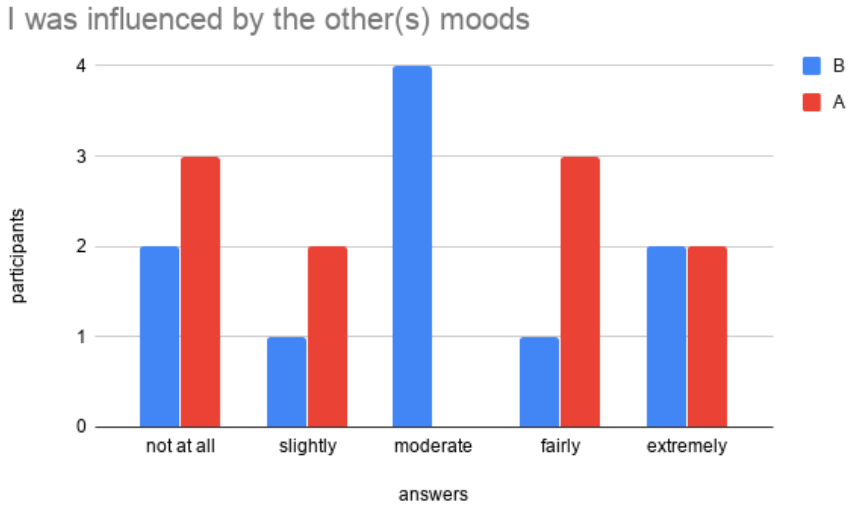

Figure 5.10: Results to the following statement: "I was influenced by others moods"

The participant's answers showed that the system did not negatively influence the social aspects of the game.

5.6 Sensory and Imaginative Immersion Statements

The sensory and imaginative immersive statements present in the *game experience questionnaire* were used to evaluate the level of engagement of the participants with the context of the game. These statements allowed to understand if the ARA enhanced the theme of the game. All the results can be found in appendix A.1. The first statement served to understand if the participants felt the game aesthetic pleasing:

- While in session B the majority of the participants felt a high degree of aesthetic pleasure. Only one of the participants stated that he only found it moderating pleasing.
- In session A all the participants felt the game aesthetically pleasing with the number of the participants answering extremely rising to 40%.

The participants found the augmented version more appealing than the non-augmented version. The next statement evaluates how imaginative the participants felt. The statement was "I felt imaginative".

- In session B the majority of the participants stated a slightly or moderated imaginative feeling.
- Session A demonstrated an increment of high degree imaginative feelings with 20% of the participants answering "extremely", 50% answering questions "fairly". However 10% of the participants answered "slightly" and 20% "moderately".

To compare how the participants felt about the experience with and without the augmented audio the following statement was used " It felt like a rich experience" (figure. 5.11):

- Session B had a diverse group of answers with one participant answering "slightly", two participants answering "moderate", 50% "fairly" and 20% "extremely".
- Session A had all the participants feeling a richer experience with 40% answering "fairly" and 60% answering "extremely".

As shown in participants' answers the version A had more positive results than it was initially expected.

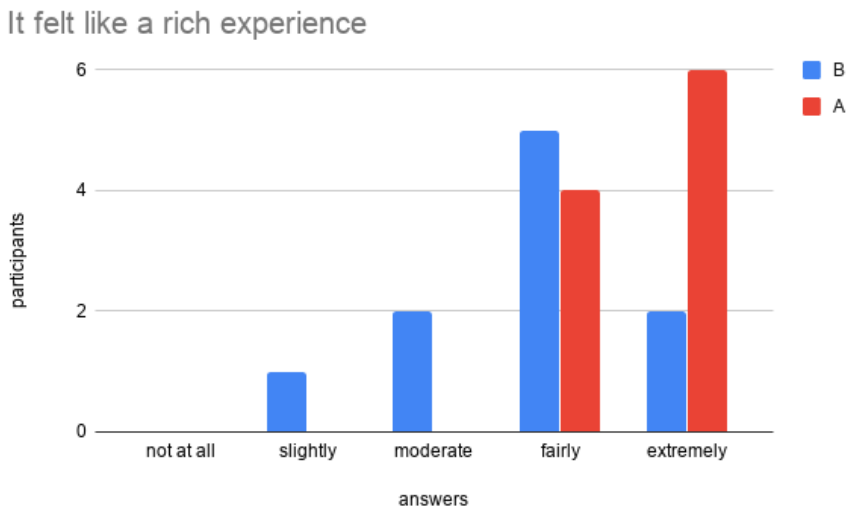

Figure 5.11: Results to the following statement: "It felt like a rich experience"

5.7 In-Game Positive and Negative Emotions

Flow is associated with positive feelings during the activity, some statements in the game experience questionnaire were used to evaluate the player's positive and negative feelings as well tiredness and annoyance. As seen in the graphics in the appendix sections (A.2, A.3, A.4,), the majority of the participants did not report strong significant negative effects. One statement where participants felt significant differences was in the "I thought about other things". Compared to session B where the majority of the participants reported thinking about other subjects, in session A this did not occur in the majority of the participants since 70% of the participants claimed that they did not think about anything besides the game. Another statement with substantial differences was " I found it tiresome", where in session A 80% of the participants claimed not feeling tiresome while in session B only 60% claimed not felt tired.

When comparing the in-game positive effects the results show that from the four questions, all of them show an increment in participants answering "fairly" and "extremely" in session A. The statement " I enjoyed it " gets 80% of the participants answering "extremely" in session A compared with 20% in session B.

5.8 Post-Game

The next section of the questionnaire intent to evaluate the post-game effects of the ARA (sections, A.5, A.6, A.7), allowing for a better understanding of the possible flow experience of the participants. The statements present in the questionnaire intended to evaluate the positive effects, tiredness, and how difficult it was to return to reality.

Regarding the positive effects participants registered an increased percentage of answers “fairly” and “extremely” in session A compared to session B. The statement “I felt energized” register a considerable difference:

- Session B 20% of the participants reported not feeling energized, another 20% answered “slightly” and 60% answers “moderately energized”.
- Session A had 40% of the participants answering “moderate” and another 40% fairly. 20% reported feeling “extremely energized”.

As shown in the appendix section A.5 the participants felt more satisfied after finishing session A. In both session B and session A sensations of tiredness were small but fewer participants related sensations of tiredness in session A than session B.

Flow can be an intense experience allowing to disconnect from the surroundings (Csikszentmihalyi, 2014) (Sweetser & Wyeth, 2005). Three statements were made to evaluate how difficult it was for participants to return to reality. When participants answer to the following statement “I found it hard to get back to reality (figure, 5.12):

- Session B had more participants feeling that it was easier to return to reality. 80% answers “not at all”, 10% “slightly “and 10% “moderate”.
- Session A had also participants finding it easy to return to reality, with a small increment of participants finding it “moderate” and another finding it “fairly”. The percentages were 70% “not at all”, 20% “moderate”, and 10% “fairly”.

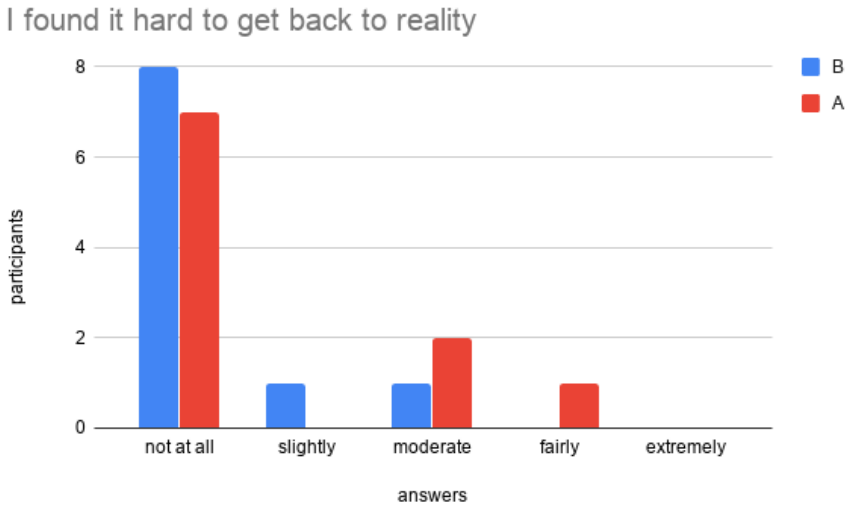

Figure 5.12: Results to the following statement: "I found it hard to get back to reality"

When answering the statement “I felt disoriented” participants’ answers stayed almost the same in both sessions, with 80% choosing “not at all” in both sessions. The last statement introduced analyzed the immersion in the game “I had a sense of returning from a journey” (figure, 5.13):

- Participants in session B answered 30% “not at all”, 60% “slightly”, and 10% “moderate”.
- All the participants in session A had a sense of being in a Journey to some degree. 30% answer “slightly”, 50% “moderate”, 20% “fairly”.

