Master's thesis

**NTNU**
Norwegian University of Science and Technology
Faculty of Information Technology and Electrical Engineering
Department of Computer Science

Sondre Schirmer-Mikalsen

# Evaluating the Usability and User Experience of XR Augmented Board Games with Physical Interfaces

Master's thesis in Informatics
Supervisor: Dag Svanæs
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# Sammendrag

Denne avhandlingen utforsker utviklingen av en prototypet brettspillapplikasjon i utvidet virkelighet (Extended Reality, XR) ved bruk av skjermbriller (head-mounted displays). Hovedfokuset i oppgaven er knyttet til å analysere resultater og observasjoner fra en kvalitativ brukertest (n = 12), hvor testbrukerne utforsket forskjellige måter å flytte på virtuelle brettspillbrikker. Dette inkluderer to forskjellige mekanismer som muliggjør flytting av virtuelle brikker både med og uten bruk av fysiske brikker, for å se nærmere på hvordan taktilitet (det å fysisk kjenne brikkene) påvirker brukbarheten og spillopplevelsen. Applikasjon er designet slik at brukere kan instansiere (lage) et virtuelt sjakkbrett og plassere det på et fysisk sjakkbrett, slik at brukerne kan flytte på fysiske og korresponderende virtuelle brikker samtidig. Dette ble muliggjort ved å implementere en løsning for manuell ankring av virtuelle sjakkbrett, hvor man kan opprette et virtuelt sjakkbrett og bestemme brettets størrelse og posisjon slik at det samsvarer med det fysiske sjakkbrettet. Dette gjør at man kan flytte på fysiske og virtuelle brikker samtidig, uten bruk av gjenstandsdeteksjon eller elektroniske spillbrett. Denne oppgaven utforsker brukbarheten, potensialet og begrensningene med med denne tilnærmingen. I tillegg blir andre faktorer som potensielt kan ha en påvirkning på brukeropplevelsen og det sosiale aspektet ved brettspill testet, analysert og diskutert gjennom prototypen. Dette inkluderer sammenligning av brukeropplevelsen i virtuell virkelighet (VR) og augmentert virkelighet (AR), samt å studere effekten av digitale avatarer på sosial tilstedeværelse og fordypning i spillet. Til slutt ble dataen som ble samlet fra brukertestene gjennom intervjuer og observasjoner analysert og diskutert for å skaffe verdifulle innsikter knyttet til brukervennlighet, brukeropplevelse og potensielle områder for forbedring i forbindelse med design og utvikling av brettspill i utvidet virkelighet.

# Abstract

This thesis explores the design, creation, and use of a prototype application developed with the purpose of creating a tabletop playing experience for extended reality (XR) using head-mounted displays (HMDs). The main research focus is related to analyzing results and observations from a qualitative user test (n = 12), where test participants explored different ways of moving virtual board game pieces. This includes two different methods of moving virtual pieces, each of which were tested with and without physical pieces, to compare the effect tactility has on the usability and user experience. The application was designed to enable users to spawn a virtual chessboard and pieces on top of a physical chessboard, allowing them to move physical and virtual pieces simultaneously. This was made possible by manually anchoring the virtual gameboard to the physical gameboard, without relying on object recognition or electronic gameboards or pieces. The thesis explores the usability, potential and limitations of this approach. Moreover, other factors that was considered to potentially have an impact on the user experience and social presence while playing board games with XR is tested, analyzed and discussed. This includes studying and comparing the playing experience in virtual reality (VR) and augmented reality (AR) environments and studying the effect of digital avatars on the social presence and immersion. Finally, the data gathered from interviews and observations was analyzed to gain valuable insights into the usability, user experience, and potential areas for improvement in XR board game design and implementation.

# Acknowledgements

I would like to thank my supervisor, professor Dag Svanæs at the Department of Computer Science at the Norwegian University of Science and Technology (NTNU). Your support and enthusiasm for the project in the past year has been encouraging, and i am thankful for the guidance you have given me.

I would also like to thank Nicolai André Daalaker for collaborating with me during the preparatory project for this thesis, and for his significant role in the development of the prototype application. It was a pleasure working with you.

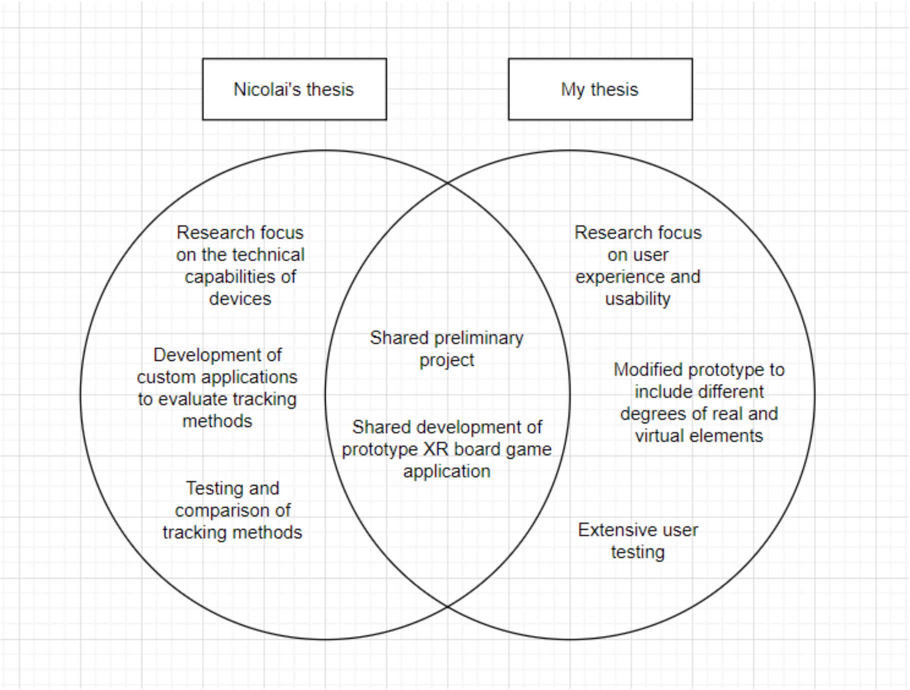
Finally, I would like to thank Terje Røsand at the Department of Computer Science at NTNU, for the help i received when preparing for the user tests. You were very helpful by giving me access to the UX Lab for the tests, and for learning me how to use the recording equipment.

# Previous and Shared Work

In the preparatory project for the master thesis, I collaborated with Nicolai André Dalaaker, a fellow Informatics student at NTNU, with exploring potential research areas related to augmented board games and XR technology. We collaborated on a preparatory project report, in which we explored relevant technologies, and started discussing research questions. Parts of section 1-4 (Introduction, Literature Review, Methodology and Technology) in this thesis are based on or copied from the preparatory project report. Hence, some of these sections might overlap with the report, and some parts may overlap with his master thesis.

While we shared the similar vision of wanting to develop a prototype XR board game application, our research focus differed. For this reason, we developed the prototype application together, but went in separate directions once it was completed. While I focused on the usability and user experience of the XR prototype board game application, Nicolai focused on exploring technical aspects related to the problem of tracking physical objects and representing them virtually in XR.

During the development of the prototype application, Nicolai was in charge of enabling cross-platform development, and the manual anchoring process of the virtual board. For this reason, i will not focus on explaining how this was implemented. In the development of the application, some of my main contributions include setting up the multiplayer system, creating the GUI interface used to setup and configure application settings, and creating the digital avatars for player representation.



# Table of Contents

# List of Figures

# List of Tables

# 1 Introduction

The emergence of Extended Reality (XR) technology in recent years has transformed the way people interact with digital content. Through combining digital elements with the physical world, they can offer new possibilities for gameplay and entertainment by blurring the boundaries between the real and the virtual world. The focus of this thesis was to explore the realm of augmented board games with XR technology. Augmented board games utilize digital technology to enhance traditional tabletop board games, and can introduce many new features that board games cannot produce by themselves, such as adding visual effects and facilitating remote multiplayer possibilities.

The employed research strategy in the thesis was design and creation. A prototype XR application was developed, featuring an implementation of chess. The prototype was developed as a means of exploring the usability and user experience of XR board game applications. The main feature evaluated was a novel feature that enables players to spawn a virtual gameboard with pieces on top of a physical gameboard, emulating the function of a 'digital twin', and adding a tactile element to XR board games. Two different mechanisms for moving the virtual and physical pieces simultaneously were developed, and these mechanisms were tested by users both with and without physical pieces. The usability and user experience of these approaches was measured, compared and analyzed. Additionally, the impact of visual environments on the social presence and immersion during XR board game play was evaluated using the prototype. The usability and user experience evaluation was performed through analyzing results from a qualitative user test, in which test participants played against each other while testing a variety of metrics. The data generation method was mixed, using a combination of observation and interviews.

Figure 1: Image from prototype user test

Figure 2: View of virtual environment in the prototype application, with an avatar representing each player

## 1.1 Background

### 1.1.1 Tabletop Gaming

Tabletop gaming has been a popular social activity for centuries. While board games are typically used for entertainment purposes, they can also bring value through fostering cognitive development, problem-solving capabilities and developing social connections between people. The effects and benefits of board games have been studied in many contexts and demographics. Some board games have been designed as learning tools for students and employees, and have proved to be significantly more effective than using more traditional learning methods, such as lecturing and reading [1]. Other studies indicate a possible beneficial effect on the risk of dementia among regular board game players [2], and considerable effectiveness on developing social skills among children [3].

While it would be reasonable to think that the popularity of board games has taken a hit due to the emergence of digital gaming over the past few decades, the board game industry is in fact growing. According to Statista, the estimated annual revenue growth rate of board game sales in the U.S between 2022 and 2027 is 9.31% [4]. Board games can be a valuable tool for researching a variety of topics, including game design, user experience design, psychology, sociology and education, and can be used to gain insights into how people learn, strategize, and interact with one another in complex situations.

### 1.1.2 Digital Gaming

Digital gaming has become an increasingly important part of modern society. In 2020, "playing games and computer use for leisure" was ranked as the second most popular leisure activity in the United States, above other activities such as socializing, exercising and reading [5]. This growing impact and prevalence of video games have prompted the need for research to understand their effect on individuals and society as a whole, which can be approached from various academic perspectives and fields, including behavioral psychology, sociology, and software development. Although video games share some common traits with board games, the capabilities of digital technology have also introduced an entirely different source of entertainment. Video games allow players to immerse themselves into virtual worlds, and engage players more deeply in the gameplay through the use of visual and audio effects. A number of studies have shown that playing video games evokes strong positive emotions and can improve players' mood and promote relaxation [6]. Whereas traditional tabletop gaming is reliant on players being co-located, digital gaming has made it possible for players to play with and against each other remotely. These factors, along with the accessibility and convenience of video games, have contributed greatly to its massive rise in popularity in recent years.

### 1.1.3 Direction of the Video Game Industry

Since the construction and release of the world's first computer game *Spacewar* in 1962 [7], the video game industry has undergone several significant transformations which were both a consequence of, and a cause of rapid improvements in technology. Examples of this include the shift from 2D to 3D graphics, the rise of online and multiplayer games, and the shift towards mobile game development since the introduction of smart phones and tablets. Today, console, pc and mobile games are dominating the market share in the industry. However, it is believed that the emergence and development of virtual and augmented reality technologies will shape the future of gaming by offering players more interactive and immersive experiences [8][9].

### 1.1.4 Extended Reality

The emergence of Extended Reality (XR) technology in recent years have transformed the way people interact with digital content. XR is an umbrella term that encompasses Virtual Reality (VR), Augmented Reality (AR) and Mixed Reality (MR). These technologies combine digital elements with the physical world, and provide more immersive and natural experiences to its users compared to using traditional 2D displays. Advancements in hardware and software have made XR devices increasingly more powerful and accessible for the public. In 2020, the total number of XR device shipments surpassed 7 million, and the number is rapidly increasing, with Statista estimating that more than 100 million devices have been shipped by 2025 [10].

### 1.1.5 Mixed, Virtual and Augmented Reality

Before going any further, definitions for mixed reality (MR), virtual reality (VR) and augmented reality (AR) will be introduced. These terms do not have universal definitions, and many experts within the field use the terms in different ways. Speicher, Hall and Nebeling [11] gathered and categorized qualitative data through interviews with prominent researchers and literature in an attempt to develop a shared understanding of the terms, and this forms the base of the definitions used in this thesis.

Milgram et al. [12] developed the *Reality-Virtuality Continuum* in the 90s as a means to facilitate a better understanding of AR, VR, MR and the differences between them. This continuum is a spectrum, where one extrema is the fully real environment (the real world), and the other represents a fully virtual environment. They defined everything in between to be within the scope of XR. In AR, the visual environment is closely associated with the real world, but incorporates an of overlay of digital elements on top. On the other hand, the visual environment in VR is fully virtual. MR blends the physical and virtual environment similarily to AR, but in MR, the physical and virtual elements can interact.

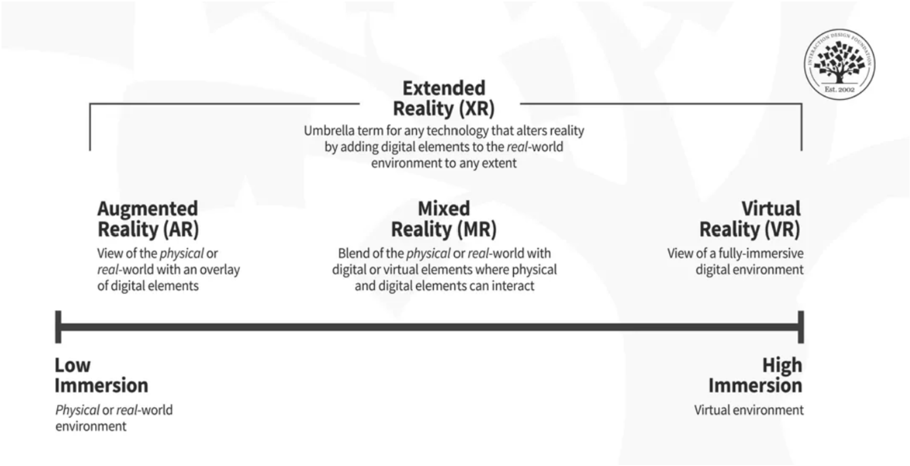


Figure 3: Representation of the Reality-Virtuality Continuum. Source: [13]

AR combines the real world with virtual elements. Generally, most of the environment consists of real, physical objects, but 3D graphics are added on top to display virtual objects. AR devices are dependent on the user being able to see the real world, either through glasses or through cameras which display the world on a screen.

While experts struggle to agree on what constitutes AR, the general definition of VR is more defined [11]. In VR, the environment, including the visual display and audio, is entirely synthetic. VR requires head-mounted displays so that the real world is not visible.

An important term in the extended reality field is *immersion*. Being immersed refers to the feeling or sensation of being involved in an experience [14]. Immersion can refer to both mental and physical immersion [15]. In Milgram's reality-virtuality continuum (figure 3), the real-world environment is associated with a low level of immersion, and the fully virtual environment is associated with a high level of immersion.

Mental immersion is the general state of mind where one feels deeply engaged or involved with something. This can include being deeply engaged in an activity, such as watching a movie, a football game, or playing video games.

In contrary, being physically immersed refers to the sense of being physically involved with the environment. Sherman and Craig [16] refer to this type of immersion as being physically surrounded by stimuli with the goal to achieve mental immersion. Physical immersion is much more highlighted when playing games using XR devices compared to playing computer or console games, where mental immersion is the main focus. In XR, physical immersion can be achieved through visual effects or through the use of motion tracking, e.g. to enable the user to interact with virtual objects or walk around in a virtual environment. Modern mixed reality devices also support head-mounted displays that keep track of the users' direction of view, which enhances the feeling of being physically present in the environment.

Another term associated, and often mistakenly used interchangeably with physical immersion is presence. Presence is more related to the users' state of mind, and refers to the subjective sensation and experience of "being there". While physical immersion primarily relies on the physical environment and sensory stimuli, presence is more related to the psychological and perceptual aspects of the user's experience [17].

### 1.1.6 Augmented Board Games

The advancements in XR technology has opened up new doors for what such technology can be used for. This includes the creation and development of "augmented board games". Peitz et al. [18] defines augmented board games as "using computational power to extend functionality and gameplay in board games". Augmented board games utilize digital technology to enhance their gameplay and provide new ways to interact with tabletop board games.

While augmented board games have yet to reach mainstream popularity, it has become an increasingly popular topic in the field of human-computer interaction. Researchers have especially taken interest in the idea of combining the physicality and social interaction of traditional board games with the interactivity and dynamic elements that digital tecnology can provide. One example is IncreTable [19], where players combine using virtual and physical pieces on a projection screen to solve puzzles in the game. Other augmented board games has a more clear distinction between the digital and virtual elements. For instance, De Boer et al. [20] developed an electronic augmentation of the popular board game "Settlers of Catan", where LED-displays were used to randomize the board state by automation, but there was no direct link between the physical and virtual elements.

Figure 4: IncreTable, an augmented board game which combines the use of virtual and physical elements. Source: [19]

## 1.2 Motivation and Research Gap

Many augmented board games have been developed for research purposes (covered in section 2). A central aspect of many of these games is the way in which the gameplay combines using tangible interfaces such as physical pieces and physical boards with virtual elements. While several of these implementations have received positive feedback, they do have some limitations. Most existing augmented board games use 2D screens to display digital content on a physical table. This limits the possibilities of creating immersive gaming experiences. The presence (sense of being in an environment) in 2D virtual environments is limited, and research shows that the 3D environments that can be experienced with XR technology significantly enhances the presence in comparison [21].

With respect to the moving game objects and pieces in augmented board games, most existing games distinguish between the physical and virtual game elements, often by using physical pieces to interact with a virtual gameboard through using some sensing mechanism, such as radio frequency identification (RFID), electronic gameboards or camera recognition to provide input to the computer devices [22]. The pieces are used as input for a computer or hand-held devices, which use the information to display visual effects or add virtual elements on a digital display (often a shared gameboard). Although it is possible to facilitate mixed reality experiences this way, there is still a clear distinction between the physical elements (the pieces) and the virtual content.

The rapid advancements in XR technology in recent years have opened up new possibilities for what this technology can be used for. VR and AR headsets such as the Meta Quest 2 and Microsoft Hololens 2 now support hand-tracking, which makes it possible for users to interact with virtual 3D elements solely by using their hands, as hands can be represented virtually [23]. In the context of augmented board games, this can potentially help narrow the gap between the physical and virtual domains, as AR environments blend these environments together, and can allow users to interact with both physical and virtual objects while playing. Still, research exploring augmented board games with XR technology is very limited. One reason for this could be that this possibility has only opened up in recent years, as with older XR devices, users were restricted to using hand controllers for virtual hand representation, making it difficult to interact with physical board game elements while playing.

Explored methods used for creating mixed reality environments in augmented board games by enabling interaction between physical and virtual elements have mostly relied on using sensory technology to track physical objects, and use this information as input to change the output from a virtual display. The sensory technology used for achieving this generally rely on using specific hardware such as cameras for object-detection or electronic gameboards with custom-made pieces, which is often expensive and requires a lot of effort to configure. Furthermore, they are generally not very adaptable, and are mostly designed for specific games. [24]

Using the hand-tracking technology that many modern XR devices provide, it is theoretically possible to interact with physical objects and virtual objects simultaneously. Several VR and AR headsets, such as the Meta Quest 2, have integrated hand-tracking systems that allow users to interact with virtual objects in a similar way to how they would interact with physical objects in the real world, by tracking gestures to trigger actions such as grabbing, holding, moving and dropping virtual objects [23]. This way, users can pick up and interact with physical and virtual objects at the same time if the objects are aligned in the same spatial position (see figure 5). This technique could potentially be used to represent physical board game pieces in virtual environments, without the need of sensory technology for piece detection, which could add a physical and tactile element to XR board game experiences. By creating digital clone of a physical gameboard with pieces, it might be possible to represent an entire gameboard virtually. However, the feasibility of using such a technique to facilitate interaction with physical and virtual pieces simultaneously have yet to be investigated, and exploring the feasibility of this approach might provide value to research, as it could, if satisfactory enough, reduce the need of object-detection devices. Other benefits with this approach is that it could potentially be very adaptable and easy to set up for any board games where the board state mainly relies on moving physical pieces on a gameboard. Furthermore, it could allow players to use physical pieces while playing with others players remotely, with the other players' pieces being represented virtually.

Figure 5: Real hand and physical object (left) and corresponding virtual hand and virtual object (right). Source: [25]

In order for physical pieces to hold value in XR augmented board games, the tangible and tactile interaction they offer must provide a distinct advantage to the playing experience. Previous research has indicated that individuals generally have a preference for physically playing board games rather than engaging with their digital counterparts [26]. However, the impact and significance of tangibility in the context of XR board games have not been extensively studied. Understanding the specific benefits that tangible elements could bring to XR augmented board games, such as enhanced haptic feedback, physical manipulation, and embodied interactions, is crucial to determine the added value they contribute to the overall gameplay experience. Investigating user experience with respect to perception, emotional engagement, and gameplay outcomes associated with the integration of physical pieces in XR board games can help provide valuable insights into optimizing the design and interaction strategies of future XR augmented board game experiences.

In the context of XR board games, there also exists a notable research gap regarding the impact of factors related to the users' visual environments, and how it can affect the social presence, immersion, and overall playing experience. Playing board games in XR can enhance the traditional tabletop board game experience by introducing visual effects, representing players as digital avatars, or placing the players in a virtual environment. However, there is also a possibility that users might prefer more simplistic enhancements to maintain the realism and resemblance of traditional tabletop games. Gaining a better understanding of user preferences can also contribute to creating more enjoyable XR board game experiences.

## 1.3 Research Questions

This study attempts to address the gap in the research by investigating the following research questions:

**RQ1**: How does the approach used for moving board game pieces in XR affect the usability and user experience while playing?

**RQ2**: How does the usability and user experience of XR board game applications compare when using physical and virtual pieces versus virtual pieces only?

**RQ3**: Is it feasible to accurately represent physical board game pieces virtually by positionally aligning physical boards with a virtual one?

**RQ4**: How does external factors related to the visual environment, such as the physical/virtual environment and digital avatars, affect the playing experience and social presence in XR augmented board games?