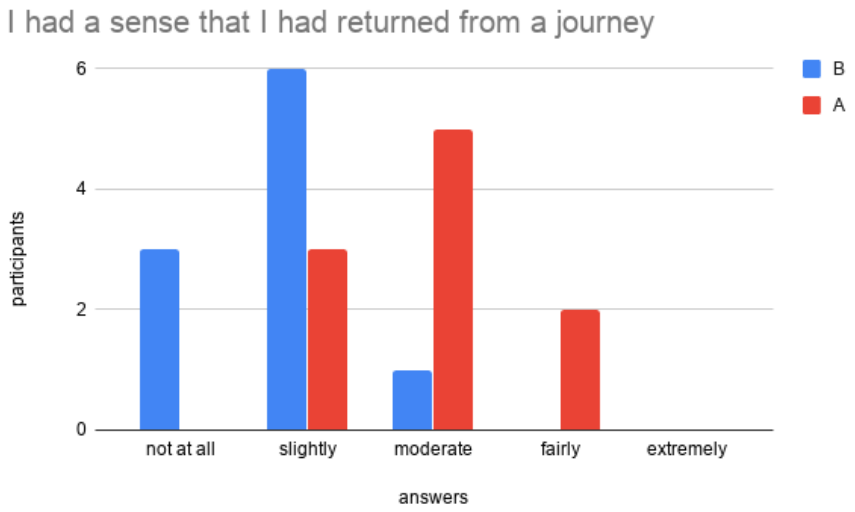

Figure 5.13: Results to the following statement: "I had a sense that I had returned from a journey"

5.9 System Usability

Related to the research questions defined in the section 1.1, statements were added in the questionnaire to understand the impact of the system in the user experience. Five statements were used from the *system usability questionnaire* with five options on a Likert scale. Both sessions had the same setup with participants using the same material. However, in session B no sound was being outputted from the headphones. In session B, the majority of the participants provided neutral answers. Session A presented the participants’ opinions about the usability of the system. The following results are all related to session A. When asked if they like to use the system frequently participants answered:

- 30% answered “neutral”, 40% “agreed” and 30% “strongly agreed”. Participants also reported finding the functions well integrated with 10% “disagreeing", 80% “agreeing”, and 10% “strongly agreeing”.

- When asked if they find the system inconsistent 10% of the participants answered neutral, 60% disagree, and 30% strongly disagree.
- To evaluate if the system was interfering with the gameplay the following statement was used “I found the system very cumbersome to use”, 90% of the participants answered “I disagree” or “strongly disagree”.
- Participants reported confidence using the system with 50% “agreeing” and 30% “strongly agreeing”.

5.10 Results Discussion

As mentioned in this section the tests were made with fewer participants than initially desired due to the COVID-19 pandemic. Although these results seem positive, the interpretation may be subject to further validation in future research due to the low sample size. The interpretation of the results will take into consideration the substantial differences between augmentation and non-augmentation. Minor differences will be discussed only if relevant. Session A refers to the experience with the ARA and session B to the one without it.

The results about flow may suggest that augmented audio can contribute positively to flow. The concentration in the task at hand was increased during the augmented trial. All the participants’ answers in session A revealed a high degree of occupation, suggesting that the virtual elements may help in concentration and focus. The results of absorption and concentration seem to positively correlate with this statement. It is possible that the use of thematic sounds made the game more engaging and gave the players cues that grabbed their attention during the game. Results seem to show that participants did not have different experiences regarding the disconnection from external elements. As this may be seen as a negative result for immersion, this may suggest the presence of the social element that positively correlates with flow. Some comments also suggested that participants needed some time to adjust to listen to their surroundings using headphones. Concerning the possible impact of augmented audio, only one participant reported that he had faced difficulties connecting to others. One result that may show interesting possibilities is that participants enjoyed more to be with others using augmented audio. This can be related to the fact that participants had access to virtual elements that reacted to other players’ choices, possibly making it a more enjoyable social experience.

The answers about the sensory and imaginary experience can reveal if the sound was well integrated into the game and if it allowed for a better immersion during the game. All participants seemed to find that augmented audio enriched the playing experience and enhanced the overall aesthetics of the game. This suggests that the sound design elements respected the overall theme of the game without being intrusive. Besides, a large number of participants answered that they had felt more imaginative during the augmented game than during the non-augmented one.

According to the answers concerning in-game positive and negative emotions, several participants reported to have experienced positive feelings using the augmented version. This may

suggest that they experienced flow during the game. However some increased discomfort caused by the use of augmented audio was sometimes reported. This may be justified by the fact that participants could hear their voice in the headphones with the reverberation of the room I323 in FEUP. Four participants commented on this problem but not to the point of finding it disruptive.

As regards the post-game section of the questionnaire, answers reported very positive results when using augmented audio. Participants felt less tired when compared to the non-augmented version. When asked about the difficulty of getting back to reality, respondents did not report any real trouble. However, the results show that augmented audio may reinforce a sense of journey. These results may be correlated with the answers given to the imaginative and sensory statements.

The system usability strongly suggests that participants revealed interest in continuing using the system and felt confident using it. No major problems were reported, some comments however mention the small delay and reverberation effect on the room. One of the participants mentioned that he felt the game empty without the augmented audio.

As seen in the analysis of the results may be possible to induce flow using augmented audio.

Chapter 6

Conclusions

This thesis intended to evaluate how the use of Augmented audio in board games could induce flow. The research was focused on the main features of board games, the potential of Augmented Reality technologies and the effects of the flow state on the games.

A prototype was designed for applying audio cues during the board game Rising Sun. The implementation needed to have several aspects into consideration, the level of the sounds, the possible delay introduced by Unity, the correct spatialization for sound location, thematic sounds to introduce feedback as well as a layer for the theme of the game and no elements that could disrupt flow.

Although the tests were done with fewer participants than initially planned, the results suggest that using Augmented Audio in board game induced flow in the players. Due to the social interaction available in the game, players' could not disconnect completely from the surroundings. The system usability proved to be mainly positive. It is important however to take in consideration the room acoustics as this can affect user perception. The natural feature method using a webcam can be accessible but at the same time somewhat limited due to the need for good natural features. Spatial audio is an important feature to have in augmented reality audio systems, allowing for localization of other players in the space through their speech. Although first-order Ambisonic was used, higher-orders may deliver different experiences.

To the best of our knowledge this is the first study using augmented audio in board games in order to answer the questions defined in section 1.1. Other Future research may present many possibilities related with the use of Augmented Reality Audio with Modern Board Games.

6.1 Future Work

This study showed promising results for a first exploration of using Augmented Audio with Board Games, and thus further opportunities for research are available. Further research with a bigger

sample size is needed to provide scientific validation of the research question. A higher diversity of genres in the sample should be also used to further prove the results.

Improvements for detection and audio quality can be researched, for example, the possible application of near-field controllers to improve detection. Research and improve a general method to apply augmented audio to multiple board games.

This work explored the incorporation of sound design elements in the game, but the use of music specifically instead of sound effects could have different results in flow. Other concepts related to enjoyment in games can be explored related to the use of augmented audio in board games.

References

Azuma, R. T. (n.d.). *Predictive tracking for augmented reality*. Retrieved from https://www.researchgate.net/figure/Optical-see-through-HMD-conceptual-diagram_fig2_2379978

Azuma, R. T. (1997). A survey of augmented reality. *Presence: Teleoperators & Virtual Environments*, *6*(4), 355–385.

Bauer, V., Nagele, A., Baume, C., Cowlishaw, T., Cooke, H., Pike, C., & Healey, P. G. (2019). Designing an interactive and collaborative experience in audio augmented reality. In *International conference on virtual reality and augmented reality* (pp. 305–311).

Belousov, D. (2019, May). *The complete history of board games.* Retrieved from https://boardgamesland.com/the-complete-history-of-board-games/

Benford, S., Greenhalgh, C., Reynard, G., Brown, C., & Koleva, B. (1998). Understanding and constructing shared spaces with mixed-reality boundaries. *ACM Transactions on computer-human interaction (TOCHI)*, *5*(3), 185–223.

Beseda, J. (2016). *Flow zone factors and different flow zones according to different players*. Retrieved from https://www.researchgate.net/figure/FLOW-ZONE-FACTORS-AND-DIFFERENT-FLOW-ZONES-ACCORDING-TO-DIFFERENT-PLAYERS_fig3_333172490/actions#caption

Booth, P. (2016). Board, game, and media: Interactive board games as multimedia convergence. *Convergence*, *22*(6), 647–660.

Brooks, C. (2015). *Advanced squad leader - the guards counterattack with doug*. Retrieved from https://www.flickr.com/photos/chrisbrooks/23088233021

Calleja, G. (2011). *In-game: From immersion to incorporation*. mit Press.

Chen, J. (2007). Flow in games (and everything else). *Communications of the ACM*, *50*(4), 31–34.

Comparison of several fiducial markers for computer vision by cmg lee. (n.d.). Retrieved from https://commons.wikimedia.org/wiki/File:Comparison_of_augmented_reality_fiducial_markers.svg

Costanza, E., Kunz, A., & Fjeld, M. (2009). Mixed reality: A survey. In *Human machine interaction* (pp. 47–68). Springer.

Cowley, B., Charles, D., Black, M., & Hickey, R. (2008). Toward an understanding of flow in video games. *Computers in Entertainment (CIE)*, *6*(2), 1–27.

Csikszentmihalyi, M. (2014). *Flow and the foundations of positive psychology: The collected works of mihaly csikszentmihalyi.* New York/London: Springer.

Dana, B., & Brown Christopher. (1982). *Computer Vision* (First ed.). New Jersey: Prentice Hall.

Davidson, D., & Costikyan, G. (2011). *Tabletop: Analog game design*. Lulu. com.

Dunnigan, J. F. (2000). *Wargames handbook: How to play and design commercial and professional wargames*. IUniverse.

Eckel, G. (2001). Immersive audio-augmented environments: the listen project. In *Proceedings fifth international conference on information visualisation* (pp. 571–573).

field of view for both eye - human binocular vision. (2014). Retrieved from https://commons.wikimedia.org/wiki/File:FOV_both_eyes.svg

Fonseca, N. (n.d.). *All you need to know about 3d audio*. Retrieved from https://soundparticles.com/resources/ebooks/3daudio/

The four b-format signals convey everything there is to know about the amplitude and direction of acoustic signals arriving at the microphone. (2001). Retrieved from https://www.soundonsound.com/techniques/surround-sound-explained-part-3

Georg neumann ku 100 dummy head. (2011). Retrieved from https://commons.wikimedia.org/wiki/File:Georg_Neumann_Ku_100_Dummy_Head.jpg

Gordon, D. (2013, Oct). *The cardboard republic » risk vs diplomacy.* Retrieved from https://www.cardboardrepublic.com/classics/risk-vs-diplomacy

Guild, C. (2017). *Rising sun board*. Retrieved from https://boardgamegeek.com/image/3468783/rising-sun

Hatala, M., Kalantari, L., Wakkary, R., & Newby, K. (2004). Ontology and rule based retrieval of sound objects in augmented audio reality system for museum visitors. In *Proceedings of the 2004 acm symposium on applied computing* (pp. 1045–1050).

Holo lens 2. (n.d.). Retrieved from https://www.microsoft.com/pt-pt/hololens/developers

Hong, J. Y., He, J., Lam, B., Gupta, R., & Gan, W.-S. (2017). Spatial audio for soundscape design: Recording and reproduction. *Applied sciences*, *7*(6), 627.

An image an the corresponding z-buffer. (2005). Retrieved from https://commons.wikimedia.org/wiki/File:Z-buffer_no_text.jpg

James, W. (1890). The perception of reality. *Principles of psychology*, *2*, 283–324.

Järvinen, A. (2008). *Games without frontiers: Theories and methods for game studies and design*. Tampere University Press.

Jianbo, S., & Tomasi, C. (1994). Good features to track. In *Ieee computer society conference on computer vision and pattern recognition* (pp. 593–600).

Johnson, H. (2004). *The koto: a traditional instrument in contemporary japan*. Hotei Publishing.

Krevelen, R. V. (n.d.). *A survey of augmented reality technologies, applications and limitations - scientific figure on researchgate*. Retrieved from https://www.researchgate.net/figure/Typical-AR-system-framework-tasks_fig2_279867852

Luigi, R. P. (2005). *The picture show the map of a dungeons and dragons game,*. Retrieved from https://commons.wikimedia.org/wiki/File:Dungeons_and_Dragons_game.jpg

Maad, S. (2010). *Augmented reality*. BoD–Books on Demand.

Mariette, N. (2007). From backpack to handheld: the recent trajectory of personal location aware spatial audio. In *Perthdac 2007: Proceedings of the 7th digital arts and culture conference. curtin university of technology, perth* (pp. 233–240).

Mey, J. (n.d.). *Classical board game "go"*. Retrieved from https://www.needpix.com/photo/download/1504398/go-strategy-gogame-goboard-baduk-weichi-finished-go-game-free-pictures-free-photos

Milgram, U.-K., Takemura. (2011). *Reality-virtuality continuum in according to milgram, takemura, utsumi and kishino (1994).* Retrieved from https://commons.wikimedia.org/wiki/File:Reality-Virtuality_Continuum.svg?wprov=srpw1_2

Most funded tabletop games. (n.d.). Retrieved from https://www.kickstarter.com/discover/advanced?category_id=34&sort=most_funded&seed=2664861&page=1

Nah, F. F.-H., Eschenbrenner, B., Zeng, Q., Telaprolu, V. R., & Sepehr, S. (2014). Flow in gaming: literature synthesis and framework development. *International Journal of Information Systems and Management*, *1*(1-2), 83–124.

Orbit, A. (n.d.). Approaching Static Binaural Mixing with AMBEO Orbit. , 1–21.

Parlett, D. (1999). *The oxford history of board games*. Oxford University Press, USA.

Piccione, P. A. (2007). The egyptian game of senet and the migration of the soul. *Ancient Board Games in Perspective, Ancient Board Games in Perspective*, 54–63.

Piumsomboon, T., Clark, A., & Billinghurst, M. (2011). Physically-based interaction for tabletop augmented reality using a depth-sensing camera for environment mapping. *Proc. Image and Vision Computing New Zealand (IVCNZ-2011)*, 161–166.

Playing cards board games market size worth $21.56 billion by 2025: Grand view research, inc. (2020, Sep). Bloomberg. Retrieved from https://www.bloomberg.com/press-releases/2019-10-09/playing-cards-board-games-market-size-worth-21-56-billion-by-2025-grand-view-research-inc

The political mandates of rising sun. (n.d.). Retrieved from https://www.ungeek.ph/2017/03/with-every-alliance-theres-always-an-inevitable-betrayal-rising-sun-overview/

Rämö, J., & Välimäki, V. (2012). Digital augmented reality audio headset. *Journal of Electrical and Computer Engineering*, *2012*.

Rising sun player aid. (n.d.). Retrieved from https://ludopedia.com.br/topico/21744/rising-sun-nao-e-apenas-um-blood-rage-no-japao

Rupert, N. (2008). *Magic the gathering cards*. Retrieved from https://www.flickr.com/photos/nathaninsandiego/2711372623

RØde nt-sf1. (n.d.). Rode Microphones. Retrieved from https://cdn2.rode.com/images/ntsf1/ntsf1_mic_mobile.png

Schmalstieg, D., & Hollerer, T. (2016). *Augmented reality: principles and practice*. Addison-Wesley Professional.