# 2 Literature Review

This section provides an overview of existing research related to the topic of augmented board games and the research questions defined in section 1.3. This information was used as a foundation for gaining a better understanding of board game play in general, and the ways in which they could be augmented or enhanced with the use of digital technology. Topics covered include comparing physical board game play to digital play, a review of the importance and impact of tangibility in board game play and human-machine interaction, and a review of existing augmented board games and the feedback they have received. Various ways in which physical objects can be tracked and represented virtually are discussed, as well as a review of how digital avatars and visual environments affect the social presence in XR. Overall, the exploration of the current body of knowledge is analyzed and used to extract key findings and identify research gaps.

## 2.1 Board Games and Social Play

Xu et al. [27] performed an empirical study examining and observing physical board game play sessions as part of their research on augmented board games . They presented five categories of social interaction in an attempt to gain a better understanding of how players communicate when playing. One of these, the ”chores” category, refers to the effort required to play the game. This can include activities such as setting up the board, shuffling cards, moving pieces to update the game state as well as practicing rule enforcement and bookkeeping. The effect and importance of this category of social interaction is particularly important to understand when designing digitally augmented board games: digital games can automate most chores, which reduces the effort required to play, but this can also damage the nature of the social interactions, which is a central element of board game play.

Xu’s findings indicated that chores are integral to social play. From observations, they found that several chores, such as throwing dice and moving pieces, creates a mutual focus of attention among the players. This can contribute to enhancing the co-presence (feeling of being in the physical presence of others), and the synchronization (the shared mood and emotional experience) while playing, which according to Collins [28], are key ingredients to successful social interaction. Xu further suggested that when designing digital games, having a set of chores that can be observed by all players might be beneficial since it can contribute to creating rich social interactions, compared to having automated chores.

Xu also found that manipulation of physical objects can contribute to the social enjoyment in board games. The turn-based nature of board games alternates which player is the focus of attention. When a player is in focus, the others pay attention to the chores the player performs. This naturally leads to players using the physical objects as 'props' to increase the tension and level of excitement among the group when it is their turn (e.g. by dramatically shaking dice), which helps elevate the level of social enjoyment.

The continued success of tabletop board games is by many accredited to the focus on social interaction. Face-to-face communication is one of the most important characteristics of board games [29] (p. 29). In contrast to digital games, board games are typically open in the sense that communication signals (speech, gestures and movement of tangible objects) are viewable for all players. Magerkurth et al. [24] states that "the unbroken success of old-fashioned board games clearly relates to the social situation associated with them". They also claim that computer games are perceived as mostly isolated activities regardless of the number of players involved, due to the technology-oriented nature of the players' interaction. Moreover, they underline that human-to-human interaction through eye-contact and physical gestures elevate the social richness of board games, and that these factors are difficult to replicate in digital games.

## 2.2 Tactility in Board Games

A central element of traditional board games is the physical elements and interactions. Typically, board games include physical objects such as a gameboard, pieces that represent players, cards, dice and tiles. Throughout a play session, players interact with these objects in turns, which changes the game state. These physical actions are often observable by the other players, and can help create a higher level of shared emotions among players [27]. Maneuvering physical objects creates opportunities for players to express themselves, which affects and evokes emotions in the players who observe them.

Menestrina et al. [30] compared tangible and graphical game interfaces with the motive of studying the advantages and disadvantages with the two types of interfaces . Here, a comparative evaluation of the user experience when playing the same game with two different interfaces (one strictly digital, the other an augmented gameboard with tangible pieces) was performed. Their results suggested that there was a positive correlation between using tangible pieces with regard to the users' sense of immersion, competence, and experience, as it allowed for more intuitive and natural interaction. They also concluded that manipulation of real objects increased the players' engagement and curiosity, and that it stimulated a greater desire for interaction and experimentation.

Fang et al. [26] performed a study comparing emotional reactions of players when playing traditional physical board games and when using a digital 2D interface format. They compared the level of satisfaction when playing using the different interfaces with respect to Norman's three emotional design levels - visceral (appearence), behavioral (fun and utility to use), and reflective (self-image, personal satisfaction and memories). The results from the study showed that the level of satisfaction was significantly greater in all design levels when playing the traditional board games. The form, texture and colors of the physical objects were much preferred compared to their digital counterparts. Moreover, the tangibility of the physical board games contributed to the physical games scoring significantly higher than the digital games with regard to the comfort, ease of operation and easy understanding. The study also concluded that traditional board games can improve interpersonal relationships through social interaction, while the digital games failed to replace the sense of social interaction found in physical board games.

## 2.3 Conceptual Model for Augmented Board Games

Magerkurth et al. [24] introduced a new conceptual model with the purpose of enriching digital entertainment experiences by focusing on physical and social game elements. The motivation behind the development of this model was justified by arguing that most forms of entertainment heavily rely on human interaction, such as face-to-face communication, eye-contact, mimics and gestures to create joyful experiences, and that this element is lacking in computer games. They claim that the social richness of board games is far richer than in computer games, and that new interfaces should be introduced in computer games to facilitate stronger social interaction. For this to be achieved, they proposed using the model displayed in figure 6.

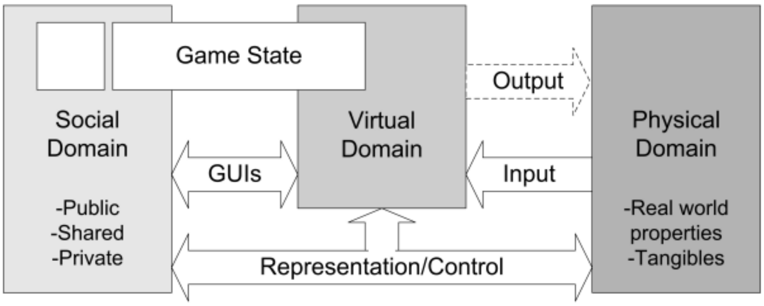


Figure 6: Magerkurth's conceptual model of augmenting gaming applications. Source: [24]

The model separates between the social domain, the virtual domain, and the physical domain. Here, the physical domain mediates the interaction between the players (social domain) and the virtual game world (virtual domain), which is represented through a digital display shared by the players. The players interact with the pieces, and the physical pieces moving modifies the state of the virtual game world. This is mentioned as a key element, as the players modify the game state jointly when interacting with physical elements and have to synchronize their actions, instead of each player using their own controllers to interact with the digital game. This, according to them, preserves the social group dynamics of board games. Moreover, they claim that the addition of the digital elements and the visual and audio presentation capabilities has the potential to create much more immersive and richer gaming experience compared to traditional board games.

The tangible interfaces (e.g. physical gameboards) are necessary to avoid that the attention of the players is focused on the social interaction instead of the technology. The principle attribute of tangible interfaces is the ”seamless integration between representation and controls” [31]. Compared to graphical user interface (GUI) interaction, in which the controls (input, e.g. a mouse click) and the representation (output, e.g. a player moving to the clicked position) are separate entities, ideal tangible interfaces should fuse the controls and representation [24]. Having virtual representations that match the physical representations and game elements when possible thus creates a more natural form of interaction between the players and the virtual elements. When a physical object is moved or rotated, the virtual representation should be moved or rotated accordingly. However, not all the characteristics or states of the physical representation (e.g. shape or color of a piece) have to be transferred. Additionally, Magerkurth et al. [24] mentions that the virtual representation can be more complex, and have characteristics such as health, speed etc. that can be conveyed to the social domain through the GUI. They also discussed whether rule enforcement of the games should be automated and implemented in the virtual domain, and how it impacts the social aspects of playing. They suggest that it might be beneficial to leave rule enforcement to the players around the table. Xu et al. [27] also mentioned rule enforcement as a chore that contributes to the social experience of board games. Magerkurth states that players establishing ”house rules” and discussing the rules in general can be enjoyable for the players.

## 2.4 Physical Interfaces and Object Detection Methods

To augment board games with digital elements, a physical interface mediating the social domain (the players) and the virtual domain is required. Magerkurth et al.’s [24] approach was based on using digital board interfaces capable of detecting tangible board game pieces. They explored several technologies that could enable this. The most important state information of the tangible pieces that had to be detected and transmitted to the virtual domain was the position of the pieces, which could be either discrete or continuous. In some games, detecting the identity and the rotation of the piece could also be important, and these factors are important to consider when deciding what is the most suitable technology.

### 2.4.1 Camera Recognition

One way to track physical game objects and pieces is through camera recognition. This was the method used for the augmented board game platform STARS [24]. The board game itself featured a virtual touch-display board and physical game objects on a table, with a camera placed above it. Image analyzing software was used to identify the pieces and track their discrete positions on the board. This method had many potential benefits, including the use of a shared visual display with dynamic game elements, physical pieces and the generic nature of visual recognition. However, the technical aspects were problematic, as the quality of the camera made it hard to detect the pieces. Other drawbacks of the approach was that the setup was time-consuming and quite expensive, making it difficult to use for consumers.

### 2.4.2 RFID Technology

Tan and Pei-Luen [32] explored tracking physical board game pieces using Radio-Frequency Identification (RFID) by developing a new board game. Here, they tagged each board game piece with RFID transponders, making each piece uniquely identifiable. An RFID module antenna was installed in the physical gameboard, and was used to detect the signals from multiple pieces simultaneously. Additionally, a GUI was set up separately to display the graphical output. Magerkurth et al. [24] also used RFID technology to develop various augmented board games. While RFID technology is a very robust approach for representing physical pieces virtually, it has the downside of being quite expensive due to the cost of the radio antenna. Another downside with this approach is that all the physical pieces have to be tagged individually, which can be time-consuming.

### 2.4.3 Electronic Gameboards with Magnets

In digital chessboards (e-boards), physical pieces are tracked so that games can be monitored, stored and reviewed. They are also commonly used in professional settings to transmit the board position on live television broadcasts, and for training and online play. The boards manufactured by Digital Game Technology uses patented sensor technology that registers the identity (piece type and color) and the position of every piece on the board. This technology is relatively cheap. One limitation with these boards is that they rely on setting up the pieces in a standardized way. They are also restricted to only moving one piece at a time, and can only track positions discretely based on which tile on the gameboard the pieces are placed on. [33]

### 2.4.4 Tangible VR

Cardoso and Ribeiro [34] published a paper exploring tangible interfaces for mixed reality. They assert that introducing tangible elements to virtual reality has a huge potential because they can provide rich and natural haptic cues that is missing in most VR experiences where hand-held controllers is the main input. This is backed by Carrozino and Bergamasco [35], who mention that tangible user interfaces correspond to a better VR solution. Cardoso and Ribeiro also mention that this tangible interaction can result in higher immersiveness (particularly physical presence) and more fun experiences due to the haptic feedback.

Caroso and Ribeiro further distinguishes between passive and active tangibles as two different approaches for facilitating tangible object-interaction in VR. Active tangible objects require power and integrated sensors to be tracked, whereas passive objects do not transmit state information, but is rather tracked by an external device (e.g. through camera recognition). Compared to active tangibles, which are rather expensive and require considerable effort to develop, passive tangibles are often cheap and simplistic. However, tracking them accurately can be more difficult, and depends on the capabilities of the external detecting devices. Still, passive tangibles have shown to significantly enhance physical environments [36].

Cardoso and Ribeiro implemented a Tangible VR Book prototype through the use of visual markers. This method relied on camera detection to scan codes (e.g. QR codes) on the physical objects to be tracked. This method was also used by De Paolis et al. [37] to implement a simulation of billiards by placing the visual marker at the tip of the billiard cue. In Cardoso and Ribeiro's design, they placed visual markers on pages in a physical book, and used a smartphone device to scan the markers and display pages on a virtual book visible on the smartphone. Through user testing, they identified several usability issues with this method, including technical problems related to the detection of the markers and issues with properly rendering virtual elements. However, results indicated that users were optimistic about the prototype, as almost all test users enjoyed using it.

### 2.4.5 Unity Slices: Table

Unity Slices: Table is an experimental mixed-reality demo application developed by Unity Labs that demonstrates a way to use any table as a physical interface to interact with virtual board game pieces (see figure 7) [38]. Here, the players can instantiate a virtual board on a physical table surface by placing the hand-held controllers on the table, and pressing a button to instantiate the virtual board. Integrated cameras can track the users hand movements (hand-tracking), allowing the hands to be represented virtually. When the physical hand touches the table, the virtual hand also touches the virtual table, which can be used to interact with the virtual board. This way, users can move virtual pieces and get physical feedback through using the physical table to slide or drag pieces on the virtual gameboard. However, there are no physical board game pieces, as they can only be interacted with through using the table.

Figure 7: Unity Slices application. Source: [38]

## 2.5 Tangible Board Game Interfaces and Research Gap

As seen, there are various approaches that can be used in order to represent physical board game pieces virtually. However, most of these methods require using active tangibles (sensor-based technology) or cameras that are capable of recognizing unique board game pieces. However, as illustrated by Unity Slices, with XR devices, it is possible to create tangible board game experiences without using additional hardware for tracking physical objects, by positionally aligning physical and virtual elements. Other research exploring this approach and how it can be applied in a board game context was not found, indicating a gap in the research. The Unity Slices demonstration video [39] was received with a lot of enthusiasm and positive feedback, but has not yet been released to the public or been properly evaluated or tested on users in an academic context.

The potential of the Unity Slices, blending the virtual and physical domains together with XR to create a unique board game experience contributed to the development of the new proposed idea for physical piece interaction in XR used in this thesis. Using a similar approach for aligning the physical and virtual table as in Unity Slices, it was thought that it was possible to instantiate (spawn) a virtual gameboard on top on a physical gameboard instead. This way, virtual pieces could be added ”on top” of physical pieces, and functionality could be added to enable the physical pieces and their virtual representations to be moved and interacted with simultaneously. Compared to Unity Slices, this adds another dimension to the tangible interface since the players can physically interact with the pieces by picking them up, holding them and releasing them.

## 2.6 Augmented Board Games

In recent years, various digital augmentations of tabletop board games have been developed with the purpose of enhancing the gameplay. Researchers exploring such technologies have found that there is a huge variety of reactions among test users - some users find it exciting, whereas others prefer distancing tabletop games from computers and digital technology. Kosa and Spronck performed a qualitative content analysis on people's opinions on augmented tabletop games. Their results were also mixed, but they identified and categorized key factors which contributed to people welcoming digital augmentations, including "enhances enjoyment / fun", "different number of players", "not taking away traditional games", "decreases tediousness", and "multimedia effects". Some also stated that digital augmentations can improve the immersion, thus creating a more engaging experience. The possibility of playing against remote players or an AI was also mentioned as one of the possible benefits.

Rogerson et al. [40] referred to physical board games that integrate smart digital technologies as Hybrid Digital Boardgames (HDBs). More specifically, they limit this to games that require both physical and virtual elements to be playable. They distinguish between digitally augmented board games, where the term implies that digital elements are added on to an existing board game, and HDBs, where the physical and digital elements are purposefully designed to work in unison to give rise to "novel possibilities that the artifacts would not afford in isolation".

Leitner et al. [19] developed the augmented board game Incretable with the purpose of exploring ways in which the boundary between the virtual and the real world could be dissolved. Here, digital pens were used to interact with digital elements on the tabletop surface, and physical objects were tracked using a depth camera, which allowed virtual and physical domino pieces to interact with one another. The game was based on co-located gameplay using a shared interface, encouraging collaboration between the players. When tested on users, the game received highly positive feedback, with users enjoying playing with a tabletop interface that combined the use of physical and virtual objects.

Loenen et al. [29] (p. 18) developed Entertaible, an interactive digital display which used touch-sensors to detect physical objects. This way, co-located players can play together using a shared digital display and use traditional, tangible board game pieces while the board setup is entirely digital. The game was tested on children, who reacted with curiosity and interest, and preferred using Entertaible over playing video games.

Huyhn et al. [41] developed a hybrid digital boardgame, Art of Defense, which was based around using hand-held AR devices and a shared physical interface with board game pieces to merge virtual and real-world elements. The goal of the study was to explore the affordances and constraints of handheld AR interfaces for collaborative social games. From a user study, they found that the use of the AR interface increased the level of enjoyment while playing. Players were seated around the same interface, which fostered communication between the players and positively affected the gameplay experience. However, they also found technical limitations of using hand-held devices for digital augmentation. Due to a limited field of view, players had to move the device around to look for the virtual elements, which negatively affected the gameplay.

## 2.7 Digital Avatars in Virtual Reality

A digital avatar can be defined as a virtual representation of a person or user within a virtual environment. In the context of XR, avatars are also a virtual embodiment that represents the individual's presence and actions in the virtual world. Digital avatars can take various forms, including human-like representations, cartoony characters, or abstract shapes.

Greenwald et al. [42] investigated how "embodied" avatars and its effect on social presence and communication in VR. By embodied, they refer to avatars whose movements are one-to-one, synchronized with the movements of the user they represent. They performed an experiment with the goal of comparing face-to-face communication with communication through avatar representation in VR when playing word-guessing games that revolved around non-verbal and gestural communication (Charades and Pictionary). The avatars they developed were very simplistic, consisting only of virtual hands and a head. The virtual hand representations were not fully one-to-one however, as they were based on input from hand-controllers rather than hand-tracking technology.

From their results, they found that the avatars were not sufficient for Charades, as the absence of detail (facial expressions, hand gestures, finger movements and body) was considered highly problematic. On the other hand, this was not a problem when playing Pictionary, where the game revolved less around analyzing body movement. With these results, they proposed that, for games that are collaborative and communicative, where the focus is on not on the body movements, minimal avatars will yield an overall experience similar to when playing face-to-face, as even these avatars were found to be expressive and emotive.

Yoon et al. [43] performed a comparison evaluation, comparing the effect of avatar appearances in augmented reality. They compared the social presence when using avatars with different levels of body visibility (head and hands, upper body, and whole body avatars), and also compared two different character styles (realistic and cartoony avatars). They found that full-body avatars produced the highest sense of social presence, but that the differences between whole body and upper body avatars was not significant. This indicated that connected body parts elevated the social presence. When comparing character styles, they hypothesized that the realistic avatars would produce a higher social presence compared to cartoony avatars, but according to their results, there were no significant difference between the two character types, suggesting that realistic avatars might not be that important. They further proposed that the character style should be chosen based on the communication context, as realistic avatars could be more fitting in professional settings (such as remote meetings), while cartoony avatars could be more suitable gaming or other entertainment contexts.

With regard to the research gap and **RQ4**, studies comparing the effects of digital avatars in augmented board game play and interaction with physical board game pieces in XR was not found. Additionally, as hand-tracking is relatively new, most research on digital avatars, including the ones mentioned, relied on the use of hand controllers for virtual hand representation, which limits the possibilities of communication through hand gestures. Developing avatars that represent virtual hands more accurately by using hand-tracking technology could also provide value through investigating the effect of hand gestures on the social presence. Moreover, comparing the effect of digital avatars in a fully VR environment and an AR environment, and how it affects the social presence based on the visual environment was also considered to be valuable research for this thesis.

## 2.8 Virtual Environments in AR/VR

AR and VR have been extensively studied in the context of gaming, revealing notable differences in user experience. AR offers a more seamless integration of digital content with the user's physical surroundings. In contrast, VR provides a heightened sense of immersion by transporting users into a completely virtual environment.

Escapism is a term often associated with VR, as it allows individuals to transcend the physical constraints of the real world and immerse themselves in rich, imaginative virtual environments, providing a temporary escape from the real world. Loureiro et al. [44] stated that escapism can stimulate the user's cognitive and affect state that increases pleasure. According to Han et al. [45], escapism in the employment of AR has been less impactful than in VR, since the digital content is only overlayed on top of the physical environment, therefore limiting the extent to which users can fully detach themselves from reality.

While there exists extensive research on many different topics related to AR and VR and user experience, not many direct comparisons between the two have been conducted. However, Woods et al. [46] performed a comparative analysis, comparing the user experience of VR and AR versions of an immersive virtual image gallery. They found that the VR version received higher enjoyment scores. Moreover, the perceived presence was considerably higher in VR. They discussed that this may attributed to the disruptive nature of AR in relation to the ”place of illusion”. According to Slater and Steed [47], the concept of ”place illusion” is a crucial element in achieving a sense of presence, and it can be compromised when users transition back and forth between the virtual world and the real world.

# 3 Methodology

In this section, the theoretical research framework used to make decisions with respect to the research design and method is discussed. This includes describing the intentions of the research, and justifying the chosen research strategy and data generation methods.

## 3.1 Research Framework

The objective of all research is to add to the body of knowledge and increase the understanding of one or more topics by producing some form of information. This can be done by uncovering new insights, investigating theories or providing explanations.

March and Smith [48] explains different ways of approaching research within the field of Information Technology (IT). They proposed a two-dimensional framework for describing information technology research in terms of *Research activities* and *Research output* [48]. This framework is particularly useful, as it takes into account that there is a dichotomy in IT-research, in that it consists of both design science and natural science. Design science is technology-oriented research and focuses on the creation of things and products that can serve human purposes, while natural science attempts to increase our understanding of reality and explain the laws of the natural world.

March and Smith argues that both the research activities of natural science and the research outputs produced in design science are needed to produce relevant and effective research in IT. Natural science provides a foundation for understanding the underlying principles in IT, while design science enables the creation of specific solutions and innovations to address specific IT related problems. March and Smith's framework helps both in describing the IT research's place in relation to the dichotomy of the two sciences, and further helps identifying which approach should be taken to produce knowledge in the field. The research activities and research outputs form a 4x4 matrix that describes the purpose and means of how the research is conducted. Appropriate methods should be taken based on which cells the research relates to. The matrix can be seen in figure 8.

### 3.1.1 Research Outputs

Research outputs in design science determine what is produced by the research. This can be either *Constructs*, *Models*, *Methods* or *Instantiation.*

Constructs and Models refer to conceptual ideas, where several constructs constitute a model. The overall goal of these models and constructs is to improve the efficiency of working in that field, by explaining and refining difficult concepts. These are heavily based on their environment. Methods refer to algorithms, approaches or methodologies. These are not implementations themselves, but tools that should make the processes more effective. On the other hand, instantiation relates to artifacts, such as implemented software and creations. March and Smith state that instantiations are particularly important, as they verify methods and models, and can also lead to the production of them [48].