Sweetser, P., & Wyeth, P. (2005). Gameflow: a model for evaluating player enjoyment in games. *Computers in Entertainment (CIE)*, *3*(3), 3–3.

Teburu: A new evolution in board games. (2019). CMON.inc. Retrieved from https://www.cmon.com/news/teburu-a-new-evolution-in-board-games

Tikander, M., Karjalainen, M., & Riikonen, V. (2008). An augmented reality audio headset. In *Proc. of the 11th int. conf. on digital audio effects (dafx-08), espoo, finland.*

Tilt five. (n.d.). Retrieved from https://www.engadget.com/2019-09-24-tilt-five-kickstarter-hands-on.html

Turkay, S., Adinolf, S., & Tirthali, D. (2012). Collectible card games as learning tools. *Procedia-Social and Behavioral Sciences*, *46*, 3701–3705.

Van Krevelen, D., & Poelman, R. (2010). A survey of augmented reality technologies, applications and limitations. *International journal of virtual reality*, *9*(2), 1–20.

Vazquez-Alvarez, Y., Oakley, I., & Brewster, S. A. (2012). Auditory display design for exploration in mobile audio-augmented reality. *Personal and Ubiquitous computing*, *16*(8), 987–999.

Woods, S. (2012). *Eurogames: The design, culture and play of modern european board games*. McFarland.

Xie, B. (2013). *Head-related transfer function and virtual auditory display*. J. Ross Publishing.

Yonghokim. (2019). *A game of settlers of catan*. Retrieved from https://commons.wikimedia.org/wiki/File:A_game_of_Settlers_of_Catan.jpg

Zhang, W., Samarasinghe, P. N., Chen, H., & Abhayapala, T. D. (2017). Surround by sound: A review of spatial audio recording and reproduction. *Applied Sciences*, *7*(5), 532.

Appendix A

User results

A.1 Sensory and Imaginative immersive statements

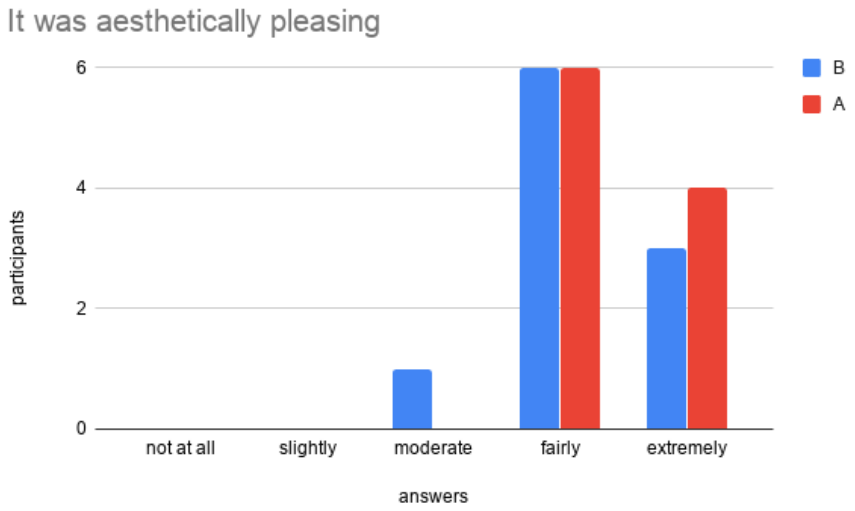

Figure A.1: Results to the following statement: "It was aesthetically pleasing"

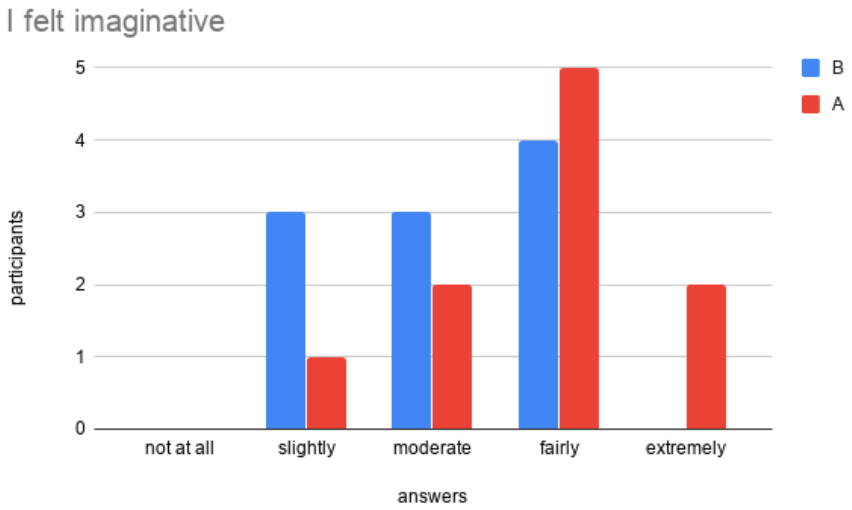

Figure A.2: Results to the following statement: "I felt imaginative"

A.2 Tension and annoyance

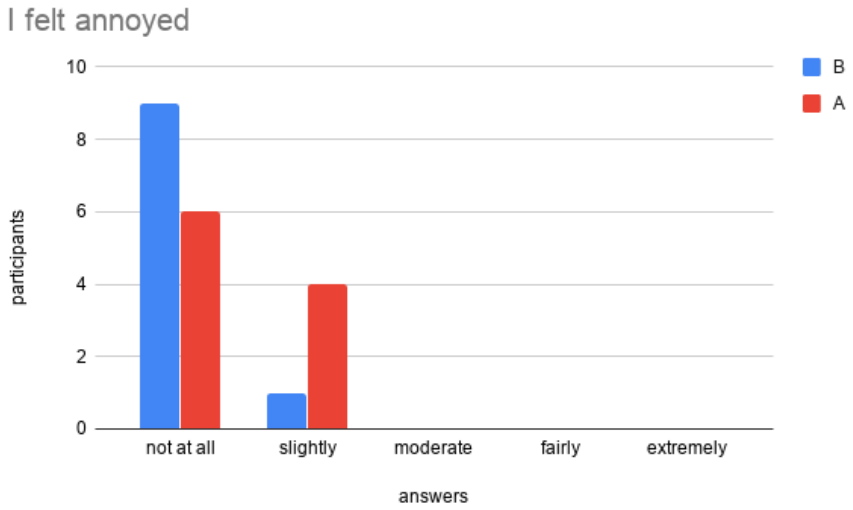

Figure A.3: Results to the following statement: "I felt annoyed"

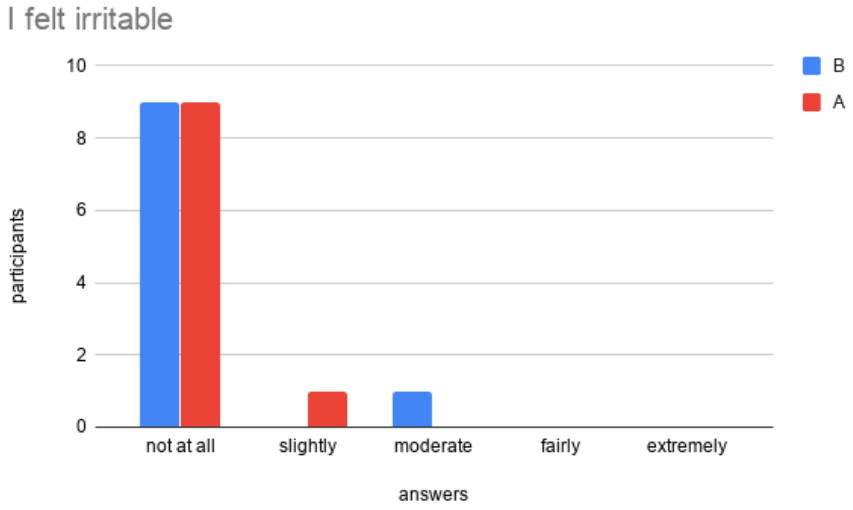

Figure A.4: Results to the following statement: "I felt irritable"

A.3 negative effects

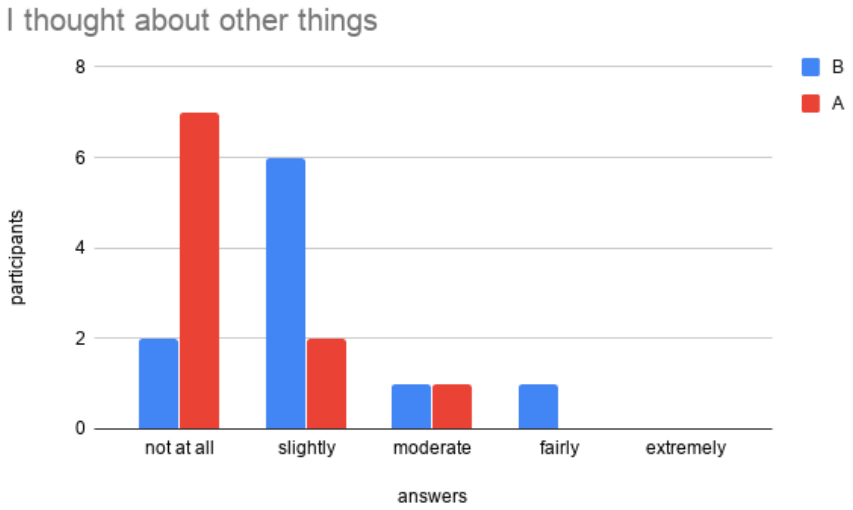

Figure A.5: Results to the following statement: "I thought about other things"

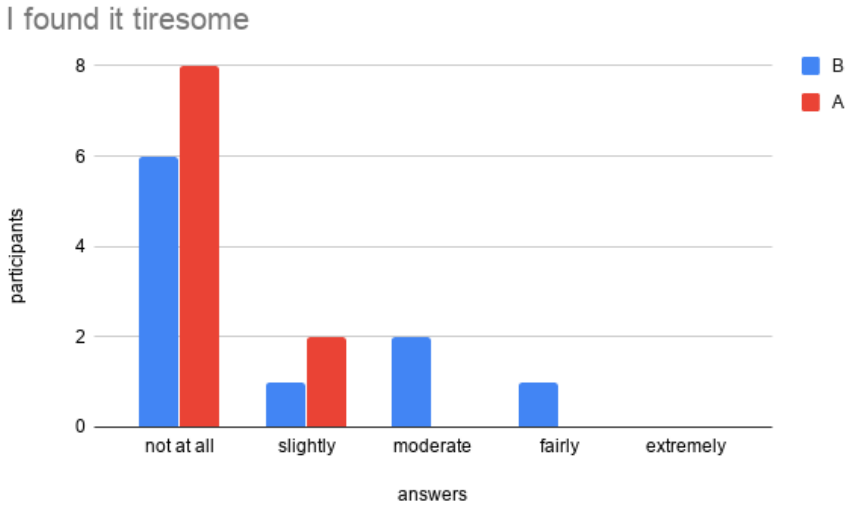

Figure A.6: Results to the following statement: "I found it tiresome"

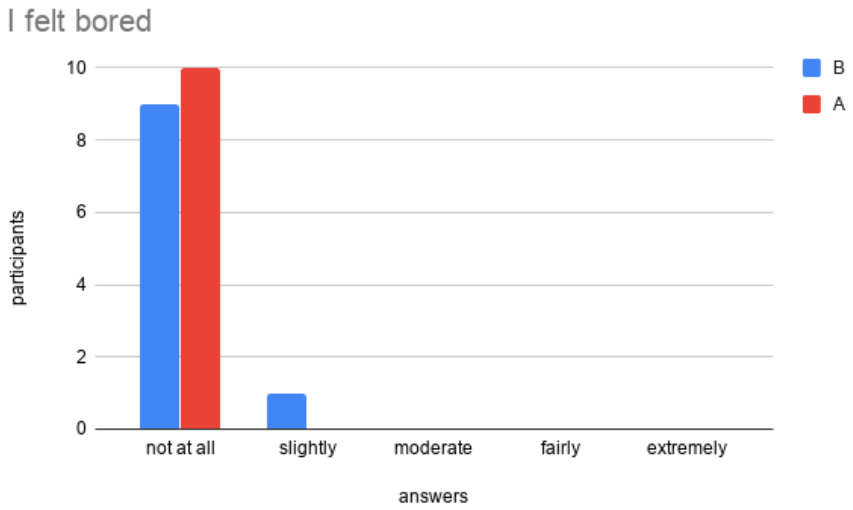

Figure A.7: Results to the following statement: "I felt bored"

A.4 positive effects

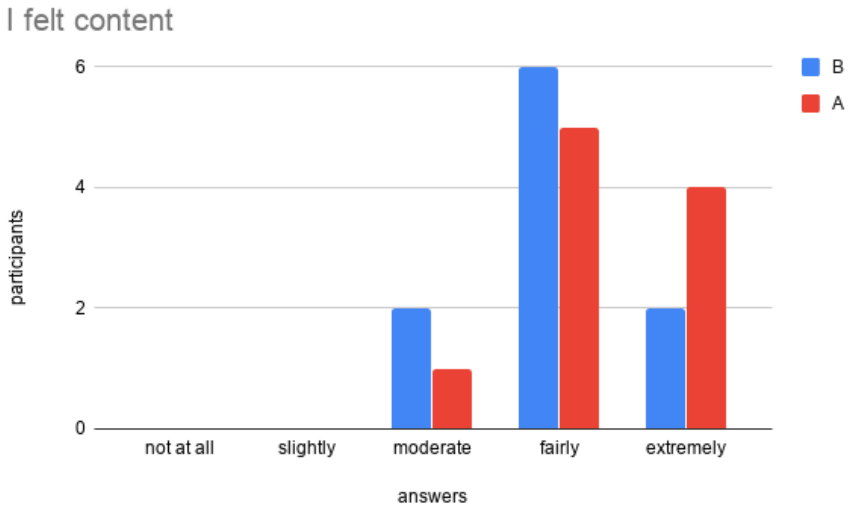

Figure A.8: Results to the following statement: "I felt content"

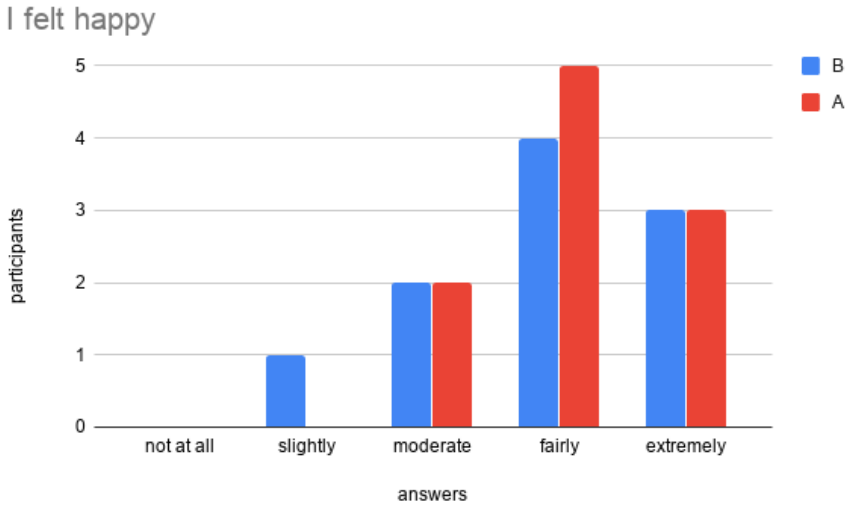

Figure A.9: Results to the following statement: "I felt happy"