### 3.1.2 Research Activities

Research activities in natural science refer to what types of activities are performed, and by extension indicate the purpose of the research. These activities are *Build*, *Evaluate*, *Theorize* and *Justify*.

Build and Evaluate share similarities to instantiation in design science. Build is the creation of research output, with the purpose of exploring if it can be constructed. Evaluate refers to using metrics to determine how well the research outputs perform. In contrast, the Theorize and Justify activities are mostly connected to the natural sciences. Theorizing is the construct of theories that explain how something works the way it does. Justification is the act of proving if the theories are true.

## 3.2 The Research in Relation to March and Smith's Framework

Existing research on augmenting board games with XR technology, particularly in combination with physical board game pieces, is very limited. The research questions defined in section 1.3 explore the usability and user experience of XR board game applications. This requires the need of an XR application that can be tested by users. As no existing XR application allows exploration of all these topics, it was deemed necessary to develop a prototype application. As March and Smith states, the creations of artifacts and products in design sciences can "give rise to phenomena that can be targets of natural science research" [48] (p. 254). The creation of this software product provides a new way of interacting with technology and socializing through play, which can lead to interesting and valuable findings in natural science research by increasing the understanding of immersive playing experiences.

In relation to March and Smith's research framework, the main research focus therefore lies within the build and instantiation cell. Through producing a prototype XR software application, the feasibility and effects of combining physical and virtual elements and studying the impact of the visual environment during board game play could be achieved. Another focus is to evaluate the built solution. This way, the performance of the prototype can be measured. As the performance of an artifact is related to its intended use, the prototype should be measured by users. Evaluation of artifacts can be used to determine if progress has been made. In design science, this occurs if the artifact improves upon or replaces current technology. In order to properly evaluate an artifact, evaluation metrics must also be developed and defined. When evaluating the artifact, it is important to understand how and why something worked or did not work. For this, researchers must *theorize* and *justify* their theories.

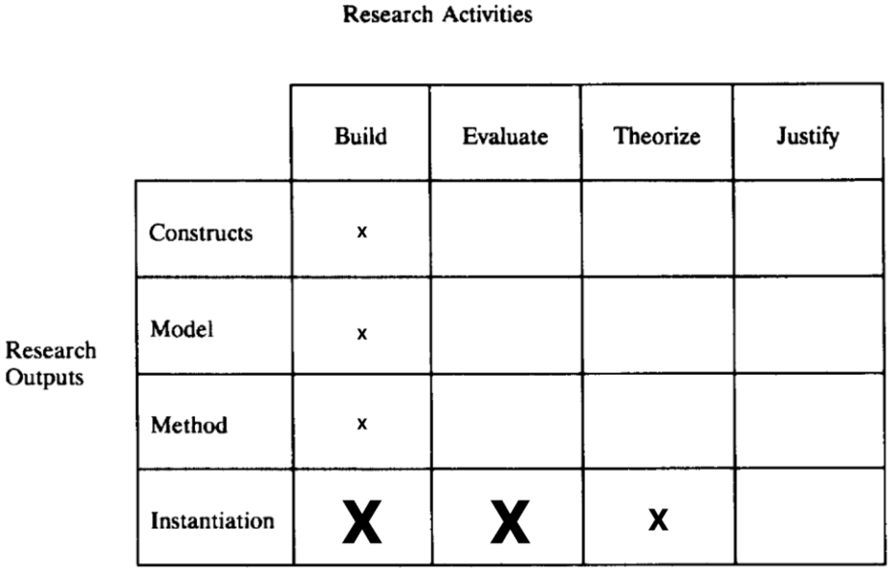
According to March and Smith, research in the build activity should be judged by the utility it brings to a community of users. In this thesis, this community refers to the users of XR applications and people who might be interested in augmented board games, and the utility is related to whether users enjoy and are capable of using the built solution. However, novel artifacts can have a research contribution despite not having high utility, since the value of new methods, models and constructs in computer science are dependent on the existence of instantiations that implement them. [48]

When evaluating an instantiation, metrics such as efficiency and effectiveness are typical measures. To measure these metrics, a common approach is to obtain a subject group to perform the tasks and measure the performance. This performance can be measured through comparing it to other existing instantiations. The main purpose of evaluation is to determine how well something works, rather than understanding how and why it does or does not work. Reasoning about the results of the evaluation is part of the theorize activity.

The research questions for this thesis relates to analyzing the usability and user experience of the built prototype. Usability is heavily linked with the evaluation research activity, as it is easier to measure objectively, while user experience is a more subjective metric. Hence, analyzing the user experience depends on finding patterns in the evaluation data, and using them to develop theories. Theories, when justified, are useful because they can contribute to the development and design of new, similar technologies and products in the future.

In summary, the main research output for this study is an instantiation of an XR prototype application, with the purpose of gaining a better understanding of underlying concepts, models and methods which can be used to develop augmented board games in XR. The main research activities are build, evaluate, and theorize. By building the prototype application, the feasibility of creating a functional augmented board game application in XR with tangible piece interaction can be explored. The build can help discover new possibilities and identify limitations of the technology. Moreover, it enables the developed features to be tested and evaluated through user testing. This can lead to new theories, which can be used as a reference and knowledge base if similar products are produced in the future.

While the build activity plays a central role in the research as it allows exploration of the research questions, describing the technical implementation is not in focus. However, it is still considered to be a highly important activity, as the *evaluate* and *theorize* activities require the artifact to be built. The research focus is summarized in figure 8.



**Research Activities**

| Research Outputs | Build | Evaluate | Theorize | Justify |
|---|---|---|---|---|
| Constructs | x | | | |
| Model | x | | | |
| Method | x | | | |
| Instantiation | **X** | **X** | x | |

Figure 8: March and Smith's research framework, adapted from [48]. The research focus is marked with crosses, where the the size of the cross indicate the degree of focus.

## 3.3 Research Design

Using March and Smith's framework, the scope of the research has been properly defined. Having defined *build*, *evaluate* and *theorize* to be the main research activities, and the research output to be an instantiation, the process of choosing a suitable research strategy is simplified. In the following subsections, the research design is defined. This includes establishing the chosen research strategies and data generation methods. The research design was heavily influenced by Oates' *Researching Information Systems and Computing* [49].

## 3.4 Research Strategy

A research strategy is the overall approach used to answer a research question. Each research question typically has one research strategy [49] (p. 35). Each strategy has its own strengths and weaknesses, and it is therefore important to be aware of these in order to gather the right kind of information in the right way. Oates defined six different strategies in his book, namely *survey*, *design and creation*, *experiment*, *case study*, *action research*, and *ethnography*.

The research questions as defined in 1.3 are all related to XR augmented board game applications in particular, which is very much a distinct and unexplored topic. To address these questions, it was therefore deemed necessary to develop an XR application that could facilitate the exploration of all the research questions. This falls within the *design and creation* research strategy, which by Oates' definition, revolves around "developing new IT products" (artifacts) [49] (p. 108). Going back to March and Smith's research framework, the particular IT artifact developed is an instantiation. The design and creation research strategy can contribute to knowledge through exploring the possibilities of digital technology. The creation of the artifact is not always the research focus however, and can also, as Oates states, be a "vehicle for something else" [49] (p. 110). This is the main idea behind choosing the design and creation strategy for this thesis. The prototype application facilitates a way to allow users to test playing XR augmented board games with various parameters, which can then be analyzed and discussed in order to answer the user-centred research questions. The design and creation research strategy can also contribute to knowledge through gaining a better understanding of the capabilities and limitations of existing technology and the feasibility of creating a product that brings ideas and concepts to life.

## 3.5 Data Generation Methods

A data generation method is the means through which empirical data is produced. Data generation methods can be used individually or in combination, depending on the research goals, context, and available resources. A research strategy contains one or more data generation methods [49] (p. 186). Each method offer their own strengths and limitations, and it is important to consider which methods are the most appropriate with respect to the research objectives. The chosen data generation methods for the user test was a combination of two qualitative methods, namely interviews and observations.

### 3.5.1 Interviews

Interviews are a versatile and commonly used data generation method, and involve direct conversation between the researcher and participants. According to Oates, interviews are especially suitable when the goal is to gather detailed, in-depth information [49] (p. 187). Additionally, Oates mentions that they allow the researcher the opportunity to delve into the realm of emotions, experiences and feelings that are challenging to observe and describe via pre-defined questionnaire responses.

Interviews can be structured, semi-structured or unstructured. Structured interviews are similar to questionnaires, as the questions are asked in a pre-determined, standardized way. This has the benefit of mitigating biased or directed questions from the interviewer, as well as being more suitable and a more organized way of gathering quantitative data (ensuring consistency). Conversely, unstructured interviews has the benefit of being flexible and allow for more open-ended exploration. Here, the researcher has the freedom to adapt the questions according to the flow of conversation, probe deeper into responses, and follow emerging themes. Semi-structured interviews strike a balance between these two approaches by providing a framework of core questions and themes while allowing for additional exploration and probing based on the participants' responses.

### 3.5.2 Observation

Observation is a data generation method where the aim is to find out what the participants actually do, which can often differ from what they report they do when questioned [49] (p. 202). Observation involves systematically watching and documenting behaviors, interactions and events in real-world settings. Compared to interviews, observation can be useful to gather more objective data, since the researchers are less reliant on the participants' self-reporting or interpretation.

## 3.6 Qualitative Data Analysis

Once the data has been generated, it must be analyzed in order to produce research value. Qualitative data includes non-numeric data that is collected and analyzed in order to gain insights, find patterns or develop theories often with respect to subjective experiences that cannot easily be measured with numbers. Qualitative data analysis focuses on capturing the richness and depth of participants' perspectives, beliefs, behaviors and emotions. It is heavily based on abstracting the focal points of the qualitative data to identify themes and patterns relevant to the research topic [49] (p. 267).

Once the data generation is complete, the data should be turned into a form that makes it easier to analyze. For instance, data generated through interviews and observation may be captured using video and audio recording devices, and should be transcribed and stored in a systematic way. Oates [49] (p. 268) then suggests that the data should be categorized into three themes, as follows:

1. Segments that bear no relation to your overall research purpose so are not needed
2. Segments that provide general descriptive information that you will need in order to describe the research context for your readers
3. Segments that appear to be relevant to your research questions

Thereafter, the focus should be on the third category, where the segments (units of data, such as words, sentences and observations) should be labeled in a way that describes the theme of the segment. This can be used for thematic analysis of the qualitative data. Segments within the same categories can be used to find patterns in the data and develop theories. It is also possible to support qualitative data and developed theories with quantitative analysis [49] (p. 266). For example, during interviews, it might be useful to count the number of times a particular theme is brought up.

## 3.7 Research Process Model

In figure 9, the research approach used for this thesis in relation to Oates' research process model is illustrated.

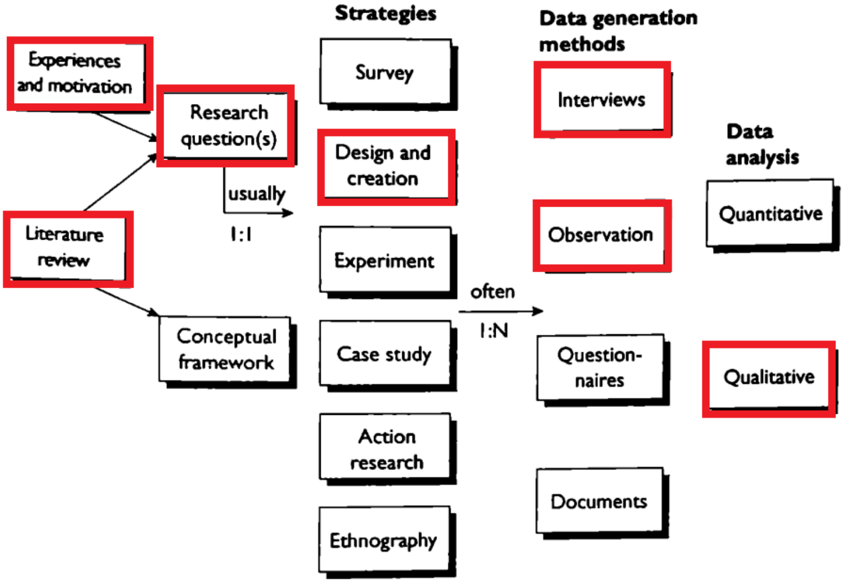


Figure 9: Oates' model of the research process, with the components chosen for this thesis is highlighted in red [49]

## 3.8 Research Purpose and its Relevance to the Methodology

Oates describes the main reasons why people do research. This includes "to add to the body of knowledge", "to solve a problem", "to contribute to other people's well being", and "to test or disprove a theory" [49]. These were especially regarded as important factors for conducting a user test to evaluate the prototype application. In this thesis, the main "problem" was related to incorporating a tangible interface to board game play in virtual and augmented reality. The main motivation for this relates to contributing to other people's well being, as research has shown that augmented tabletop gaming and the combination of virtual and physical play can lead to new and enjoyable experiences for people. The proposed theory was that it might be possible to introduce tangible elements (i.e. board game pieces) to augmented tabletop games without using custom-made, electronic boards and pieces. To determine whether this approach was usable and capable of providing a positive user experience, a user test was deemed necessary. The feedback obtained from the user test, whether positive or negative, would hopefully enhance the body of knowledge by providing a deeper understanding of the advantages and limitations of this approach.

While tangibility and physical board game piece interaction with XR technology was the main focus, gathering and analyzing data for factors related to the players' visual environments and how they impact the user experience was also considered important. An idea was developed to let users test the application in both VR and AR environments using different devices and while using digital avatars to represent players. This could add to the body of knowledge in the field of augmented board games, as few have developed such applications for head-mounted displays and explored the potential and possibilities which arise from the enhanced immersion these devices can offer. The results of this research can be used to inform the development and design of similar applications in the future, and contribute to the growing field of augmented board games.

# 4 Technology

This section presents an overview of the state of the art of extended reality technology. The potential and limitations of current hardware and software technologies are explored. The XR devices used for prototype developent and user testing are introduced, and other alternatives are also discussed. Additionally, the game engine used for prototype development (Unity) and the key concepts of the software are covered.

## 4.1 XR Device Types

XR devices are hardware that provide computer-generated environments that allow users to experience a simulated physical presence in the real world (augmented reality) or a virtual world (virtual reality). XR devices are commonly associated with head-worn devices, which usually feature a head-mounted display (HMD), sensors, and computational power.

XR devices consist of VR, AR and MR headsets. VR headsets differ from AR and MR headsets in the way in which digital content is displayed. In AR and MR headsets, digital content is transparent (holographic), and displayed on top of the real world. In VR headsets however, the visual environment is completely virtual, and the real world is blocked out. While AR and MR headsets present digital content in similar fashion, MR offer more possibilities. In AR, there is a distinct separation between digital and physical world elements. In contrast, MR devices allow interaction between physical and virtual elements. [13]

## 4.2 Types of Mixed Reality Headsets

Mixed reality head-mounted displays (HMDs) can be divided into two different categories based on how the AR functionality is implemented, Video See-Through (VST) and Optical See-Through (OST) devices [50].

VST devices utilize a camera feed to project the external reality on a screen within the headset. Graphics can be placed on top of the camera feed, creating an AR effect. Sensors on the headset make the graphics move based on the user's movement, which creates the illusion that the graphics are rooted in the real world. These HMDs are generally VR-first, in the way that they implement AR on top of a fully working VR solution. Examples of these HMDs are the Varjo XR-3 [51], Meta Quest 2 [52] and Pico 4 [53] [50].

In contrast, OST devices utilize a see-through glass screen to display graphics that intercept the user's sight of the real world. Some of these devices use sensors that map the surroundings such that the graphics can placed in relation to a point in the physical world (see subsection 4.6). This gives the appearance that virtual objects exist in the real world, rather than just on the screen itself. Examples of OST devices are the Microsoft HoloLens HMDs, the Magic Leap HMDs, and Google Glass [50].

Compared to VST devices, OST devices give a more detailed view of the real world, as they are not limited by the quality of the camera and the display of the digital screen. However, this comes with a drawback regarding their virtual graphical capabilities. Current OST devices are not able to fully obstruct the outside view due to the see-though glass screen [50]. This causes the real world to always be partially visible. The graphics therefore always appear see-through, like 'holograms', which can have a significant effect on the user's experience of immersion.

## 4.3 Hand-tracking

Hand-tracking is a feature supported by many modern XR devices. Hand-tracking refers to technology that enables the detection and tracking of the user's hands and gestures. This way, users can interact with virtual elements without relying on hand-held controllers [54]. Hand-tracking technology uses a combination of sensors, cameras, and computer vision algorithms to accurately capture and interpret the position and orientation of the hands. This way, the devices can register when a virtual object is touched, pushed, picked up, dropped or thrown. This method of interaction has numerous potential benefits. Firstly, it increases the immersion and presence in the virtual environment by allowing a more natural way of interaction [55]. Moreover, not being restricted by manual controllers can enable users to interact with physical and virtual objects at the same time, which can add a tactile and tangible element dimension to the user's interaction.

Figure 10: Hand-tracking with representation in the Meta Quest 2. Source: [25]

## 4.4 Choice of Devices

To focal point of this thesis was to evaluate the impact of various factors on the usability and user experience when augmenting board games. This was done through developing an XR application which was tested on users. Before starting with the development process, decisions had to be taken with respect to choosing which devices to use. In this section, the VR and MR headsets used for development of the prototype application are introduced. Technical aspects of the devices which were deemed to be beneficial for the research, and the potential and limitations of each device are also discussed.

To compare the user experience when playing augmented board games in VR and AR, one device of each type was required. In order to seamlessly build and run the application on both, the devices had to support cross-platform development. To enable moving physical board game pieces by hand while playing, hand-tracking support was also a required feature for both devices, as using hand-held controllers was considered highly impractical.

### 4.4.1 Meta Quest 2

The Meta Quest 2 (also known as the Oculus Quest 2) is a popular consumer VR headset, created by Meta. It has a low price point, and requires no external cameras ('lighthouses') or computer to use [52]. As of June 2022, the Quest 2 accounted for 90% of the marked share of VR headsets [56], which makes it the most common headset among consumers.

The Meta Quest 2 has four infrared cameras that can capture visual information around the user. These were initially restricted to guiding the user out of hazards when walking too far from their specified playing area (guardian area), and are therefore monochromatic. However, since 2021, Meta has allowed developers to access the camera feed with the Pass-through API in VR applications [57, 58]. This allows the headset to be used as an VST MR headset.

One major limitation of this Pass-Through API, is that developers are currently restricted from processing the camera feeds' content, due to privacy concerns [57]. This means that it cannot scan QR codes or recognize objects and surfaces. However, using a technique called anchoring (see subsection 4.6), it is possible to mark a virtual point spatially to the real world, creating an illusion that objects are tracked. This is a limitation shared by similar HMDs, such as the HTC Vive [59].

Other alternatives for VST HMDs are the Valve index [60], Vive [61], Pico 4 [53], Varjo XR-3 [51] and the new Quest Pro [62]. The Index and Vive were not chosen, as they provided no new additional interaction methods, while also requiring external computers to run their software. The Pico 4 boasts of a similar feature set and price point as the Quest 2, but with full color cameras. However, it lags behind software wise, being a new headset, with limited adoption. The Varjo XR-3 has a much greater feature set, being purely designed as a VST AR headset, rather than a VR headset. However, it is catering to an enterprise audience, has a price point tenfold of the Quest 2, and requires a powerful computer. The Quest Pro improves on the Quest 2 by having higher resolution color cameras. However, it currently has no additional methods for interaction compared to the Quest 2. It was also significantly more expensive, and it was therefore decided that the Quest 2 was sufficient enough for prototype development.

### 4.4.2 Microsoft HoloLens 2

The HoloLens 2 is a OST mixed reality HMD created by Microsoft, and displays graphics on a see-through visor. It is similar to the Quest 2, being a standalone, inside-out tracking HMD, with full hand-tracking capabilities [63].

In contrast to the Quest 2, the HoloLens was purely designed for mixed reality. It gives the developer additional tools to interact with the surrounding world. Two of these features are the ”spatial mapping” and ”scene understanding” tools. These tools allow applications to know the surroundings of the user, as well as recognizing specific elements, such as walls, platforms and floors [64] [65]. In addition, The Hololens supports Vuforia, which can be used to track images, QR-codes and objects, and display graphics that appear on top of them [66]. This means that the Hololens has much better capabilities to observe changes in the environment around the user, and possibly has less need for the manual anchoring workaround, described in section 4.6.

As of today, few OST HMDs have the capabilities of the Hololens, as most of them not interactive, but are rather intended as an additional screen to consume visual media. However, the recently released Magic Leap 2 is a close competitor to the Hololens functionality wise [67] [68]. Still, the Hololens was chosen as the MR device, as it was more established, and provides the same solid comparison point to the Quest 2.

Figure 11: Image showing the Meta Quest 2 Source: [69].

Figure 12: Image showing the Hololens 2 on a user. Source: [70].

## 4.5 The Unity Game Engine

The chosen game engine for used for prototype development for this thesis was Unity [71]. Unity is a 3D game engine which allows developers to easily create games and virtual experiences using C# scripts. It has a modular interface that can be extended by plugins, and has over the years become one of the largest platforms for creating VR games. It focuses on interoperability, and allows building games for mobile, PC and console. In addition, it has good support for XR development, as it supports building applications with the OpenXR plugin [72], which can be used on most VR headsets. In addition, it has plugins and support specific software development kits, such as Microsoft's Mixed Reality Toolkit (MRTK) [73], which can be used to leverage specific headset features and shortens development time. Furthermore, Unity gives access to the Unity Marketplace, which contains tools, prefabricated models and code, which speeds up the development process significantly.

### 4.5.1 Unity GameObjects

Most elements in Unity are represented as *GameObjects*, and can be placed within the virtual space or "*Scene*". GameObjects are containers that have a specified position, scale and rotation. In addition, they can also have components such as meshes (shape), materials (color) and scripts attached to them. These GameObjects represent virtual objects within the game. For instance, they can be a chess piece, the ground or the hands of a VR-user. GameObjects can also be parented, making their position relative to their parent. A use-case of this is to parent a characters arm to its body. The arm would then always be positioned relative to the body, even if the body itself is moved or rotated.

### 4.5.2 Scenes

A scene in Unity represents a specific virtual environment in a Unity application. One scene can for instance represent a level in a game or a navigation menu. The scene serves as a container that stores and organizes the various GameObjects, assets, and components that are present when the scene is active at runtime. The GameObjects in the scene are displayed in the hierarchy window in the Unity application.

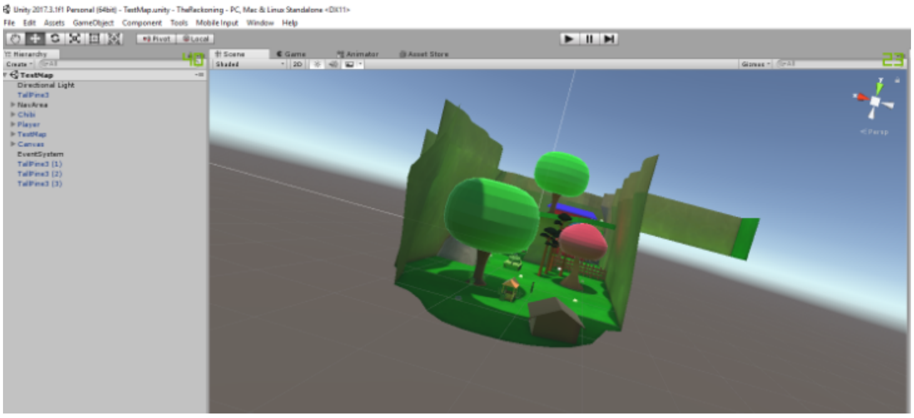


Figure 13: Example of a scene in Unity. A list of the GameObjects in the scene are shown in the Scene hierarchy on the left. Source: [74]

### 4.5.3 Instantiation

In Unity, instantiation refers to the process of creating an instance of a GameObject at runtime. GameObjects can be instantiated (spawned) into a scene by calling the Instantiate()-function from a script. The GameObject to be instantiated is passed as a function argument. A transform component can also be passed as an argument to specify the world space position, rotation and scale of the instantiated object.

### 4.5.4 Prefabs

In the Unity game engine, a prefab refers to a replicated version of a GameObject or a hierarchy of GameObjects. It serves as a template that can be easily instantiated and reused throughout a scene. The prefab contains all the components, properties, attached scripts, and child GameObjects (if any) of the original GameObject that was copied. By instantiating the prefab multiple times, identical copies with the same configuration can be created. This feature proves beneficial when there is a need for multiple GameObjects in the scene with identical properties, as it eliminates the need to individually configure each GameObject. Once instantiated, each instance of the prefab can have its properties modified independently from one another.

### 4.5.5 Netcode for Unity

*Netcode for GameObjects* (NGO) is Unity's framework for creating multiplayer experiences [75]. NGO allows two or more Unity application instances to connect over the internet, and specify certain GameObjects to be synchronized between these instances. This way, if a synced GameObject changes for one user, the same change would be shown for all the other users. This can be used to make users' interactions visible for each player. For instance, if one user moves a GameObject, it would appear moving in real-time for the other users as well. Since each player is represented as a GameObject, NGO can also enable players to see each other's movements in real-time.

It is also possible to use other multiplayer solutions, such as custom servers for handling the synchronization. However, a benefit of using NGO is that it is a higher level framework which is heavily integrated with Unity. This makes it quick to get started with and easy to use with the Unity engine [75].

## 4.6 Anchoring

Anchoring is here defined as the process of setting a virtual object's position (such as a Unity GameObject) based on a physical position (anchor). Anchoring is useful, as it allows for the placement of virtual objects in relation to the real surroundings. An example of this is to place a virtual character on top of a QR code. This example is illustrated in figure 14.

Anchoring is implemented in many AR applications by using a physical object, such as a QR-code, as the anchor. The anchor works as a point of reference in the real world that is also tracked digitally. It can therefore be used to place virtual object according to this position. For instance, if a QR-code is printed on a piece of a paper, an AR headset could continuously track the QR-code's position, making it an anchor. Virtual graphics could then be accurately linked to the top of the anchor. This would make it appear as if the graphics were on top of the QR code. Since the QR-code is tracked continuously, any movement of the QR-code would result in movement of the virtual graphics. This is illustrated in figure 15.

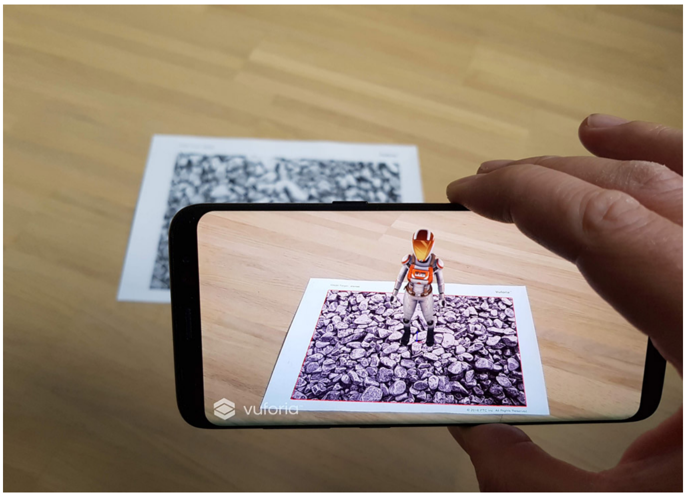
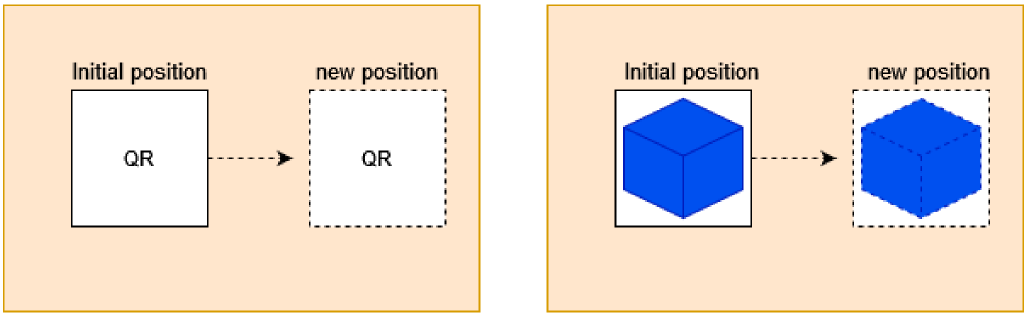


Figure 14: Anchoring with a QR-code, using the software Vuforia [66], with a phone acting as a VST mixed-reality device. Source: [76]



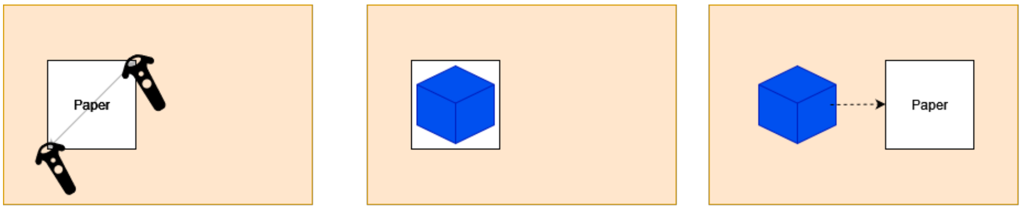
(a) Movement of QR-code in the physical world (b) The corresponding change in the virtual world

Figure 15: The relationship between the movement of a physical QR-code (a), and the corresponding effect on anchored virtual graphics (b)

One significant limitation with most VR headsets, such as the Meta Quest 2, is that the camera feed cannot be accessed by developer's software due to privacy issues [57]. This prevents QR-codes or other visual information from being used as anchors, as the application itself cannot process the image data, which is necessary to recognize them.

However, there is a workaround that allows anchoring to be performed by the user (here defined as manual anchoring). Developers have access to the right and left-hand controllers' position, as they themselves are represented as Unity GameObjects. The user can therefore move their controllers to a specific point in the physical space, such as around a sheet of paper, and mark its physical position as an anchor for virtual graphics.

Manual anchoring creates a similar anchoring effect. However, a limitation with this technique is that the manually created anchor is not a continuously tracked object, in contrast to the anchor in the QR-code example. Therefore, if a manual anchor is placed on a physical object, it would not move if the physical object itself moves. Instead, the user would need to manually anchor the object again, "re-anchoring" the virtual object to the physical object's new position. This limitation is illustrated in figure 16.



(a) Using controllers to manually specify anchor graphics to a sheet of paper

(b) Virtual graphics will be shown at the initial anchoring point

(b) Moving the paper, the virtualgraphics will not follow

Figure 16: Manual anchoring being performed (a,b), and the limitations of its movement (c).

### 4.6.1 Fragility of Anchors

Anchoring relies on overlapping the virtual world on top of the physical. These worlds need to be consistent. This means that there should be a direct relationship between the user's movement in the physical world and the virtual world. Teleporting or walking by using the controllers in the virtual environment would diverge the overlapped virtual world from the physical. This would cause inconsistencies to virtual objects anchored to the physical world. This means that applications relying on anchors, especially manually placed ones, should have a world smaller or equal to that of the physical room to allow for the user to move properly.

### 4.6.2 Persistent Anchors

Features in recent headsets, called *spatial anchors* [77], allow for the use of persistent anchors. These anchors will persist even if the headset is displaced or the application is reset. This is done by allowing the sensors to anchor the virtual-world in relation to the surroundings of the user, which the headset is able to continuously track.

# 5 Prototype Application

In this section, the development and implementation of the prototype XR board game application is covered. After a thorough review of existing augmented board games, no existing XR board game applications featuring tangible piece interaction was found. To study the feasibility, usability and user experience of such an application, a prototype application was developed. For this thesis, the prototype development was mainly a means to allow exploration of the research questions as defined in 1.3, and is therefore only discussed on a surface level, despite being a significant part of the research.

The code for the prototype application discussed in this thesis is available on a GitHub repository, accessible through the following link: https://github.com/Nicolaad/Master

## 5.1 Motivation

The primary goal of the prototype was to augment a physical board game with extended reality technology and introduce a way to interact with physical board game pieces while playing with XR devices. The main idea was based upon using a physical gameboard with pieces while wearing an XR device, and somehow ”transfer” the board state to the XR headsets so that virtual, digital twin representations of the physical pieces would move accordingly. This could facilitate a way for players to experience augmented board games that closely resemble physical board games, while adding a layer of virtuality and digital elements on top to create a more immersive experience. This was thought to bring value to research through user testing, where the effect of tangible piece interaction on the usability and user experience could be analyzed through having users test the prototype application both with and without physical pieces. When performing user tests that revolved around evaluating the user experience in XR, it also felt natural to analyze the impact of the virtual and physical environments on the players’ experiences. This led to adding multiplayer functionality and allowing players to play in both VR and AR environments, playing against each other both co-located and remotely, and playing against digital avatars.

## 5.2 Prototype Features

The most essential features of the prototype application are presented in table 17.

| Feature | Description |
|---|---|
| Instantiate (spawn and anchor) virtual chessboard | The user should be able to instantiate a virtual chessboard. The size and the location of the chessboard should be configurable, so that it can be spawned ”on top” of a physical chessboard or on a physical surface. |
| Multiplayer functionality | Multiple players should be able to connect to the same server and play against each other using the virtual chessboard. |
| Cross-platform compatibility | The application should be fully playable for the Meta Quest 2 and the Microsoft Hololens 2. |
| Avatars | The players should be able to see a virtual representation (avatar) of the other connected players. |
| Player and board synchronization | When connected, the players are always positioned relatively to the board and the other player |
| Virtual environment | It should be possible to play in a fully virtual environment (VR) and in a partially virtual environment (AR) |

Figure 17: Prototype features

## 5.3 Choice of Board Game

The research questions were based around exploring the usability and user experience of different approaches of moving board game pieces, as well evaluating virtual environments and their effect on the user experience. Therefore, the type of board game developed for the prototype was in itself not very important. However, it was decided to use an existing board game, since this would reduce the time spent on developing an entirely new game concept and design. Another important factor was to use a game that test users were likely familiar with, so that they would not have to spend much time on learning the rules of the game. For these reasons, chess was chosen as the board game to be implemented in the prototype application.

## 5.4 Software

### 5.4.1 Unity Setup

The prototype application was developed in Unity version 2020.3.42. This version was mainly chosen due to its compatibility with Microsoft's Mixed Reality Toolkit 2 (MRTK2) and the OpenXR plugin, which were used to setup the XR configuration in Unity. The 3D core template was selected upon project initialization. A new scene was created. The entire prototype application uses the same scene.

### 5.4.2 OpenXR

Mixed Reality OpenXR (OpenXR) is a plugin compatible with a wide variety of XR devices, including the Meta Quest 2 and the Hololens 2. OpenXR abstracts the hardware and software differences between XR devices, and simplifies the development process by allowing developers to create cross-platform compatible applications without having to rewrite code.

### 5.4.3 Mixed Reality Toolkit 2

To enable seamless builds to both devices (the Hololens and the Quest), Microsoft's Mixed Reality Toolkit 2 (MRTK2) was used. MRTK2 is a development toolkit that can accelerate cross-platform XR development. In the prototype, some of the used features from MRTK2 includes components and scripts for handling object manipulation and interaction in mixed reality, UX components (e.g. buttons and input fields), and the input management system, which enables hand-tracking in XR.

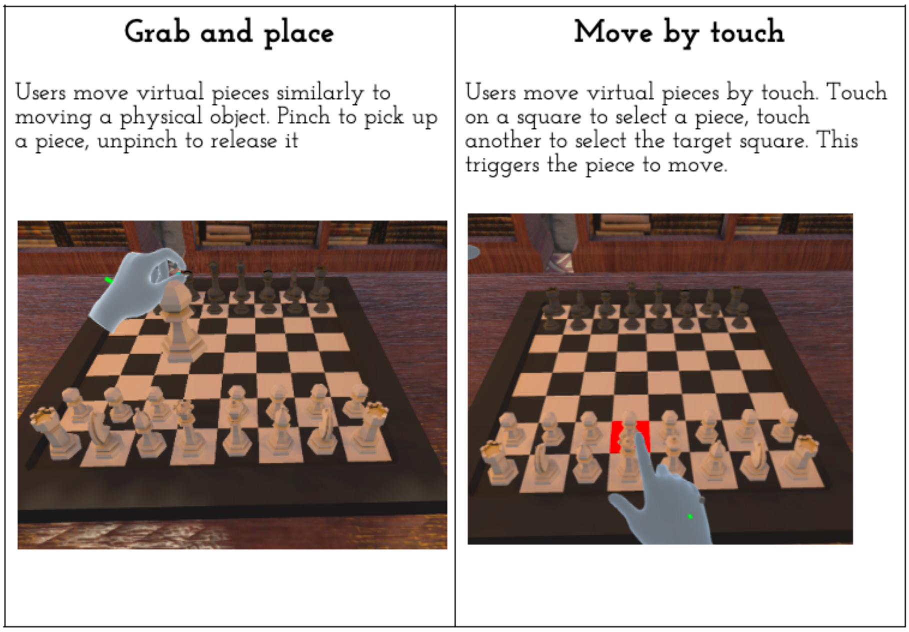
### 5.4.4 Plugin Setup and Installation

MRTK2 and OpenXR was setup in the Unity project by following Microsoft's documentation [78]. Having installed the necessary packages in the project, MRTK was added to the scene. Separate configuration guides were used to enable building and deploy the application to the Quest [79] and the Hololens [80] devices.

## 5.5 Virtual Chessboards

A chessboard prefab asset [81] was downloaded from Unity Asset Store. The prefab includes a chessboard and chess pieces, as seen in figure 19. The board and pieces were separate Unity GameObjects without functionality, and had to be configured in order to make them interactable.

Using the downloaded chessboard assets, two different chessboard prefabs were developed with the intention of testing two different approaches to moving physical and virtual board game pieces simultaneously. These are referred to as the "grab-and-place" chessboard, and the "move-by-touch" chessboard. The two chessboards look identical, but have different interaction methods for moving the pieces.



Grab and place

Users move virtual pieces similarly to moving a physical object. Pinch to pick up a piece, unpinch to release it

Move by touch

Users move virtual pieces by touch. Touch on a square to select a piece, touch another to select the target square. This triggers the piece to move.

Figure 18: The grab-and-place chessboard and the move-by-touch chessboard

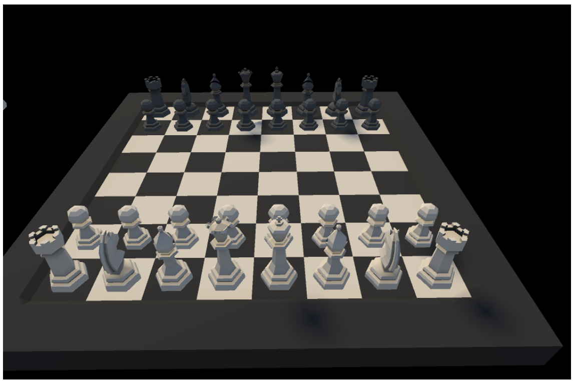


Figure 19: Chessboard prefab

### 5.5.1 Grab-and-place Chessboard

The grab-and-place chessboard was configured to allow users to pick up, hold, and drop chess pieces similarly to the way in which pieces and physical objects are moved in the real world. To enable users to move and manipulate the pieces with their hands, an *objectManipulator* [82] script and *nearInteractionGrabbable* [83] script was added to each chess piece in the grab-and-place chessboard prefab. These scripts were provided by MRTK2, and did not have to be modified.

The objectManipulator script enables objects to be movable, scalable and rotatable using one or two hands. The nearInteractionGrabbable script makes it possible to grab objects by pinching, and releasing them by unpinching. This only works on game objects with a collider component, so a MeshCollider component was added to the chess pieces.

### 5.5.2 Move-by-touch Chessboard

The move-by-touch chessboard prefab was configured to allow the user to move the chess pieces by touching the chessboard squares, as illustrated in figure 28. To move a piece, the user taps on the square which contains the piece to activate it, before tapping on the target (destination) square. This causes the piece to move automatically with a constant speed until it reaches the destination square. If there is a piece in the destination square, the piece is automatically captured.

This functionality was developed by creating an 8x8 grid of invisible, empty GameObjects, with each GameObject (cell) being positioned so that they corresponded to a square on the chessboard. A NearInteractionTouchableVolume component (provided by MRTK) [84] was added to each cell to make them touchable. Two additional scripts, *squareHandler.cs* (Appendix 11.3) and *handleActiveSquares.cs* (Appendix 11.2) were developed to handle the logic of accessing the piece upon touch detection, moving them to the destination squares, and handling piece captures.

## 5.6 Navigation Menu

A navigation menu (displayed in figure 20) was developed in order to make it easy to configure the application settings during the user tests. The most important buttons are "Instantiate Board" (starts the board instantiation process), "Toggle Avatar" (enables/disables player avatars), "Toggle passthrough" (enables/disables passthrough, switches between AR/VR mode) and the board toggler, which decides which board type is used in the instantiation.

As the users did not have to interact with the menu themselves, it was not considered important to make it particularly user-friendly and intuitive.

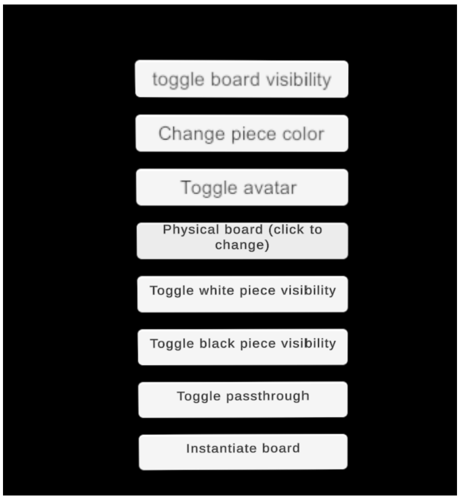


Figure 20: Navigation Menu

## 5.7 Chessboard Instantiation

To begin the instantiation process of spawning the virtual chessboard, the user presses a "Start Setup" button. The passthrough setting is enabled in the prototype application by default when using the Meta Quest, making the physical environment visible to the user. As the Hololens is an optical see-through device, the physical environment is also fully visible by default. Before starting the instantiation process, the user can choose between instantiating the grab-and-place chessboard and the move-by-touch chessboard by selecting the board type in the navigation menu.

The board instantiation works by placing two virtual markers on a physical surface to set the position of the virtual chessboard. The markers are represented as red pins (spheres with an attached cross). The pins can be dragged around and repositioned within the scene. Having pressed the "Start Setup" button, the first pin is presented to the user. The placement of the first pin determines the position of the bottom-left corner of the virtual chessboard. Once the position of the pin is confirmed, a second pin shows up. The placement of this pin determines the position of the top-right corner of the virtual chessboard. The distance between the pins represents the diagonal distance of the board, and determines the size of the board. Figure 21 shows the steps of the instantation process. To instantiate a virtual board on top of a physical chessboard, the pins must be placed on the corners of the physical chessboard, as illustrated in figure 22. If not using a physical chessboard, the virtual chessboard can still be instantiated on a physical surface such as a table, which makes it possible to touch the virtual chessboard and the physical table at the same time when using the move-by-touch chessboard.