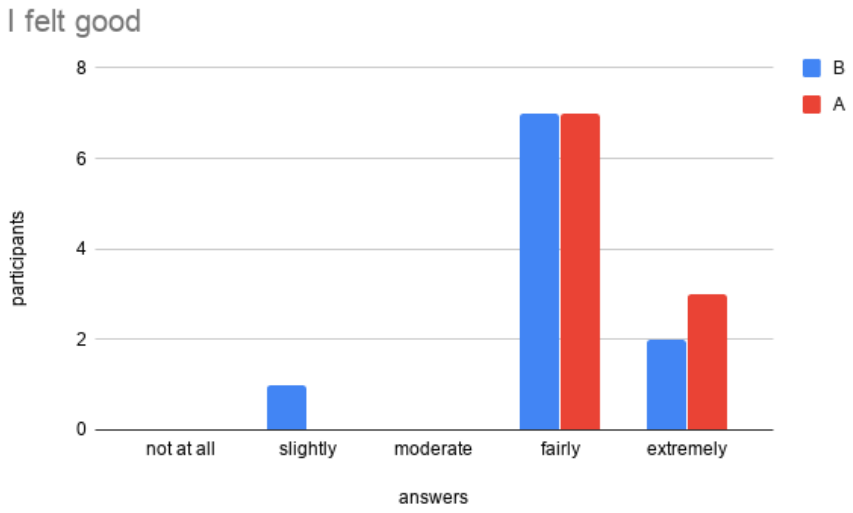

Figure A.10: Results to the following statement: "I felt good"

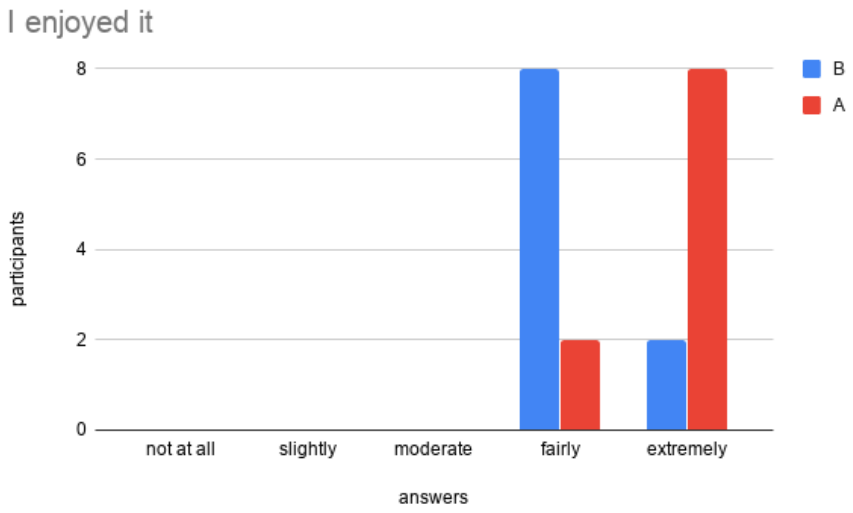

Figure A.11: Results to the following statement: "I enjoyed it"

A.5 Post-game Positive effects

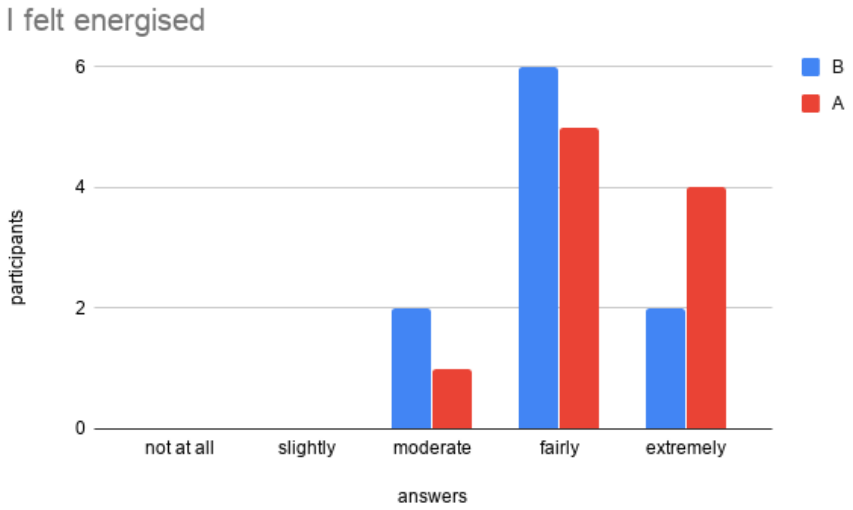

Figure A.12: Results to the following statement: "I felt energised"

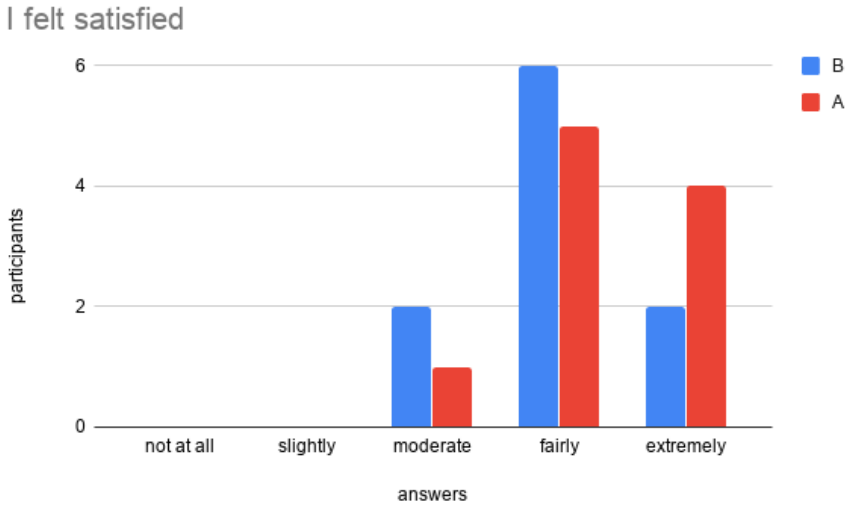

Figure A.13: Results to the following statement: "I felt satisfied"

A.6 Post-game Tiredness

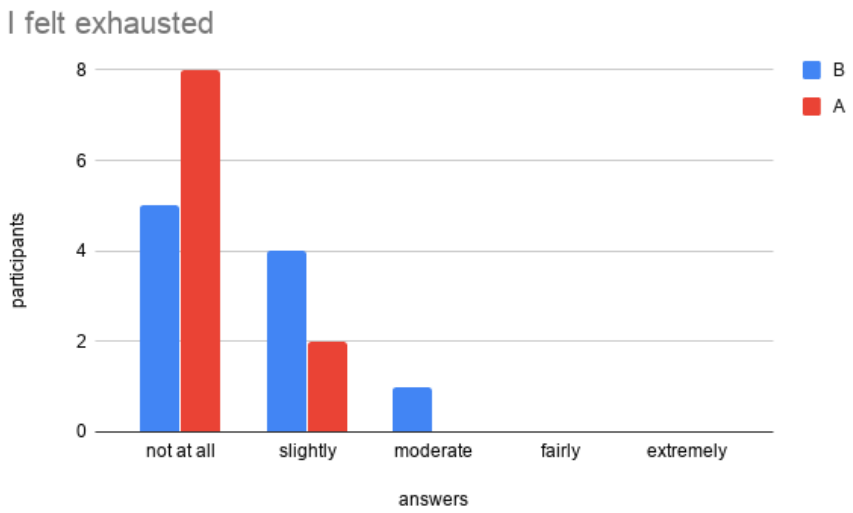

Figure A.14: Results to the following statement: "I felt exhausted"