(a) Clicking the "start setup" button initializes the instantiation process

(b) First marker is placed on the bottom-left corner of the board

Confirm board placement

Please press confirm if you are satisfied with the mapping of the board. Please press the button if you wish to quith the proccess inseatd

(c) Second marker is placed on the top-right corner of the board

(d) Marker placement is confirmed, instantiates the virtual board on the marked position

Figure 21: Steps in the board instantiation process

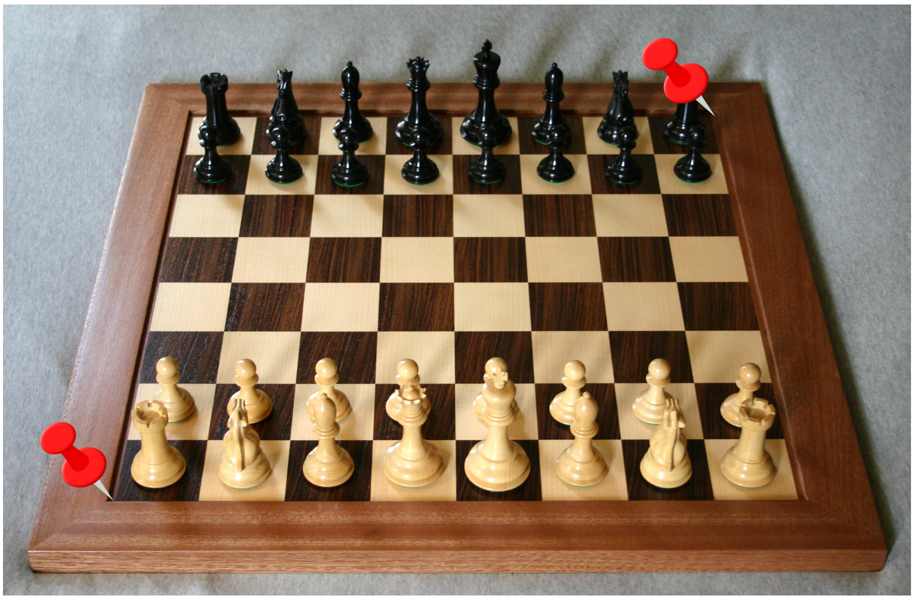


Figure 22: Image illustrating where the markers should be placed to instantiate the virtual board on top of a physical chessboard. Original image source: [85]

## 5.8 Multiplayer implementation

### 5.8.1 Netcode for GameObjects

Unity's Netcode for GameObjects (NGO) [86] networking library was used for abstracting networking logic, and sending world data across the networking session. It was installed through the package manager in the Unity project.

Unity's documentation [87] was followed in order to implement networking logic in the prototype application. A NetworkManager GameObject with an attached NetworkManager component (provided by NGO) was added to the scene. This component handles spawn management, which determines how the connected players are represented in the virtual space. The network manager was also used to determine where the players were spawned when connecting to the server.

By default, the GameObjects in Unity are not synchronized between the players in the network. This means that if one player moves an object in the scene, the state of the same GameObject remains unchanged for other connected players. To allow synchronization of GameObjects, a NetworkObject component was added to the chess piece GameObjects. This was required to enable connected players to send or receive remote procedure calls (RPCs). RPCs are necessary to allow connected clients to request ownership of the chessboard whenever they want to move a piece, as NGO is server-authoritative, and therefore does not allow clients to move GameObjects without permission.

To allow the board state (position of the pieces) to be synchronized between the players, a ClientNetworkTransform component (provided by NGO) was added to the chesspieces. This way, the position of the pieces are updated for each player connected in real-time, and the players can see each other interact with and move the chesspieces.

### 5.8.2 Unity Relay

Unity Relay is a multiplayer service provided by Unity. It allows multiple players to connect to a dedicated server instance. Using Unity Relay, players can create a session as a host. The host is given a "join code", which can be sent to other players, who can enter the code in order to join the session as clients.

Unity's Relay documentation [88] was followed in order to implement a Relay system in the application. The script that provides functions for creating and joining relay sessions can be found in the appendix, section 11.5.

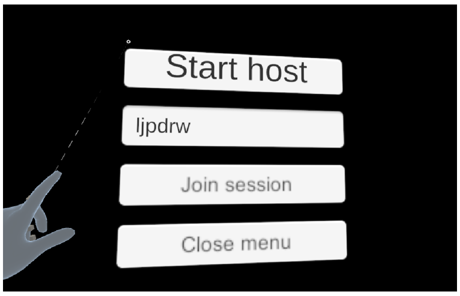


Figure 23: User interface for starting / joining server

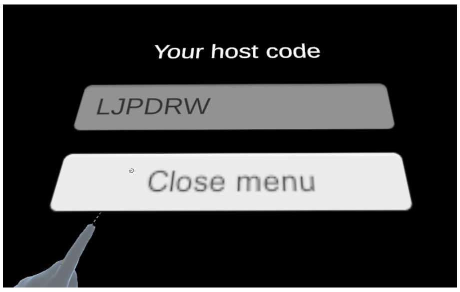


Figure 24: The generated host code is displayed on the screen

Upon starting the prototype application, a UI menu is presented to the user, as shown in figure 23. This menu features a ”Start host” button. When pressed, the CreateRelay function is triggered, which creates a new Relay session as a host, and presents a join code for the host. To join the session, other users can enter the code in the ”enter join code” field (second from the top in figure 23, and press the ”join session” button.

### 5.8.3 Player Avatars

A simple prefab avatar consisting of a head, arms and a body was created, as seen in figure 25. The head prefab was downloaded from the Unity asset store [89].

In the NetworkManager component, the ”player prefab” GameObject was set to the avatar prefab. This way, each player connected to the Unity Relay server are uniquely represented by the avatar prefab. The avatars are hidden by default but can be displayed by toggling the ”Toggle avatar” button in the navigation menu.

To make the head, arms and the body follow the physical movements of the player wearing the XR device in real-time, simple scripts were added to these gameobjects that receives data from the XR device through the MRTK input system in every frame, and updates the transform (position and rotation) of the respective GameObjects accordingly. The transform data from the head mesh was set to track the transform of the main camera in the scene, which is the viewpoint of the player.

The script developed to access the hand positions (*getHandPos.cs*) can be found in the appendix, section 11.4). Similarly to the chess pieces, a NetworkObject component and a ClientNetworkTransform component was added to make the movements visible for all players in the networking session.

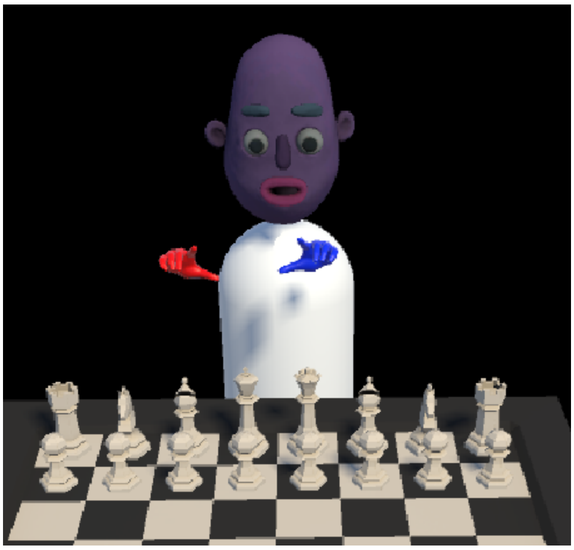


Figure 25: The avatar used for player representation

## 5.9 Virtual Environment

The VR scene environment used in the prototype was a medieval library room, as seen in figure 26. The scene was downloaded from the Unity Asset Store [90], and configured so that the board was instantiated on top of a virtual table within the scene. By clicking the "Toggle passthrough" button in the navigation menu, the user can switch between seeing the VR scene environment, and being in AR mode, where the physical environment is viewable and the virtual board and avatars (if turned on) are the only virtual elements in the scene.

Figure 26: The VR Scene. Source: [90]

# 6 Method: User Test

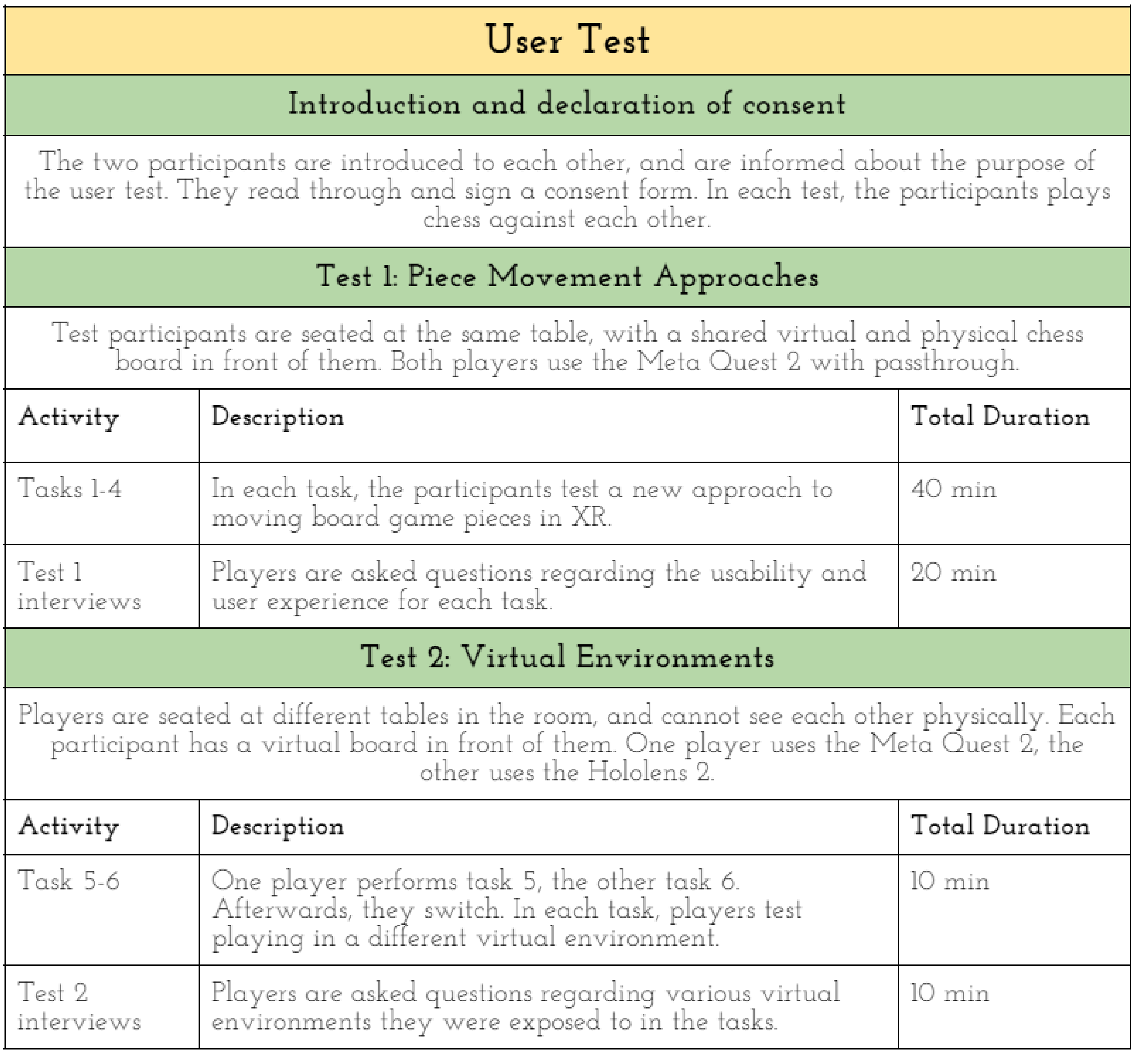
## 6.1 Test Setup

The user test was divided into two parts. The first test, *Test 1: Piece Movement Approaches* was both a usability test and a user experience test, whereby test participants explored four different approaches to moving virtual board game pieces while using the XR prototype application. In the second test, *Test 2: Virtual Environments*, users tested playing in different virtual environments in XR. Test 1 was the main test, as it covered **RQ1**, **RQ2** and **RQ3**. Test 2 was a secondary test, exploring **RQ4**. Each test featured two participants playing chess against each other. Subsequently after each test, an interview round was conducted with the participants. A brief outline of the user test is displayed in Table 1. More thorough descriptions for each test and the individual tasks are detailed in subsections 6.3 and 6.4.

## 6.2 Participants

The most important criterion when recruiting participants was that they represented the target user group: they had prior experience with playing board games, and were familiar with or interested in XR technology. To attract suitable participants, an interest form was sent out to students through a student organization communication channel. The interest form explained the prototype concept and the purpose of the user test, as this was deemed to be an appropriate way of attracting target users. A total of 12 participants were recruited, forming six individual pairs, each scheduled for testing at different time slots.

Upon entering the test room, the two participants in each test were introduced to each other. Then, they were handed a declaration of consent form (appendix 11.1), explaining the information that would be stored about them, in addition to the purpose of the test. Once they had filled out the consent form, they also filled out a short questionnaire (appendix 11.6) in which they were asked about their experience with playing board games and XR technology. In the questionnaire, eleven of the participants reported having used XR devices a few times, and one participant used them regularly. Four participants reported that they played board games once or multiple times a week, six played roughly 1-2 times a month, and the remaining two played board games a couple of times a year. All participants fell within the age range of 22-26 years old. Among the twelve participants, there were eleven males and one female. Eleven were students, and one was working full-time. Information about each participant is presented in table 2.



**User Test**

**Introduction and declaration of consent**

The two participants are introduced to each other, and are informed about the purpose of the user test. They read through and sign a consent form. In each test, the participants plays chess against each other.

**Test 1: Piece Movement Approaches**

Test participants are seated at the same table, with a shared virtual and physical chess board in front of them. Both players use the Meta Quest 2 with passthrough.

| Activity | Description | Total Duration |
|---|---|---|
| Tasks 1-4 | In each task, the participants test a new approach to moving board game pieces in XR. | 40 min |
| Test 1 interviews | Players are asked questions regarding the usability and user experience for each task. | 20 min |

**Test 2: Virtual Environments**

Players are seated at different tables in the room, and cannot see each other physically. Each participant has a virtual board in front of them. One player uses the Meta Quest 2, the other uses the Hololens 2.

| Activity | Description | Total Duration |
|---|---|---|
| Task 5-6 | One player performs task 5, the other task 6. Afterwards, they switch. In each task, players test playing in a different virtual environment. | 10 min |
| Test 2 interviews | Players are asked questions regarding various virtual environments they were exposed to in the tasks. | 10 min |

Table 1: User Test overview

| **Participant** | **Gender and Age** | **Board Game Experience** | **XR Experience** |
|---|---|---|---|
| P1 | F26 | Plays a couple times a year | Tried a few times |
| P2 | M24 | Plays weekly | Tried a few times |
| P3 | M22 | Plays a couple times a year | Tried a few times |
| P4 | M24 | Plays about once a month | Tried a few times |
| P5 | M24 | Plays about once a month | Tried a few times |
| P6 | M22 | Plays about once a month | Tried a few times |
| P7 | M25 | Plays weekly | Tried a few times |
| P8 | M24 | Plays weekly | Tried a few times |
| P9 | M23 | Plays about twice per month | Tried a few times |
| P10 | M24 | Plays about once a month | Tried a few times |
| P11 | M25 | Plays daily | Tried a few times |
| P12 | M26 | Plays about once a month | Use it regularly |

Table 2: Participant Details. Participants in the same pair has the same color

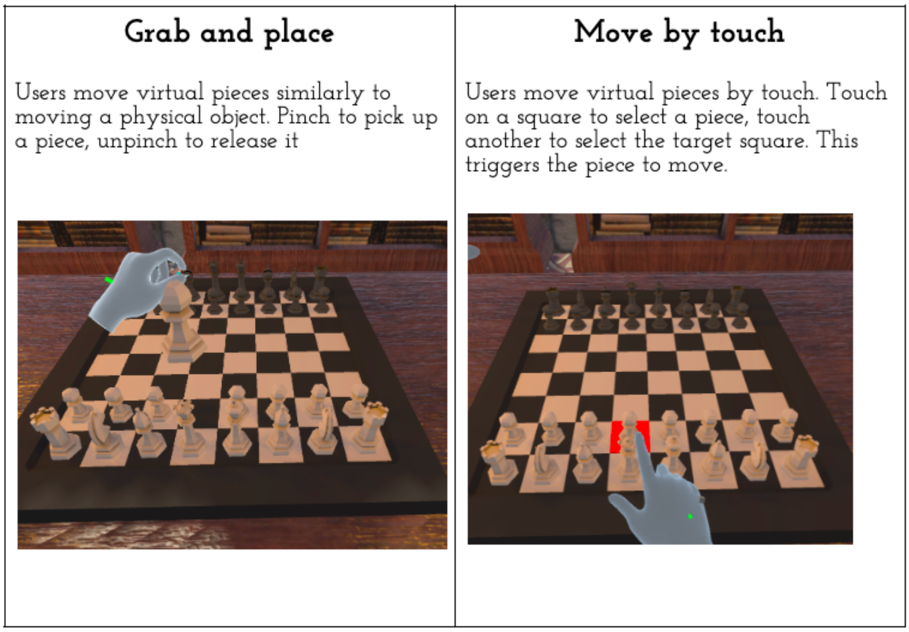
## 6.3 Test 1: Piece Movement Approaches

In this test, each participant was handed a Meta Quest 2 device running the prototype application. The passthrough setting was turned on, making the physical environment visible to the players when wearing the head-mounted display. The players were seated on each side of a table. A physical chessboard was placed on the table. The chessboard was used as a reference point, and a virtual chessboard with virtual chess pieces was instantiated on top of it. One player got the white pieces, and the other got the black pieces. Players were informed that the chess game itself was not important, and that the focus was on their interaction with the chess pieces. They were also told to think out loud about what they experienced when testing the piece movement approaches.

Figure 27: Picture captured from one of the user tests

### 6.3.1 Piece Movement Mechanisms

A *Piece movement mechanism* is defined as a way to move virtual board game pieces. The prototype application features two piece movement mechanisms, referred to as *Grab-and-place* and *Move-by-touch*. These are explained in figure 28. Each of the two piece movement mechanisms were tested with and without physical pieces, creating a total of four *piece movement approaches*.



**Grab and place**

Users move virtual pieces similarly to moving a physical object. Pinch to pick up a piece, unpinch to release it

**Move by touch**

Users move virtual pieces by touch. Touch on a square to select a piece, touch another to select the target square. This triggers the piece to move.

Figure 28: Screenshot displaying the piece movement mechanisms within the application

### 6.3.2 Tasks

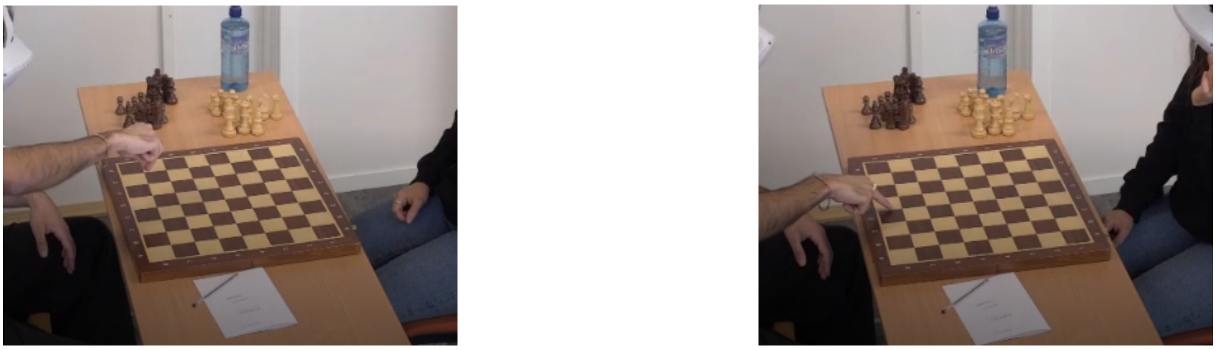
In each task, the participants tested a new piece movement approach. These are explained in Table 3. Images displaying each piece movement approach are shown in table 4. First each participant were instructed to make one move each with a virtual piece. Once they understood the piece movement approach, they played a game of chess against each other.

In the first two tasks, users were introduced to the two ways to move virtual pieces, namely the grab-and-place mechanism, and the move-by-touch mechanism. After getting familiar with these, they tested the same two mechanisms again with another approach, this time playing with a physical chessboard with pieces in front of them. These tests lasted longer, as the added complexity of physical pieces was presumed to take longer to get used to.

| Task Name | Task Description | Duration |
|---|---|---|
| 1. Grab-and-place, virtual pieces | Taking turns, players move virtual pieces using the grab-and-place mechanism. | 7 min |
| 2. Move-by-touch, virtual pieces | Players move virtual pieces using the move-by-touch mechanism, using a physical table as an interface to touch and select the start square and target square. | 7 min |
| 3. Grab-and-place, virtual and physical pieces | Players move virtual and physical pieces simultaneously, using the grab-and-place mechanism to move the virtual pieces. | 13 min |
| 4. Move-by-touch, virtual and physical pieces | Players move virtual and physical pieces simultaneously, using the move-by-touch mechanism to move the virtual pieces | 13 min |

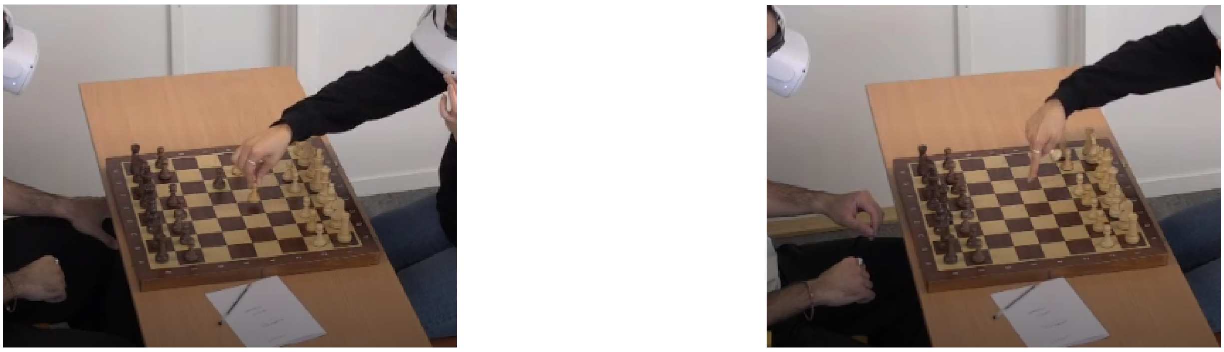
Table 3: Tasks in test 1

Table 4: Piece movement approaches



Task 1: Grab and place, virtual pieces

Task 2: Move by touch, virtual pieces



Task 3: Grab and place, virtual and physical pieces

Task 4: Move by touch, virtual and physical pieces

### 6.3.3 Test 1 Interviews

Once all four tasks had been completed, the participants were asked questions about the usability of each piece movement approach. They were asked to rank each approach based on usability, and to name the advantages and disadvantages of using the different approaches. They were also asked about how the addition of tactility with physical pieces impacted the user experience compared to only using virtual pieces. Since there were some known weaknesses with the technical implementation which affected the usability negatively, the participants were also asked about their general thoughts about the concepts behind each approach, and which approach they would prefer to use if the physical and virtual pieces and boards were perfectly aligned and "synchronized".

## 6.4 Test 2: Virtual Environments

In this test, the goal was to gather enough information to address **RQ4**. This time, the two players were seated at different locations within the test room, unable to see each other physically. Test 2 consisted of two tasks (tasks 5 and 6). One participant started with task 5, while the other started with task 6. Thereafter, the participants switched tasks. In both tasks, they played using the *grab-and-place, virtual pieces* piece movement mechanism. In this test, the players were not interrupted while playing. This was intentional to allow them to fully focus on playing.

### 6.4.1 Tasks

In task 5, the players used the Meta Quest 2 device, and were introduced to a fully virtual environment, with no view of the physical world around them. The virtual environment was a medieval library scene, and the virtual board was spawned on top of a virtual table, as seen in figure 29.

In task 6, they players used the Hololens 2 device. Here, they had a complete view of the physical environment, and they could also see virtual elements (i.e. the virtual chessboard and pieces) as holograms spawned on top of a physical table.

In both tasks, they first played against each other without being able to see the other player. After a few minutes, the avatar setting was activated, enabling them to see a virtual representation of the other player, represented as the avatar seen in figure 29.

| Task Name | Task Description | Duration |
|---|---|---|
| 5. Play in VR environment | The player uses the Meta Quest 2 device, and is placed in a fully virtual environment (”world”), with the chessboard spawned on top of a virtual table. First, they play without seeing their opponent, then they continue the game with the avatar setting toggled on, making the other player’s avatar visible. | 5 min |
| 2. Play in AR environment | The player uses the Hololens 2 device, and has a complete view of the physical environment around them. The virtual chessboard is displayed as a hologram, spawned on a physical table in front of them. First, they play without seeing their opponent, then they continue the the game with the avatar setting turned on, making the other player’s avatar visible. | 5 min |

Table 5: Tasks in test 2

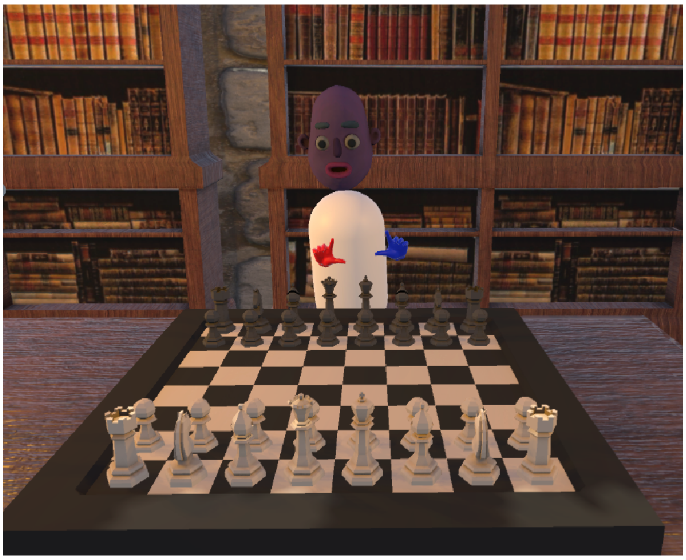


Figure 29: Point-of-view from test 5

### 6.4.2 Test 2 Interviews

Once finished with the tasks, another round of interviews was conducted. Here, the participants were asked about whether the visual environment during play affected the playing experience in a meaningful way, and if they preferred playing in a fully virtual environment or in an AR environment. Moreover, they were asked to compare the playing experience when playing against an ”invisible player”, and while seeing the opponent represented as a digital avatar. They were asked whether the avatars made them feel a higher sense of social presence, and about whether they thought the appearance of the avatar was important to the overall player experience.

## 6.5 Location and Equipment

The user tests were conducted in the UX lab at NTNU. The lab provided equipment for video and audio recording. This made it easy to focus on observing and communicating with the participants during the tests. Three main cameras were used during the user tests. One camera captured footage of the participants from distance. A second camera captured close-up footage of the table on which the virtual chessboard was spawned. A third camera was used to capture video from the interviews. In some of the tests, the Meta Quest 2 devices were set up to record the view from within the headset.

## 6.6 Data Analysis

Following the completion of the interviews, the recorded video footage from each session was securely downloaded and stored on private computers and a memory stick to ensure data backup. The next step involved transcribing the interviews and statements during gameplay, with each transcript being organized and stored in a designated file. The transcribed data was then individually organized for each participant, with focus on the segments that appeared to be relevant to the research questions. To facilitate analysis, a spreadsheet table was created, where questions or themes were assigned as columns and participants as rows. Each cell in the table captured the corresponding participant's opinion or response to the specific question or theme. This structured table served as the basis for quantifying the frequency of specific opinions or responses for each topic, enabling a systematic analysis of the data. As the data analysis was qualitative and the number of participants was fairly low, it was not considered necessary to focus on statistical measures.

In addition to the transcription, the video footage from the sessions were used to analyze the interaction between the players, as well as the players' interaction with the physical and virtual pieces when playing. These observations were not analyzed in detail, but were used to identify the techniques used to move pieces, and to roughly estimate the time and effort spent when executing moves using the different approaches.

# 7 Results

## 7.1 Test 1: Piece Movement Approaches

### 7.1.1 Grab-and-place, Virtual Pieces

Figure 30: Headset view

Figure 31: Outside view

None of the test participants experienced major problems when using the grab-and-place mechanism to move virtual pieces on the gameboard. All participants were eventually able to complete basic tasks such as picking up pieces, moving them to specific squares, and letting go of the pieces without issues.

Two participants mentioned that they had some trouble picking up pieces initially. Neither of these participants were familiar with hand-tracking in VR, and experienced that a few pieces were not picked up when they attempted to. The users were asked if the virtual hand changed color when pinching (which indicates that the hand interacts with an object), which it did not. This indicated that their pinching gesture was not registered by the headset. Once they were made aware of this, they made sure to make their pinching gesture more observable, and they did not experience any further problems. All participants quickly understood how to move pieces, and everyone managed to play seamlessly.

No participants had any complaints regarding the usability of this approach, and several positive elements were mentioned. Four participants said that it worked very well. Three talked about the ease-of-use, mentioning that that it was intuitive and easy to control the pieces. Participant 9 (P9) mentioned that it was very smooth and bug-free, which was backed by P10.

When asked about whether the lack of tangibility affected the usability, several participants mentioned that this was not an issue. One participant (P6) stated that grabbing virtual objects felt awkward initially due to the lack of tactility, but elaborated that they quickly got used to it. Another said that the visual feedback when interacting with the pieces was sufficient to gain control of the pieces.

> *"Despite the lack of tangibility, the visual feedback whenever i picked up or dropped the pieces was sufficient"*
> - Participant 4

Regarding the user experience with this approach, the participants were also very positive. Although most participants had some experience with using XR devices, most were not familiar with hand-tracking as an interaction method. Four participants described the approach as "cool". Five participants mentioned that the approach was very interactive, which contributed to increasing their level of enjoyment:

> *"I liked having to physically use my hands to move the virtual pieces, it was very interactive"*
> - Participant 6

> *"Even though i wasn't holding the piece physically, it felt real since i had to perform the same physical movements and gestures"*
> - Participant 7

> *"It was considerably more engaging than moving chess pieces by using a mouse on a computer"*
> - Participant 5

A common opinion among the participants was that the ease-of-use with this approach also positively affected the user experience:

> *"The user experience correlates with the usability, and moving pieces this way was very easy"*
> - Participant 1

Many talked about the realism of the approach as a positive element, and said that despite the lack of physical interaction, the feeling they experienced while interacting with the virtual elements still felt real. One participant mentioned that while moving a piece, they made sure to not hit other pieces, and naturally lifted the piece over the others even though pieces colliding would not be an issue with virtual pieces:

> *"It [interacting with the virtual pieces] felt so real that i was careful not to hit other pieces when moving*

*a piece"*

\- Participant 8

When asked whether they thought the lack of tangible piece interaction affected the user experience, most did not think it was particularly important:

*"Although i lost the sense of physically feeling the pieces, i did not really think much about it"*

\- Participant 10

### 7.1.2 Move-by-touch, Virtual Pieces

Figure 32: Headset view

Figure 33: Outside view

This piece movement approach introduced the players to some element of tactility, by spawning the chessboard on a physical table, allowing the players to move pieces by physically touching the table.

Users generally considered this method very intuitive. All users quickly understood how the mechanism worked, and for the most part managed to move pieces to the intended squares on the virtual chessboard. One mentioned reason for the method being intuitive and easy to learn was the resemblance of playing chess on a computer:

*"It was similar to moving pieces when i play chess online, except that you use the hand instead of a mouse to select the squares"*

\- Participant 6

Another mentioned that this approach was practical to use, since it required little effort to move the pieces properly:

> *"I liked that the pieces moved automatically to the center of the squares, it gave me a feeling of control"*
>
> \- Participant 5

One participant noted that pieces being captured automatically was nice, as this way, they did not have to manually move the captured piece off the board by themselves.

Although most participants were also generally positive regarding the usability of the move-by-touch method, several people identified some usability issues. When interviewed, high/unpredictable sensitivity was frequently mentioned. When playing, all participants noticed this. Many participants struggled to activate certain squares on the board by touch, and sometimes accidentally clicked on the wrong square, which caused the wrong piece to move or resulted in the piece being moved to the wrong square. As no "takeback" functionality was implemented, this disrupted the flow when playing.

Another usability issue with the virtual board was that it was not always perfectly aligned with the height of the physical chessboard it was spawned upon. As the boards were re-instantiated manually for each VR headset during each test, this was only a usability issue for some participants, while others did not notice it. Some experienced that the virtual board was placed too high, causing squares to be activated before they touched the physical board, whereas others experienced that they struggled to activate squares because the virtual board was spawned underneath the physical chessboard. The latter was recognized as a bigger issue, as this could effectively make the virtual board impossible to interact with. With a couple of participants, this became a major issue, so a new virtual board was instantiated with proper alignment to mitigate this issue.

Regarding the user experience with this approach, the opinions were mixed. The participants were asked both about the user experience with the approach both when they tested the prototype, and more generally, about how they would feel about it in an "ideal" scenario, as there was considerable room for improving technical aspects and removing bugs.

Two participants particularly enjoyed that the pieces automatically moved to the target squares upon touching them, and thought this brought an element of "magic" to the playing experience.

> *"Watching the pieces move automatically in 3D kind of felt like magic"*
>
> \- Participant 8

This participant further went on to compare it to wizard chess in Harry Potter, and thought there was a potential in facilitating piece interaction that differed from the way they interacted with objects in the physical world.

A total of three participants stated that the automatic movement of the pieces was a "cool" or "nice" effect. One participant mentioned that interacting with the pieces by using the chessboard as a physical interface was a plus:

> *"I enjoyed this method because i received tactile feedback. It felt as if i was actually touching the virtual chessboard"*
> - Participant 8

On the other hand, one participant was somewhat skeptical of using the move-by-touch mechanism in virtual and augmented reality:

> *"I am not sure if i see the point of moving objects this way in VR"*
> - Participant 4

This participant thought "the point" of VR was to emulate the way in which they interacted with objects in the real world, and did therefore not think this approach was ideal.

### 7.1.3 Grab-and-place, Virtual and Physical Pieces

Figure 34: Headset view

Figure 35: Outside view

In this test, users tested moving virtual pieces and physical pieces simultaneously using the grab-and-place piece movement mechanism.

Moving the physical and virtual pieces at the same time proved to be difficult for the participants. The average time spent on executing moves significantly increased for every participant compared to the previous approaches. A commonly mentioned reason for this was that the virtual piece was not picked up along with the corresponding physical piece. The players were again instructed to make sure that the virtual hands should change color when grabbing the physical piece to make sure that the virtual piece was also picked up. However, many participants experienced that the hand did not change color, indicating that the XR headset struggled with detecting the pinch (grab) gesture. The participants were made aware that they could try other methods, including picking up the physical pieces by pinching/holding near the tip, or closing their fists when picking up the piece to make the gesture more detectable. After some trial and error, most were able to execute moves more quickly. However, none were not able to play seamlessly, and everyone spent some time to make sure that they managed to move both pieces simultaneously.

Many participants creatively experimented with other ways of executing moves when struggling to pick up the physical and virtual piece simultaneously. The most common method was to pick up the physical piece, then pinch to pick up the virtual piece, before moving the pieces to the target square in unison. Others did it the other way around, pinching to grab the virtual piece, before grabbing the physical piece. Although this reduced the time spent on executing moves, it resulted in other problems. Firstly, as the virtual pieces were placed at the same position as the physical pieces, the physical pieces were not visible to the players. During the start of the game, the pieces were aligned so that the physical and virtual piece were located at the same position, but as the game progressed and pieces were moved, it became more difficult to locate the physical pieces:

> *"In the beginning [of the game], the pieces were aligned well, but after a while, the misalignment of the physical and virtual pieces became a bigger problem"*
> - Participant 6

When this became a significant problem, the virtual chessboard (only the board, not the pieces) was deactivated, so that the players could move the virtual pieces on the physical chessboard. This way, it became easier to locate the physical pieces if they were not aligned with the virtual pieces, and realign them by placing the virtual piece on top of the physical piece. One participant mentioned that this made the piece movement approach more usable:

> *"The synchronization between the virtual and physical pieces did not work that well, but it was not a big problem since i could always adjust and realign them quickly if they became unsynchronized"*
> - Participant 5

Still, most participants expressed that that having to move both pieces simultaneously was cumbersome, since they often had to realign the pieces or pick up the virtual and physical pieces one by one:

> *"With this method, i had to pick up the virtual and physical pieces separately, which was a bit frus-*

*trating"*

- Participant 6

*"It required two operations to pick up the pieces, so i did not find it that usable"*

- Participant 2

Regarding the user experience, many expressed that it felt very satisfying when they did manage to move the virtual and physical piece simultaneously:

*"It was very satisfying when i managed to move both pieces simultaneously."*

- Participant 5

*"It felt really cool when it worked"*

- Participant 2

One participant was especially excited, mentioning that the tangibility added another dimension to XR:

*"Physically holding the piece 100% had a positive effect on my user experience. It adds a new dimension to VR"*

- Participant 5

#### 7.1.4 Move-by-touch, Physical and Virtual Pieces

Figure 36: Headset view

Figure 37: Outside view

In this test, the participants moved pieces by picking up the physical piece, using the move-by-touch mechanism to move the virtual piece, and then dropping the physical piece on the target square.

Compared to the grab-and-place mechanism with physical pieces, the participants on average executed moves faster using this approach, but with lower accuracy. Many noted that one disadvantage with this approach was that more operations were required to execute moves:

> *"I did not really like this method, as it required four steps to move the piece"*
>
> - Participant 1

Four others said something similar, mentioning that the added number of steps negatively affected the usability of the approach. Still, a total of five participants thought executing moves with physical pieces was easier with this approach compared to the grab-and-place method, as each step could be performed relatively quickly, and because they did not have to bother with re-aligning the virtual and physical pieces that often:

> *"The method was relatively straight-forward, and i did not have to concentrate too much on moving the pieces correctly"*
>
> - Participant 10

Another usability issue that led to some confusion among the players was when they attempted to capture pieces on the gameboard. The touch-board mechanism automatically removed the captured virtual piece from the board, whereas the players had to manually remove the captured physical piece off the board. When removing the physical piece from the square, they had to be careful not to accidentally click on the square again to cause the piece to move again.

P7 mentioned that although this approach required more steps, it was more consistent compared to the grab-and-place mechanism with physical pieces, and therefore thought it was more usable. Seemingly, they thought it was easier to perform multiple "easy" steps, compared to the grab-to-place mechanism, which required less steps, but was harder to perform. This participant also said the method still felt natural. Similarly, P10 said that this method was "less of a hassle" compared to the grab-and-place mechanism with physical pieces.

Although many thought it was easier to perform moves, many struggled to see the upside of using physical pieces using this interaction method, as they thought the physical and virtual pieces felt like two separate entities:

> *"The virtual and physical piece did not feel like the same piece"*
>
> Participant 11

> *"With this method, the virtual and physical pieces felt like separate entities"*
>
> Participant 2

Regarding the user experience, many were skeptical to the approach due to this. Unless the physical and virtual piece felt like the same entity, they did not think there were benefits of using physical pieces:

> *"I did not think the physical pieces were necessary"*
>
> - Participant 9

> *"I did not see the point of using the physical pieces, as it did not feel like the same piece"*
>
> - Participant 11

### 7.1.5 Piece Movement Approaches and Usability

When asked to rate the four piece movement approaches by order of usability, it was clear that the favoured piece movement approaches were the ones in which only virtual pieces were used. Among the 12 participants, 11 ranked the *grab and place, virtual pieces* as their preferred piece movement approach, while one favored the *move-by-touch, virtual pieces* approach. Among the two piece movement approaches in which virtual and physical pieces were used, 7 favored the grab-and-place mechanism, and 5 favored the move-by-touch mechanism. The usability rankings of each participant are displayed in table 7. Table 6 shows the color codes and abbreviations used for the piece movement approaches in table 7.

| **Piece Movement Approach** | **Approach Abbreviation and Color Code** |
|---|---|
| Grab-and-place, virtual pieces | 🟥 G&P, V |
| Move-by-touch, virtual pieces | 🟦 MbT, V |
| Grab-and-place, virtual and physical pieces | 🟩 G&P, VP |
| Move-by-touch, virtual and physical pieces | 🟨 MbT, VP |

Table 6: Piece Movement Approach Abbreviations

| **Participant** | **1st** | **2nd** | **3rd** | **4th** |
|---|---|---|---|---|
| Participant 1 | G&P,V | MbT, V | G&P, VP | MbT, VP |
| Participant 2 | G&P,V | MbT, V | G&P, VP | MbT, VP |
| Participant 3 | G&P, V | MbT, V | MbT, VP | G&P, VP |
| Participant 4 | G&P, V | MbT, V | MbT, VP | G&P, VP |
| Participant 5 | MbT, V | G&P, V | G&P, VP | MbT, VP |
| Participant 6 | G&P, V | MbT, V | MbT, VP | G&P, VP |
| Participant 7 | G&P, V | MbT, V | MbT, VP | G&P, VP |
| Participant 8 | G&P, V | MbT, V | G&P, VP | MbT, VP |
| Participant 9 | G&P, V | MbT, V | G&P, VP | MbT, VP |
| Participant 10 | G&P, V | MbT, V | MbT, VP | G&P, VP |
| Participant 11 | G&P, V | MbT, V | G&P, VP | MbT, VP |
| Participant 12 | G&P, V | MbT, V | G&P, VP | MbT, VP |

Table 7: Individual Usability Ranking

In terms of usability, it was apparent that the adding physical pieces made it more difficult to move the pieces, both in terms of speed and accuracy. No participants indicated that it was more difficult to move virtual pieces alone due to the lack of tangibility. In contrary, adding physical pieces made it more difficult, as moving the virtual and physical pieces simultaneously was not a trivial task. In both of these approaches, additional effort was required to realign and locate the physical pieces if they were misaligned with their virtual representations:

> *"I preferred not using physical pieces, as moving the physical and virtual pieces simultaneously required extra steps and more effort"*
> - Participant 1

> *"When using VR, i do not think i need physical pieces, it was easier without them"*
> - Participant 3

> *"The ease-of-use is the most important factor when interacting with board game pieces, and with the physical pieces it was too difficult"*
> - Participant 11

### 7.1.6 Piece Movement Mechanisms with Virtual Pieces

Comparing the piece movement approaches where only virtual pieces were used, most participants favored the grab-and-place mechanism over the move-by-touch mechanism, both in terms of usability and because it contributed to a better user experience when playing. In terms of usability, this was mostly due to technical issues with the move-by-touch mechanism. When asked to elaborate why they thought the usability of the grab-and-place mechanism was better, the most commonly mentioned reasons were that it was "more smooth" and "bug-free". Given a bug-free implementation with a more calibrated sensitivity, some thought the move-by-touch method would function equally well, if not better:

> *"If working perfectly, the move-by-touch method might be the easiest approach"*
> - Participant 4

> *"If working perfectly, i think i would rate both approaches equally in terms of usability"*
> - Participant 11

The one participant who ranked the move-by-touch mechanism higher in terms of usability, mentioned that they they felt it was easier to control the pieces when moving them. Overall, the technical issues with the move-by-touch mechanism seemed to be the decisive factor why the participants preferred the grab-and-place mechanism for moving virtual pieces with regard to the usability.

In terms of user experience with virtual pieces only, the grab-and-place mechanism was by far the favourite. Compared to the move-by-touch mechanism, all participants thought it was more interactive. Many liked that it closely resembled moving physical objects in the real world:

> *"I preferred the grab-and-place mechanism, as i interacted with the pieces as if they were real"*
> - Participant 6

> *"Even though the piece was entirely virtual, it felt as if i was actually holding it"*
> - Participant 8

> *"The grab-and-place mechanism was better since it felt more real"*
> - Participant 9

As mentioned, some also spoke positively about the move-by-touch mechanism as they thought the pieces moving automatically felt magical or looked cool. However, most did not find it as exciting as the grab-and-place mechanism.

### 7.1.7 Piece Movement Mechanisms with Virtual and Physical Pieces

The two piece movement approaches with physical and virtual pieces were ranked lowest in terms of usability by all participants. The opinions regarding which of these two methods had the highest usability was split, with 7 preferring the grab-and-place mechanism with the physical pieces, and 5 preferring the move-by-touch mechanism.

The participants who thought the grab-and-place mechanism had highest usability generally thought that it was a closer "connection" between the virtual and physical piece with this method, whereas they thought the virtual and physical pieces felt like separate entities when using the move-by-touch method due to having to perform separate steps to pick up and release the virtual and physical pieces.

The participants who ranked the move-by-touch mechanism highest in terms of usability preferred it mostly because they struggled to pick up both pieces simultaneously when using the grab-and-place method:

*"With physical pieces, i preferred the move-by-touch mechanism. With grab-and-place, i struggled to pick up both pieces at the same time"*
- Participant 4

*"With grab-and-place, it has more of a hassle to realign the physical and virtual pieces"*
- Participant 10

In terms of user experience, the majority favoured the grab-and-place mechanism. Although some found it easier to move pieces with the move-by-touch mechanism, most participants thought the grab-and-place mechanism was a cooler and more intuitive approach, with many mentioning that it felt very satisfying when they managed to move the physical and virtual piece simultaneously.