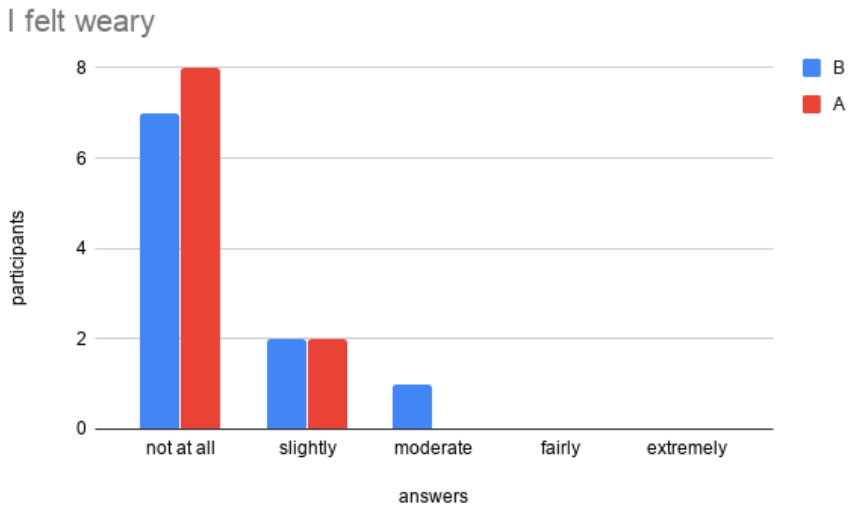

Figure A.15: Results to the following statement: "I felt weary"

A.7 Back to reality

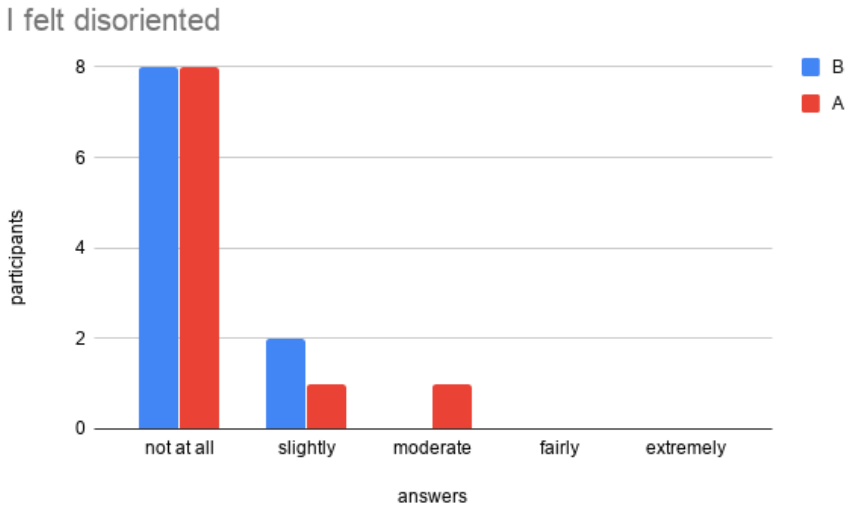

Figure A.16: Results to the following statement: "I felt disoriented"

A.8 System usability

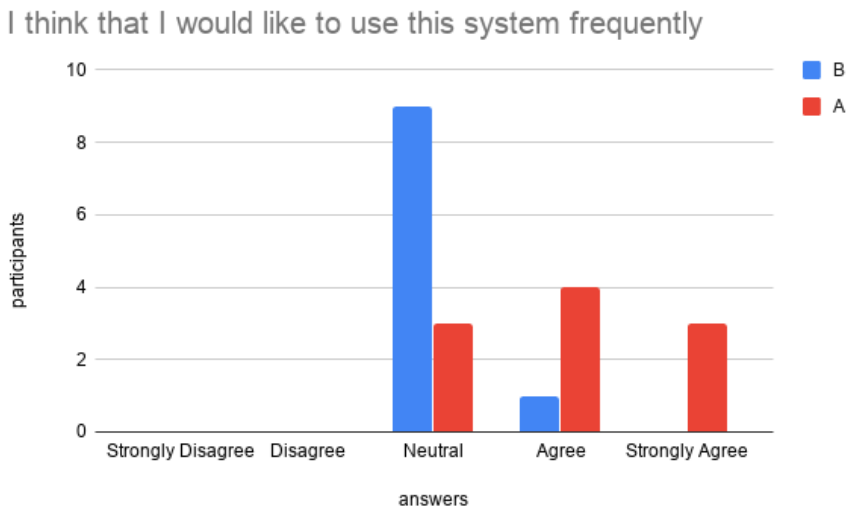

Figure A.17: Results to the following statement: "I think that I would like to use this system frequently"

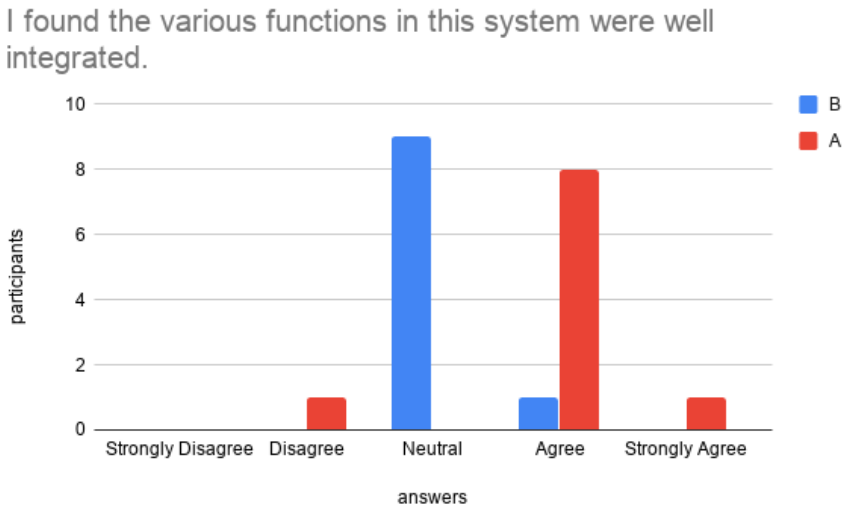

Figure A.18: Results to the following statement: "I found the various functions in this system were well integrated"

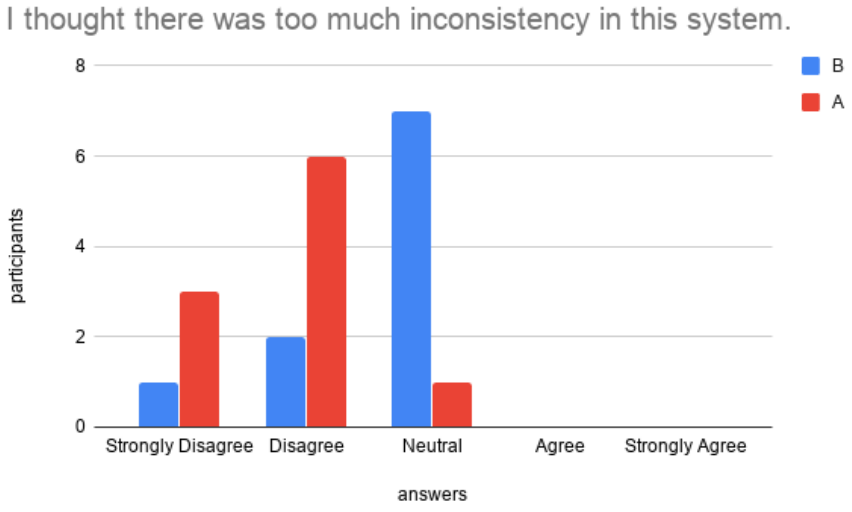

Figure A.19: Results to the following statement: "I thought there was too much inconsistency in this system"

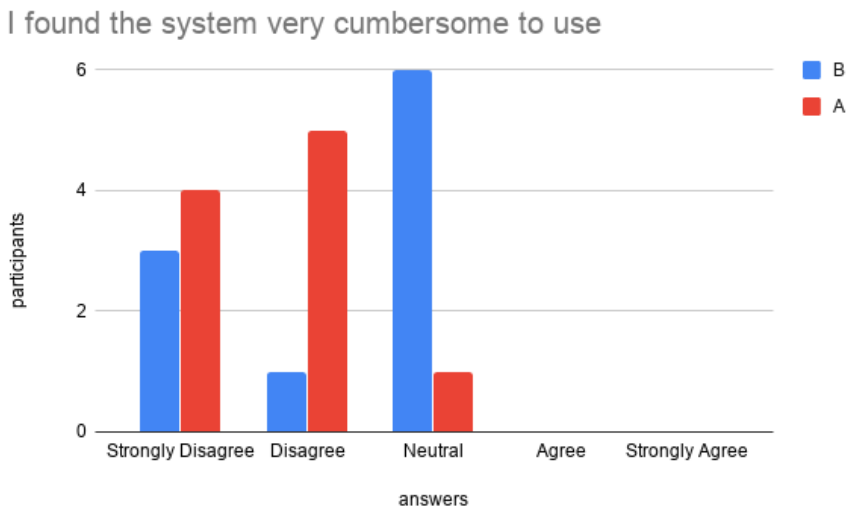

Figure A.20: Results to the following statement: "I found the system very cumbersome to use"