### 7.1.8 Tangibility Impact

Since the usability of the piece movement approaches with physical pieces was not good enough, all participants favored the approaches with virtual pieces only. However, several participants stated that they would prefer using physical pieces given a perfect implementation in which the physical and virtual pieces were perfectly aligned:

*"If the grab-and-place mechanism with physical pieces worked optimally with perfect synchronization between the virtual and physical pieces, it would easily been the best in terms of user experience"*
- Participant 2

*"If the physical pieces were properly "tracked", i would prefer the grab-and-place mechanism"*
- Participant 6

*"Physically holding the piece 100% had a positive effect on my user experience. It adds a new dimension to VR"*
- Participant 5

The opinions regarding the importance of physical pieces in augmented board game play with XR varied. Among the 12 participants, 5 thought they would prefer using physical pieces with the grab-and-place mechanism given a "perfect" implementation. Three thought it might be a cool addition, but were not sure if it was necessary. Four participants did not think physical pieces were necessary when playing board games in XR:

*"It felt cool to hold the pieces physically, but i am not sure if it is that important"*
- Participant 4

*"I don't really see the point of using physical pieces, it worked very well without them"*

- Participant 11

## 7.2 Test 2: Virtual Environments

### 7.2.1 Avatars

All 12 test participants unanimously agreed that the addition of avatars enriched the playing experience compared to not seeing the other player. Everyone enjoyed playing against an avatar, and preferred it over not seeing the opponent they were playing against. When asked why, several participants mentioned how it increased the presence of the other player:

*"The avatar gave me the impression of playing against a real person"*

- Participant 4

*"With the avatar, it felt like there was an actual person there"*

- Participant 2

When asked if they thought that the realism of the avatar was important (i.e. human resemblance), the opinions were mixed: no one was adamant that they thought human resemblance was very important. However, four participants thought realistic avatars would or could improve the user experience, with three of them mentioning that face expressions could be a nice addition.

*"Adding facial expressions to the avatar would be even cooler"*

- Participant 1

One stated that more realistic avatars could improve the immersion, but did not think it was particularly important. Another stated that it probably depended on the situation and the game:

*"In games that require focus, i think realistic avatars are more important"*

- Participant 12.

However, the majority thought that the visual realism of the avatar was not very important. The prototype avatar, though simplistic in appearance, seemed to still create a high sense of social presence since the movement of the avatar (head, body and hands) corresponded with that of the players.

*"I do not think realistic avatars is that important. The most important thing is that you can see their*

> *general movements"*
> 
> \- Participant 7

Another commonly mentioned positive effect of the avatars was that they spent more time observing and analyzing their opponent and to consider the movement of the avatars (body language) when making a move. This seemed to heighten the tension and excitement for some of the players:

> *"With the avatar, i could see where the other playing was looking, and i could almost feel that they were thinking"*
> 
> \- Participant 7

> *"With avatars, i got visual feedback and more insight into the thought process of my opponent"*
> 
> \- Participant 8

### 7.2.2 Visual Environment

Playing in a fully virtual environment was met with a lot of enthusiasm by the players. All participants preferred playing in the fully virtual environment, even though the virtual environment was not relevant to the theme of the game, or affected the game itself. Four participants stated that the experience was "much cooler" in VR than in AR. Three participants said that VR environment affected their mood in a positive way:

> *"It was much cooler to be transported into another world"*
> 
> \- Participant 2

> *"Being in a cozy environment made the playing experience more relaxing"*
> 
> \- Participant 1

> *"I liked being in the virtual environment, it set the mood"*
> 
> \- Participant 8

Some felt that they were more immersed and focused on the game in VR, as this blocked out distractions from the physical world:

> *"It was easier to focus in VR since i was closed off from the real, physical environment"*
> 
> \- Participant 7

One participant mentioned that they particularly liked that the virtual table in the scene aligned with the physical table:

> *"When i captured a [virtual] piece and placed it on the virtual table, i got in contact with the physical table, and it felt as if the virtual table was actually in front of me"*
> - Participant 4

The players were asked about in what situations they thought being in a virtual environment could enhance the board game experience. Some participants mentioned that virtual environments would be particularly interesting if the "theme" of the virtual environment matched with the board game:

> *"In VR, it would be cool to have an environment that fit with the theme of the game. For example, being in a casino while playing poker"*
> - Participant 3

> *"I think i would be even more immersed in the game if the visual environment fit the theme of the game"*
> - Participant 11

The participants were also asked about whether they thought adding visual effects and animations to the gameplay could improve the user experience. All participants thought that it would be cool to add to some board games, with some enthusiastically suggesting different possibilities:

> *"In RISK, it would be awesome to visualize the wars between the players after throwing dice on the gameboard, and see the colors of the map change when you conquer a territory"*
> - Participant 9

> *"When playing atomic chess, it would be hilarious to see the pieces explode when capturing them"*
> - Participant 6

# 8 Discussion

The purpose of the study was to investigate the usability and user experience aspects of augmented board games in extended reality. The main focus was to gain a better understanding of the impact of various approaches for moving pieces, to analyze the importance of tangibility and interaction methods during board game play in XR. Another research focus was to evaluate the feasibility of using the proposed manual anchoring method to facilitate physical piece interaction, as well as analyzing how the visual environments of the players impacted the social presence, immersion and overall playing experience.

## 8.1 Piece Movement Approaches

The first research question (**RQ1**) investigated how the approach used for moving board game pieces in XR affected the usability and user experience during gameplay:

**RQ1**: How does the approach used for moving board game pieces in XR affect the usability and user experience while playing?

### 8.1.1 Piece Movement Approaches and Usability

Usability can be measured in terms of ease-of-use and acceptance. The ease-of-use measures the difficulty of performing tasks, and affects the user performance and satisfaction, while acceptability determines whether or not the product will be used [91].

From the user tests, the *grab and place, virtual pieces* piece movement approach was the clear favourite in terms of usability. Data gathered both from interviews and observation suggests that the an important reason for this was that it was the most consistent and accurate approach, and that it had the lowest error rate. Moving the virtual pieces worked almost exactly as expected, and the participants considered it to be very easy to use.

One aspect that naturally differed from physical board game play in this approach was the absence of tactile feedback or tangibility since the pieces were entirely virtual. However, this did not seem to negatively affect the ease-of-use, the efficiency or the accuracy of moving pieces. The visual feedback the participants received, particularly with respect to seeing a virtual representation of their hands picking up and holding the pieces, provided sufficient feedback to gain control of the movement of the pieces. Additionally, some participants reported that they still felt a sense of physically holding the pieces during interaction. This feeling may be attributed to the required thumb and index finger pinch to prevent dropping the virtual piece, creating a tactile sensation of fingers touching and an illusion of physically grasping and holding the virtual piece. This factor may have contributed to a higher degree of control compared to interacting with virtual objects without receiving any tactile feedback. For instance, pushing or lifting virtual objects rather than grabbing them might be considered more difficult and less controllable, as this only relies on movement of the hand, and there is no congruence between physical touch and the interaction with the object.

The approach used in task 2, *move-by-touch, virtual pieces*, was consistently ranked as second best in terms of usability. The method introduced an element of touch to the users despite not using physical pieces, because the virtual board was aligned with a physical table in order to use the table as a touch-interface to move the virtual pieces. Although there was an inherent disparity between this interaction method and moving physical objects in the real world, as the users moved the virtual pieces by interacting with the board and not the pieces themselves, the method was still considered very intuitive, and the users quickly understood how to move the pieces. One reason for this could be the participants' familiarity with using digital touch interfaces, such as mobile phones and tablets, to interact with digital elements. As the virtual board was aligned with a physical table, the table essentially emulated a digital, touch-sensitive tablet. The move-by-touch piece movement mechanism share many similarities with moving and manipulating 2D objects when playing chess or other games on a tablet or phone, which may explain why the participants considered it to be intuitive.

The main reasons why the grab-and-place mechanism was ranked higher than the move-by-touch mechanism with virtual pieces in terms of usability was more related to the technical problems encountered by users during play with the move-by-touch mechanism, rather than differences in intuitiveness. One issue that negatively affected the usability of the move-by-touch mechanism was the sensitivity of the virtual board. This occasionally resulted in pieces not being moved or accidentally touching the wrong squares, which could cause the wrong piece to move or the piece to be moved to the wrong square. The importance of proper alignment of the virtual board and the physical interface on which it was instantiated was highlighted, as the virtual board being instantiated slightly "beneath" the physical board could result in the participants not being able to interact with the virtual board at all. However, there are many ways to improve upon and fix technical issues with this piece movement mechanism, and the general consensus among the participants was that using this method otherwise was a very viable way of interacting with the pieces in terms of usability.

In the third task, users tested the grab-and-place mechanism while moving physical and virtual pieces simultaneously. This added another level of complexity, as moving the pieces simultaneously did not turn out to be a trivial task. There were two main reasons for this. Firstly, many users struggled to grab on to both pieces at the same time. The main reason for this was that the physical pieces obstructed the camera view of the XR device, making it more difficult to register pinching when the users picked up the physical pieces. Although the users still managed to execute moves, it required more effort and took significantly longer time on average compared to not using physical pieces, which negatively affected the usability. Secondly, as the virtual representations of the physical pieces only relied on manual anchoring and not object-tracking, many experienced that the virtual and physical pieces were misaligned after moving them. This increased the difficulty of moving the pieces, as the physical pieces and their corresponding virtual pieces were often too far apart from each other. Another consequence of this misalignment was that the participants at times could not locate the physical piece, as the virtual elements obscured them from the field of view. Overall, adding physical pieces only made the grab-and-place mechanism more difficult to use.

In the fourth piece move movement approach, the participants tested the move-by-touch mechanism while using both virtual and physical pieces. Compared to the grab-and-place mechanism with physical pieces, some thought it was easier to execute moves, as they they did not have to spend as much time aligning the physical pieces with the corresponding virtual pieces. However, more than half of the participants ranked this approach lowest in terms of usability. Compared to the other approaches, which required one operation to select the piece (grab piece or activate square), and one operation to complete the move (drop piece or press target square), this approach required two operations each when selecting the piece and when completing the move. Many thought this was cumbersome and unnecessary, and it took more time and effort to complete moves as opposed to not using physical pieces. Additionally, having separate mechanisms for interacting with the physical and the virtual piece, and not moving the pieces simultaneously resulted in many participants experiencing that the corresponding pieces felt like separate entities, making it less intuitive and user-friendly. The physical pieces became more of an obstacle when making moves than an aid, and did not appear to have any benefits or improve the usability of the move-by-touch mechanism compared to only using virtual pieces.

Overall, only using virtual pieces was the most convenient way of moving pieces, and the lack of tangibility did not affect the usability in a negative way. The participants experienced that the grab-and-place mechanism with virtual pieces only was not particularly more challenging than moving physical pieces when playing traditional tabletop games. Therefore, there was no apparent benefit of adding physical pieces, with several participants mentioning that even if the physical and virtual pieces were perfectly synchronized, they did not think the usability would be significantly affected in a positive or negative way. As long as the physical piece and corresponding virtual piece did not feel like the same entity, the addition of physical pieces only seemed to impact the usability negatively. The affordances of the virtual piece movement approaches were satisfactory enough despite the lack of tangibility, suggesting that there may not be much value in refining the synchronization of physical and virtual pieces if the intention is to optimize the usability.

### 8.1.2 Piece Movement Approaches and User Experience

The results indicated that the user experience with the piece movement approaches strongly correlated with the usability. The piece movement approaches with only virtual pieces were ranked highest by usability, and also generally produced the best user experience. However, several participants thought that the addition of physical pieces positively affected the user experience in some ways, indicating that there may be a potential in XR tabletop gaming with physical board game pieces.

The prototype application featured two different piece movement mechanisms with different interaction methods, namely the grab-and-place mechanism and the move-by-touch mechanism. The grab-and-place mechanism allowed users to interact with the pieces directly, while in the move-by-touch method, the piece were moved by touching squares on the virtual chessboard. The two mechanisms had different effects on the user experience while playing.

When playing with the virtual pieces only, the grab-and-place mechanism still made the participants feel a high degree of presence of the virtual pieces, with many mentioning that it almost felt as if the pieces were physically present. From the results, the main reason for this was that the interaction method closely resembled real-world interaction with physical objects. The familiarity of using gestures and hand movements to pick up, hold and drop the pieces resulted in a natural form of interaction, and was very intuitive and user-friendly.

Generally, the participants enjoyed the grab-and-place mechanism due to the perceived realism, which appeared to enhance the participants' immersion, satisfaction and enjoyment while playing. The mechanism was considered very interactive, which might be explained by the direct interaction with the pieces, and the users having to perform all the steps necessary to move the pieces manually. The results indicated that entirely virtual elements can have a high degree of perceived realism despite not being tangible objects, as long as they can be interacted with in a realistic manner.

The user experience when using the move-by-touch mechanism with the virtual pieces comparatively resulted in a reduced sense of presence of the virtual pieces. Although this mechanism also required users to move their hands to interact with the pieces and execute moves, the lack of direct interaction with the virtual pieces reduced the perceived realism of the virtual chessboard. This seemed to be the main reason as to why the engagement and level of enthusiasm was lower when playing with this mechanism, suggesting that increased realism and more interaction generally increases the level of enjoyment. Although the move-by-touch mechanism required less effort to move the pieces, as the pieces moved automatically between the start and the destination squares, this did not seem to improve the user experience.

## 8.2 Tangibility and User Experience in XR

The second research question (RQ2) examined the comparison of usability and user experience in XR board game applications when using physical and virtual pieces versus virtual pieces only:

**RQ2**: How does the usability and user experience of XR board game applications compare when using physical and virtual pieces versus virtual pieces only?

While the piece movement approaches featuring physical pieces did not overall contribute to a better user experience due to the reduced usability, some users were quite optimistic of the idea of introducing tangible elements to board games while playing in virtual and augmented reality. Five of the 12 participants were confident that, given a "perfect implementation" in which physical and virtual pieces moved synchronously, physical pieces would definitely improve the user experience. Some simply thought that the sense of feeling the physical pieces "felt nice", while others thought it made the experience feel more real.

On the other hand, 7 of the 12 participants were not convinced or did not think tangible pieces was particularly important, even if the virtual and physical pieces were perfectly synchronized. This was an interesting finding, considering much of the existing research covered on board games indicates that interaction with physical board game elements is one of the main reasons why people tend to prefer playing traditional board games physically compared to digital variants of the same games.

One factor that is important to consider is that little research has been done comparing XR board games to physical board games, and naturally, the opinions regarding movement of pieces in XR might be drastically different from moving a piece using a mouse to move a 2D board game piece on a computer. The comparisons of physical and graphical game interfaces by both Menestrina et al.

[30] and Fang et al. [26] both compared 2D game interfaces to physical board game interfaces, and found that users strongly preferred physical interfaces. However, it could be argued that the grab-and-place mechanism used to pick up, move and release pieces in the XR prototype application is more similar to the way in which people interact with physical board game pieces in the real world than moving 2D objects with a mouse on a computer screen. The results from the user testing support this claim, as multiple participants noted that they interacted with the pieces as if they were physically present, with some experiencing that they felt like they were physically holding the pieces. The results indicated that the sense of touch in itself was not of very high importance with respect to the user experience and immersion. Rather, the way in which the virtual pieces were moved - the piece movement mechanism - was a more decisive factor.

## 8.3 Feasibility and Limitations of Anchoring Method and Physical Pieces

The third research question explored the feasibility of accurately representing physical board game pieces virtually by positionally aligning physical boards with a virtual one:

**RQ3**: Is it feasible to accurately represent physical board game pieces virtually by positionally aligning physical boards with a virtual one?

The method used to represent physical board game pieces virtually in the prototype application was by manually anchoring a virtual board on top of a physical board so that physical and virtual pieces were positionally aligned. Other ways of representing physical objects and board game pieces virtually have already been explored and researched by others, and one reason for developing the anchoring system was to see if it was feasible to achieve the same goal without the use of electronic board and pieces or cameras with object-detection. This method could have several advantages, since it could be adapted to practically any board game that revolves around using a physical board and board game pieces, as long as a virtual "clone" of the physical board is created. As the size of the board can be adjusted and configured to align with the physical board during the instantiation process, it is also a very adaptable approach, and there would be no need in using custom-made boards and board game pieces with sensors or external cameras in addition to the XR device.

From the usability testing of the piece movement approaches with physical pieces, several flaws and weaknesses of this approach were identified. With both approaches, it was evident that the usability of the approaches was drastically reduced compared to playing with only virtual pieces. Although the test participants did manage to use both the grab-and-place mechanism and the move-by-touch mechanism with physical pieces, it was not functioning well enough to allow the players to play the game naturally, and it required a lot more effort and concentration to move the pieces simultaneously compared to only using virtual pieces.

### 8.3.1 Board Instantiation

The method used to instantiate a virtual board on top of a physical board was practical and efficient. It allowed any size of physical chessboard to be represented in the virtual environment within seconds, with generally accurate positional alignment. This method also enabled remote gameplay with differently sized boards, as the boards and pieces were scale-adjusted and synchronized accordingly. Moreover, the same instantiation method could be applied to a variety of board games, simply by changing the board prefab.

However, there were limitations to the board instantiation process. Placing red pins (see figure 21b) to mark the corners of the chessboard relied on estimation by eye, as the Meta Quest could not recognize physical objects and surfaces. When using the Quest with passthrough enabled, the blurry environment made it challenging to accurately position the virtual markers, leading to slight misalignments between the physical and virtual boards and pieces. Even small misalignments could significantly affect gameplay, particularly when using physical pieces and the move-by-touch chessboard.

To address this issue, a relatively simple solution would be to make the cross (attached beneath the sphere) grabbable instead of the sphere itself. This would allow users to physically touch the corner and drag the cross to its exact position, ensuring precise alignment between the physical board and the virtual markers.

### 8.3.2 Grab-and-place Mechanism

The mechanism with most potential with physical pieces was the grab-and-place mechanism. With this approach, it was possible to pick up, move and drop the physical and corresponding virtual pieces simultaneously. When the test participants managed to do this, many enjoyed the interaction method and said it was satisfying. However, it was not consistent enough, and the participants often struggled with managing this simultaneous movement of the pieces.

The main problem identified was that the virtual piece was often not picked up along with the physical piece, as the XR device did not detect the pinch gesture that triggered the grab function. This problem occurred because the physical piece obscured the pinch gesture from being observed by the HMD sensors. As the pinch gesture relies on measuring the distance between the thumb and index finger to trigger the grab function, increasing this distance threshold (e.g. by creating a custom gesture) might mitigate this issue. Another solution could be to use smaller physical pieces.

Another factor that might have made it difficult to pick up the virtual and physical pieces at the same time was that the pieces were not identical in terms of shape and size. Measures could be taken to fix this, but this was likely not the main issue, as the virtual pieces were adjusted to roughly match the size of the physical pieces.

As there are many measures and relatively minor adjustments that could be taken to improve the alignment of the physical and virtual pieces and ensure that the pieces moved in unison, the anchoring method with the grab-and-place mechanism with physical pieces may have some potential for XR augmented board games. However, results indicated that most users would only prefer using physical pieces if the physical and virtual pieces felt like the same entity, and it is unlikely that this is achievable without some type of object-detecting system, as there are many ways in which the pieces can be misaligned.

### 8.3.3 Move-by-touch Mechanism

Although the users were split with regard to their preferred piece movement mechanism with physical pieces in terms of usability, the user experience when using the move-by-touch mechanism was much lower compared to the grab-and-place mechanism. This was mainly due the users perceiving the virtual and physical pieces as entirely separate entities, making it difficult to justify using it. Using physical pieces did not appear to have additional benefits compared to playing with virtual pieces only.

While the move-by-touch mechanism did not work in combination with physical pieces, there are still ways in which it could be used for XR augmented board games. One benefit of the mechanism is that it allowed using a physical table to interact with the virtual board, and some experienced that this was a nice way of introducing tactile interaction when playing. In particular, this alignment can enhance the presence and immersion in fully virtual environments, as it can enable the virtual table to be perceived as more real. One way of taking advantage of the tactile feeling that this mechanism offers could be to use it as a tangible virtual interface for other activities in board games not related to the pieces, such as presenting virtual elements such as game cards, text information or visual effects.

## 8.4 Visual Environments and User Experience

In the second part of the user tests, the participants explored playing each other remotely. Players switched between being in a fully virtual environment and an augmented environment, in which they could see a hologram of the chessboard in their real, physical environment. Additionally, they played each other while not seeing the other player, and while seeing the other player's virtual representation in the form of a digital avatar. The purpose of the test was to explore the fourth research question:

**RQ4**: How does external factors related to the visual environment, such as the physical/virtual environment and digital avatars, affect the playing experience and social presence in XR augmented board games?

### 8.4.1 Digital Avatars

The results from the user test indicated that using digital avatars to represent the players virtually strongly increased the level of enjoyment during gameplay. All participants found that the inclusion of avatars had a positive impact on the overall playing experience, particularly in terms of enhancing social presence.

The primary reason for this positive effect was the contribution of avatars in fostering a sense of proximity between players. Despite the simplistic appearance of the avatars, their synchronized movements with the players' actions created the perception that the other player was physically present. This aspect of embodiment increased engagement and immersion in the game, allowing participants to analyze the movements and body language of their virtual counterparts. While detailed features such as facial expressions or limb movements were not visible, the direction of gaze and hand movements of the avatars became focal points, heightening the tension during gameplay.

These findings support the theory proposed by Greenwald et al. [41] that simplistic avatars can yield similar experiences to face-to-face interactions, particularly when the game does not heavily rely on analyzing body movement. The emotive and expressive nature of the avatars was deemed sufficient for generating engaging gameplay experiences.