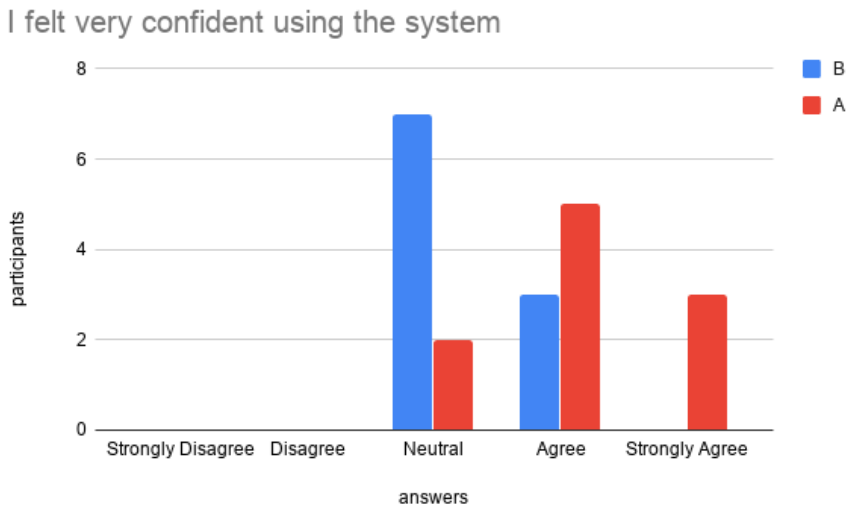

Figure A.21: Results to the following statement: "I felt very confident using the system"

Appendix B

Questionnaires

B.1 Questionnaire Augmented Audio

Questionnaire - A (ENG)

This questionnaire pretend to evaluate your experience during the game. The questionnaire will have two parts, one about your experience in the game and the other about the system. Please fill all the questions.

Thank you for your time.

General Information

1. Genre

Mark only one oval.

- ◯ Masculine
- ◯ Feminine
- ◯ Other

2. Educational level

Mark only one oval.

- ◯ Ensino Básico
- ◯ Ensino secundário
- ◯ Ensino pós-secundário não superior
- ◯ Ensino Superior

3. How often do you play board games weekly

Mark only one oval.

- ◯ 0 to 2
- ◯ 2 to 5
- ◯ 5 to 10
- ◯ more than 10

4. How many times you played Rising Sun

Mark only one oval.

- 0 to 2
- 3 to 5
- 6 to 10
- more than 10

5. Experience with Augmented Reality

Mark only one oval.

- None
- Very little
- Some
- A lot

Game Experience

6. I was fully occupied with the game.

Mark only one oval.

- not at all
- slightly
- moderately
- fairly
- extremely

7. I forgot everything around me.

   Mark only one oval.

   - not at all
   - slightly
   - moderately
   - fairly
   - extremely

8. I lost track of time.

   Mark only one oval.

   - not at all
   - slightly
   - moderately
   - fairly
   - extremely

9. I was deeply concentrated in the game

   Mark only one oval.

   - not at all
   - slightly
   - moderately
   - fairly
   - extremely

10. I lost connection with the outside world

Mark only one oval.

- not at all
- slightly
- moderately
- fairly
- extremely

11. I felt completely absorbed

Mark only one oval.

- not at all
- slightly
- moderately
- fairly
- extremely

12. It was aesthetically pleasing

Mark only one oval.

- not at all
- slightly
- moderately
- fairly
- extremely

13. I felt imaginative

Mark only one oval.

- not at all
- slightly
- moderately
- fairly
- extremely

14. It felt like a rich experience

Mark only one oval.

- not at all
- slightly
- moderately
- fairly
- extremely

15. I felt annoyed

Mark only one oval.

- not at all
- slightly
- moderately
- fairly
- extremely

16. I felt irritable

Mark only one oval.

- not at all
- slightly
- moderately
- fairly
- extremely

17. I thought about other things

Mark only one oval.

- not at all
- slightly
- moderately
- fairly
- extremely

18. I found it tiresome

Mark only one oval.

- not at all
- slightly
- moderately
- fairly
- extremely

19. I felt bored

Mark only one oval.

- not at all
- slightly
- moderately
- fairly
- extremely

20. I felt content

Mark only one oval.

- not at all
- slightly
- moderately
- fairly
- extremely

21. I felt happy

Mark only one oval.

- not at all
- slightly
- moderately
- fairly
- extremely

22. I felt good

Mark only one oval.

- not at all
- slightly
- moderately
- fairly
- extremely

23. I enjoyed it

Mark only one oval.

- not at all
- slightly
- moderately
- fairly
- extremely

24. I felt connected to the other(s)

Mark only one oval.

- not at all
- slightly
- moderately
- fairly
- extremely

25. I found it enjoyable to be with the other(s)

Mark only one oval.

- not at all
- slightly
- moderately
- fairly
- extremely

26. I was influenced by the other(s) moods

Mark only one oval.

- not at all
- slightly
- moderately
- fairly
- extremely

27. I felt energised

Mark only one oval.

- not at all
- slightly
- moderately
- fairly
- extremely

28. I felt satisfied

Mark only one oval.

- not at all
- slightly
- moderately
- fairly
- extremely

29. I felt exhausted

Mark only one oval.

- not at all
- slightly
- moderately
- fairly
- extremely

30. I felt weary

Mark only one oval.

- not at all
- slightly
- moderately
- fairly
- extremely

31. I found it hard to get back to reality?

Mark only one oval.

- not at all
- slightly
- moderately
- fairly
- extremely

32. I felt disoriented?

Mark only one oval.

- not at all
- slightly
- moderately
- fairly
- extremely

33. I had a sense that I had returned from a journey?

Mark only one oval.

- not at all
- slightly
- moderately
- fairly
- extremely

System experience

34. I think that I would like to use this system frequently.

Mark only one oval.

- Strongly Disagree
- Disagree
- Neutral
- Agree
- Strongly Agree

35. I found the various functions in this system were well integrated.

Mark only one oval.

- Strongly Disagree
- Disagree
- Neutral
- Agree
- Strongly Agree

36. I thought there was too much inconsistency in this system.

Mark only one oval.

- Strongly Disagree
- Disagree
- Neutral
- Agree
- Strongly Agree

37. I found the system very cumbersome to use

Mark only one oval.

- Strongly Disagree
- Disagree
- Neutral
- Agree
- Strongly Agree

38. I felt very confident using the system

Mark only one oval.

- Strongly Disagree
- Disagree
- Neutral
- Agree
- Strongly Agree

39. Comments (Not mandatory)

Appendix C

Consent forms

User Experiences' Consent Forms

Declaração de consentimento

No âmbito da realização da tese de Mestrado de Multimédia da Faculdade de Engenharia da Universidade do Porto, intitulada **Inducing Flow in Board Games towards Augmented Audio**, realizada pelo estudante André Emanuel Afonso Gustavo de Sousa, orientada pelo Prof. João Jacob e sob co-orientação do Prof. Eduardo Magalhães, eu abaixo assinado _____, declaro que compreendo a explicação que me foi fornecida acerca do estudo no qual irei participar, nomeadamente o carácter voluntário dessa participação, tendo-me sido dada a oportunidade de fazer as perguntas que julguei necessárias.

Tomei conhecimento da informação sobre os objetivos, métodos e a ausência de risco para a minha saúde e que está assegurada a máxima confidencialidade dos dados.

Explicaram-me que me devo manter presente durante todo o estudo.

Por isso, consinto participar no estudo e na recolha de imagens necessárias respondendo a todas as questões propostas

Porto,___de_____de 2020

(Participante)