With regard to the importance of the appearance of the avatars, results indicated that realistic avatars was not considered necessary, as most thought that being able to see the general movements of the other player was the most important aspect. However, many thought that making the avatars more detailed and realistic could be beneficial in some games. When this was brought up, adding facial expressions to the avatar was generally considered as a potential enhancement that could further enhance the social presence. As the synchronization between the players' physical movements and the movement of the avatar was mentioned as a positive, this suggests that if facial expressions was to be added, these expressions should preferably also align with the physical expressions of the player if possible. For instance, this could be achieved by using audio input to simulate mouth movements. Newer headsets that support eye-tracking could also synchronize the movement of virtual eyes with the player's actual eye movements.

In relation to Yoon et al.'s [43] findings, it appeared that full body representation was not necessary, as the avatar only represented the player's head, hands and torso virtually and still generated a high social presence. This suggests that hand, head and simplistic upper body representation is sufficient in most augmented board games in XR. The stationary nature of the players during board game likely reduces the need of full embodiment, especially considering that the virtual lower body representation is occluded from the field of view when sitting around a virtual table.

Another interesting finding in this study was with regard to the character styles, as many thought that characters that fit the theme of the game and the visual environment could facilitate an even more immersive playing experience. The findings reiterated Yoon's findings, as most did not think that the character style of the avatar (cartoony or realistic) was particularly important in terms of social presence. Yoon also proposed that the character style should be chosen based on the communication context. Whereas the character style might not be crucial for the social presence, it could still increase the level of immersion in the game and facilitate more fun and enganging playing experiences, particularly in role-playing games where the players have unique identities.

### 8.4.2 Visual Environments in XR Board Games

The visual environment turned out to have a significant impact on the playing experience, despite the environment being static and not impacting the gameplay. All test participants preferred playing in the fully virtual environment over playing in the augmented environment. There are several factors that contributed to this.

The primary factor driving users' preference for the fully virtual environment was the sense of immersion and escapism it provided. Unlike the AR environment, which was perceived as a "bland" test room, the VR environment offered a more visually captivating experience. Participants often described the virtual environment as "cool" and "cozy," indicating that even relatively simple virtual environments can significantly enhance the user experience. While not explicitly discussed, it is plausible that elements such as the presence of specific objects in the room and the lighting design played a role in creating a more engaging and appealing virtual atmosphere.

The VR environment provided users with a heightened sense of immersion and a feeling of engagement in the game, as it effectively closed them off from their physical surroundings. This disconnection from the real world contributed to a greater level of enjoyment compared to AR environments. These findings are consistent with the research conducted by Luoreiro et al. [44], that escapism in VR can stimulate the user's cognitive and affective state, resulting in an increase in pleasure. Furthermore, the findings of are also consistent with Wood et al's [46] results, where VR received higher enjoyment scores compared to AR. The immersion being higher in VR may also be attributed to AR disrupting the place illusion and the realism of the virtual environment (including the virtual chessboard and avatars), as mentioned by Slater and Smith [47], as the virtual elements may be perceived as less real when they are present in the real, physical environment.

Many participants expressed that being present in a fully virtual environment that aligns with the theme of the board game could enhance the immersion and enjoyment when playing XR board games. While this aspect may not be directly applicable to chess, games focusing more on themes, storytelling or imaginative worlds may benefit from this. This is another argument for using VR instead of AR to augment board games with XR technology, as it can create more cohesive and captivating experiences for players and strengthen the connection between the gameplay and the overarching narrative. In contrast, the physical environment always being present in AR limits the ability to transport the players into a completely virtual and immersive environment.

Most participants also thought that adding visual effects and animations to enhance the board game experience would increase the level of enjoyment. Adding a layer of visually immersive elements could complement the physical gameplay, for instance through animated characters and special effects, could add depth and richness to the game, and create more dynamic experiences compared to the limited visual stimuli present in traditional tabletop games.

## 8.5 Limitations of the Research

User testing with chess as the chosen board game introduced limitations in addressing the research questions. The individualistic nature and limited verbal communication between players in chess made it less suitable for investigating the impact of visual environments and social presence (**RQ4**) in board games emphasizing communication and collaboration. Additionally, the gameplay mechanics of chess made it hard to fully exploit the immersive capabilities of XR technologies, limiting its ability to compare AR and VR environments and assess the integration of digital avatars and virtual effects. Augmenting board games with a stronger emphasis on storytelling and visual presentation may have provided more relevant insights.

The limitations of the study related to the research questions focusing on the usability and user experience of piece movement approaches and the impact of tangible pieces were influenced by the quality of the implementation. The move-by-touch mechanism specifically, was developed within a limited timeframe, which resulted in suboptimal performance and technical flaws. Given more time for development and refinement, the outcomes of the user tests could have been influenced differently. This is also the case with regard to the tangibility, as results might have been different if a different method was used to represent physical pieces virtually.

The user test method utilized a semi-structured interview approach, which had both strengths and limitations. While standardized questions were employed, the inclusion of spontaneous follow-up questions based on the topic at hand introduced variability in question phrasing. It is also important to acknowledge that some of these follow-up questions might have been unintentionally leading or biased, potentially influencing participants' responses. Additionally, not all participants were asked the same set of questions, and some topics were brought up by the participants, leading to variations in the data collected. Moreover, the interviews being performed pairwise instead of individually might have resulted in responses being influenced by the presence and responses of the other participant. These limitations should be considered when interpreting the results obtained from the user tests.

It is also important to note that some questions posed during the user tests were hypothetical in nature and did not involve direct testing or observation of the participants. For instance, questions exploring how users would perceive piece movement mechanisms given a "perfect implementation" or whether they believed visual effects and animations could enhance the XR board game experience fell into this category. As a result, the responses obtained for these questions may be based on speculation rather than actual user experiences and observations during the testing sessions.

Another limitation of the study is the relatively homogeneous demographics of the participants involved in the user testing phase. The sample primarily consisted of male students aged between 20 and 30 years old, with limited experience using XR technology. This limited diversity in participant characteristics and the small number of participants raises concerns about the generalizability of the findings to a broader population. The experiences and preferences of this specific group may not accurately represent those of other user profiles, such as individuals from different age groups, genders, educational backgrounds, or levels of familiarity with XR technology.

# 9 Conclusion

In conclusion, the findings from this thesis demonstrate that interacting with virtual objects using hand-tracking technology can closely resemble the experience of interacting with physical objects in the real world. Furthermore, the incorporation of visual feedback, such as realistic physics-based movements and visual cues, further enhanced the sense of presence and engagement during XR board game play. For these reasons, the tangibility provided by physical pieces in XR board game play may not be necessary to achieve realistic and enjoyable playing experiences. The grab-and-place mechanism for interacting with virtual pieces was preferred by players as it was perceived as more realistic and interactive compared to the move-by-touch mechanism, which resulted in increased immersion.

It was evident that using manual anchoring to synchronize the movement of physical and virtual pieces significantly reduced the usability. This negatively impacted the user experience. Despite this, many participants expressed a preference for the tangibility offered by physical pieces if synchronization between the two could be achieved effectively. To achieve seamless piece synchronization, alternative methods such as object-tracking with sensors or camera-detection may be necessary as the manual anchoring method used in the prototype proved unfeasible.

In terms of visual environments, the use of digital avatars to represent players virtually significantly enhanced social presence, leading to increased enjoyment and immersion during gameplay. The realism and physical appearance of the avatars were not found to be crucial, with a minimal representation capturing general movements being sufficient for achieving a high social presence. However, incorporating facial expressions to make the avatars more emotive and expressive would likely further enhance social presence. Furthermore, aligning the avatar's appearance with the theme of the game could enhance immersion and player engagement.

When playing XR board games, users unanimously preferred playing in a fully virtually environment compared to an AR environment. The feeling of being transported into a virtual environment was a source of enjoyment, and could enhance the immersion when playing. Generally, users seemed enthusiastic about having environments that fit the theme of the game, and adding visual effects and animations to enhance the traditional board game experience.

Overall, these findings highlight the potential of hand-tracking technology, digital avatars, and fully virtual environments to create realistic and engaging XR board game experiences. The results provide valuable insights for designing future XR board games that maximize immersion, presence, and social interaction within virtual reality environments.

# 10 Future Work

In light of the findings in this thesis, several avenues for future research and developments in XR board games can be explored to optimize the user experience and develop more immersive playing experiences.

**Refining Synchronization Methods**

The study highlighted the limitations of using manual anchoring to synchronize the movement of physical and virtual pieces in XR board games. To overcome these limitations, using alternative methods such as object-tracking with sensors or camera-detection could be explored. With an improved synchronization methods, the impact of tangibility could be further investigated. Optimizing the manual anchoring method could also be interesting, as several ways to improve it have been suggested.

**Comparison and Enhancement of Digital Avatars**

The incorporation of digital avatars in XR board games was found to significantly enhance social presence during gameplay. To further enhance social interaction and immersion, future research could explore incorporating facial expressions and more detailed representation of avatars, and compare how different character styles (including theme-based) and levels of realism affect the playing experience.

**Enhanced Virtual Environments**

Participants in the study expressed a preference for fully virtual environments, and particularly expressed interest in virtual environments that fit the theme of the board game. Future work can explore the development of immersive and visually appealing virtual environments that enhance the thematic elements of XR board games to see how it affects the immersion and enjoyment. Additionally, making the environments interactive or adding visual effects or animations to the virtual gameboard and investigating how this affects the playing experience and immersion could also be interesting.

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# 11 Appendix

## 11.1 Consent Form

# Samtykkeskjema

Brukertest for utprøvning av brettspillapplikasjon i XR med fysisk brukergrensesnitt.

**Gjennomføring:**
I denne brukertesten skal dere teste ut en XR brettspillapplikasjon. Hensikten med brukertesten er å teste ut forskjellige varianter av en brettspillapplikasjon med fysisk brukergrensesnitt og se på hvordan ulike faktorer påvirker brukeropplevelsen. I løpet av brukertesten kommer dere til å ble bedt om å besvare spørsmål som er relevante for testene.

**Personlig data**
Under intervjuet og brukertesten blir det tatt video- og lydopptak. Disse opptakene flyttes og lagres midlertidig på en ekstern disk som kun testundersøkeren har tilgang til. Dataen fra intervjuene blir brukt for å analysere og evaluere XR-teknologi. Dette skal brukes i forbindelse med testundersøkerens masteroppgave. Prosjektet skal leveres før 1. juli 2023, og etter dette vil all personlig data bli anonymisert, og alle video- og lydopptak vil slettes permanent.

**Dine rettigheter**
Frem til dataen som er lagret om deg er fullstendig analysert, har du rett til å:

- Få tilgang til dataen som er lagret om deg
- Be om at dataen om deg slettes
- Be om at dataen om deg endres om noe ikke stemmer
- Motta en kopi av din personlige data
- Sende inn en klage til NSD (Norsk senter for forskningsdata) dersom du mistenker at din personlige data har blitt misbrukt

**Hvor kan jeg finne ut mer?**
Hvis du har spørsmål angående prosjektet eller ønsker å benytte deg av dine rettigheter, kan du kontakte:

- Testundersøker: Sondre Schirmer-Mikalsen
    - epost: sondremikalsen1@gmail.com
    - Tlf: 918 32 308
- NSD - Norsk senter for forskningsdata
    - epost: personverntjenester@nsd.no
    - Tlf: +47 55 58 21 17

**Samtykkeskjema**

☐ Jeg samtykker med at personlige data om meg fra brukertesten lagres frem til 1. juli 2023.
☐ Jeg har lest og forstått informasjonen og gir mitt samtykke til å delta i brukertesten

Mitt navn:

Signatur:

___________________

Dato undertegnet: ______

## 11.2 handleActiveSquares.cs

```
using TMPro;
using Unity.Netcode;
using Unity.Netcode.Transports.UTP;
using Unity.Services.Authentication;
using Unity.Services.Core;
using Unity.Services.Relay;
using Unity.Services.Relay.Models;
using UnityEngine;
using UnityEngine.UI;

public class TestRelay : MonoBehaviour
{

    [SerializeField]
    private Button hostButton, joinButton;

    [SerializeField]
    private TMP_InputField joinInputField, hostCodeDisplay;

    public async void Start()
    {
        await UnityServices.InitializeAsync();
        AuthenticationService.Instance.SignedIn += () =>
        {
            Debug.Log("signed in" + AuthenticationService.Instance.PlayerId);
        };
        await AuthenticationService.Instance.SignInAnonymouslyAsync();

        hostButton.onClick.AddListener(CreateRelay);
        joinButton.onClick.AddListener(JoinRelay);

    }

    public async void CreateRelay() {
        try
        {
            Allocation allocation = await RelayService.Instance.CreateAllocationAsync(3); // max number of clients
            string joinCode = await RelayService.Instance.GetJoinCodeAsync(allocation.AllocationId);

            NetworkManager.Singleton.GetComponent<UnityTransport>().SetHostRelayData(
                allocation.RelayServer.IpV4,
            (ushort)allocation.RelayServer.Port,
            allocation.AllocationIdBytes,
            allocation.Key,
            allocation.ConnectionData
            );

            hostCodeDisplay.text = joinCode;

            NetworkManager.Singleton.StartHost();
            Debug.Log("Host started");
            Debug.Log("with Joincode " + joinCode);

        }
        catch (RelayServiceException e) {
            Debug.Log(e);
        }
    }

    public async void JoinRelay() {
        try
        {
            string joinCode = joinInputField.text;
            Debug.Log("joining relay with code " + joinCode);
            JoinAllocation joinAllocation = await RelayService.Instance.JoinAllocationAsync(joinCode);

            NetworkManager.Singleton.GetComponent<UnityTransport>().SetClientRelayData(joinAllocation.RelayServer.IpV4,
            (ushort) joinAllocation.RelayServer.Port,
            joinAllocation.AllocationIdBytes,
            joinAllocation.Key,
            joinAllocation.ConnectionData,
            joinAllocation.HostConnectionData

            );

            NetworkManager.Singleton.StartClient();
        } catch (RelayServiceException e) {
            Debug.Log(e);
```

## 11.3 squareHandler.cs

```csharp
using System.Collections;
using System.Collections.Generic;
using System.Linq;
using Microsoft.MixedReality.Toolkit.Input;
using Unity.Netcode;
using UnityEngine;

public class SquareHandler : MonoBehaviour, IMixedRealityPointerHandler
{

    [SerializeField] private float moveSpeed = .2f;
    private static GameObject startSquare;
    private static GameObject targetSquare;
    [SerializeField] private GameObject networkObjectParent;

    private static float cooldownPeriod = 0.5f;

    private static float lastPieceMoveTime = 0;

    public void OnPointerDown(MixedRealityPointerEventData eventData)
    {

        Debug.Log(eventData.selectedObject);
        if (lastPieceMoveTime + cooldownPeriod > Time.time)
        {
            return;
        }


        if (startSquare == null && HandleActiveSquares.getPieceInSquare(gameObject) != null)
        {
            RequestOwnership();
            Debug.Log("active square clicked");
            startSquare = gameObject;
            startSquare.GetComponent<Renderer>().enabled = true;
            startSquare.GetComponent<Renderer>().material.color = new Color(200, 0, 0, 1);
            lastPieceMoveTime = Time.time;
        }
        else if (targetSquare == null && startSquare != null)
        {
            Debug.Log("target square clicked");
            GameObject pieceToMove = HandleActiveSquares.getPieceInSquare(startSquare);

            targetSquare = gameObject;
            targetSquare.GetComponent<Renderer>().enabled = true;
            targetSquare.GetComponent<Renderer>().material.color = new Color(0, 0, 200, 1);

            var movePieceCoroutine = movePiece(pieceToMove, startSquare, targetSquare);
            StartCoroutine(movePieceCoroutine);
            startSquare = null;
            targetSquare = null;

            lastPieceMoveTime = Time.time;
        }


    }

    private void Update()
    {

    }

    public IEnumerator movePiece(GameObject currentObject, GameObject startSquare, GameObject targetSquare)
    {
        Vector3 targetPos = new Vector3(targetSquare.transform.position.x, currentObject.transform.position.y, targetSquare.transform.position.z);
        Vector3 startPos = currentObject.transform.position;

        //float distance = Vector3.Distance(startPos, targetPos);
        //Debug.Log(distance);

        while (currentObject.transform.position != targetPos)
        {
            currentObject.transform.position = Vector3.MoveTowards(currentObject.transform.position, targetPos, moveSpeed * Time.deltaTime);
            yield return null;
        }
        startSquare.GetComponent<Renderer>().enabled = false;
        targetSquare.GetComponent<Renderer>().enabled = false;
        checkIfPieceCaptured(currentObject);
    }


    public AudioClip clip = null;
    private void checkIfPieceCaptured(GameObject currentObject)
    {
        GameObject[] whites = GameObject.FindGameObjectsWithTag("whitepiece");
        GameObject[] blacks = GameObject.FindGameObjectsWithTag("blackpiece");
        GameObject[] pieces = whites.Concat(blacks).ToArray();

        foreach (GameObject piece in pieces)
        {
            if (piece.transform.position.x == currentObject.transform.position.x && piece.transform.position.z == currentObject.transform.position.z && piece != currentObject)
            {
                //piece.SetActive(false);
                piece.transform.position = new Vector3(100, -100, 100);
                piece.GetComponent<MeshRenderer>().enabled = false;
                Debug.Log("piece captured");
                GameObject handleactivesquares = GameObject.Find("HandleActiveSquares");
                AudioSource captureAudio = handleactivesquares.GetComponent<AudioSource>();
                captureAudio.Play();
            }
        }


    }



    public void RequestOwnership()
    {
        OwnershipManager.Instance.RequestOwnershipOfObject(networkObjectParent);
    }
```

## 11.4 getHandPos.cs

```
using System.Collections;
using System.Collections.Generic;
using Microsoft.MixedReality.Toolkit;
using Microsoft.MixedReality.Toolkit.Input;
using Microsoft.MixedReality.Toolkit.Utilities;
using UnityEngine;

public class getHandPos : MonoBehaviour
{
    [SerializeField]
    private Transform handRight, handLeft;

    [SerializeField]
    private float offsetY = 0.07f;

    IMixedRealityHandJointService handJointService;
    // Start is called before the first frame update
    void Start()
    {
        gameObject.DontDestroyOnLoad();
        handJointService = CoreServices.GetInputSystemDataProvider<IMixedRealityHandJointService>();
    }

    // Update is called once per frame
    void Update()
    {

        if (handJointService != null)
        {
            try
            {
                Transform jointTransformRight = handJointService.RequestJointTransform(TrackedHandJoint.IndexTip, Handedness.Right);
                Transform jointTransformLeft = handJointService.RequestJointTransform(TrackedHandJoint.IndexTip, Handedness.Left);

                handRight.position = jointTransformRight.position - new Vector3(0,offsetY,0);
                handRight.rotation = jointTransformRight.rotation;
                handLeft.position = jointTransformLeft.position - new Vector3(0,offsetY,0);
                handLeft.rotation = jointTransformLeft.rotation;

            }
            catch
            {
                Debug.Log("cannot find hands");
            }
        }

    }
}
```

## 11.5 Relay Script

```
using TMPro;
using Unity.Netcode;
using Unity.Netcode.Transports.UTP;
using Unity.Services.Authentication;
using Unity.Services.Core;
using Unity.Services.Relay;
using Unity.Services.Relay.Models;
using UnityEngine;
using UnityEngine.UI;

public class TestRelay : MonoBehaviour
{

    [SerializeField]
    private Button hostButton, joinButton;

    [SerializeField]
    private TMP_InputField joinInputField, hostCodeDisplay;

    public async void Start()
    {
        await UnityServices.InitializeAsync();
        AuthenticationService.Instance.SignedIn += () =>
        {
            Debug.Log("signed in" + AuthenticationService.Instance.PlayerId);
        };
        await AuthenticationService.Instance.SignInAnonymouslyAsync();

        hostButton.onClick.AddListener(CreateRelay);
        joinButton.onClick.AddListener(JoinRelay);

    }

    public async void CreateRelay() {
        try
        {
            Allocation allocation = await RelayService.Instance.CreateAllocationAsync(3); // max number of clients
            string joinCode = await RelayService.Instance.GetJoinCodeAsync(allocation.AllocationId);

            NetworkManager.Singleton.GetComponent<UnityTransport>().SetHostRelayData(
                allocation.RelayServer.IpV4,
            (ushort)allocation.RelayServer.Port,
            allocation.AllocationIdBytes,
            allocation.Key,
            allocation.ConnectionData
            );

            hostCodeDisplay.text = joinCode;

            NetworkManager.Singleton.StartHost();
            Debug.Log("Host started");
            Debug.Log("with Joincode " + joinCode);

        }
        catch (RelayServiceException e) {
            Debug.Log(e);
        }
    }

    public async void JoinRelay() {
        try
        {
            string joinCode = joinInputField.text;
            Debug.Log("joining relay with code " + joinCode);
            JoinAllocation joinAllocation = await RelayService.Instance.JoinAllocationAsync(joinCode);

            NetworkManager.Singleton.GetComponent<UnityTransport>().SetClientRelayData(joinAllocation.RelayServer.IpV4,
            (ushort) joinAllocation.RelayServer.Port,
            joinAllocation.AllocationIdBytes,
            joinAllocation.Key,
            joinAllocation.ConnectionData,
            joinAllocation.HostConnectionData

            );

            NetworkManager.Singleton.StartClient();
        } catch (RelayServiceException e) {
            Debug.Log(e);
```

## 11.6 Questionnaire

# Spørreundersøkelse

## Generelle spørsmål (5 min) (10)

Først tenker jeg kjapt å gå gjennom noen grunnleggende spørsmål. For å enklere sette opp ting, vil jeg referer til dere som spiller 1 og 2. Spiller 1 er host på serveren.

1. Spiller nr

*Markér bare én oval.*

○ 1
○ 2

2. Fullt navn

3. Alder

4. Studie / arbeidsstatus

5. Hvor ofte spiller du brettspill?

*Markér bare én oval.*

- ○ Noen få ganger i året
- ○ Omtrent en gang i måneden
- ○ Omtrent et par ganger i måneden
- ○ Omtrent hver uke
- ○ Flere ganger i uken
- ○ Andre: ____________________

6. Hvor mye erfaring har du med VR- og AR-headset?

*Markér bare én oval.*

- ○ Har aldri prøvd det
- ○ Prøvd det noen få ganger
- ○ Bruker det av og til
- ○ Bruker det ofte (minst én gang i uken)
- ○ Andre: ____________________

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