University of Crete School of Sciences and Engineering Computer Science Department

Arcane Tabletop: Platform for creating, customizing and experiencing multi-player strategy board games in XR environments

Antonios Agapakis

Thesis submitted in partial fulfillment of the requirements for the Masters' of Science degree in Computer Science and Engineering

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UNIVERSITY OF CRETE COMPUTER SCIENCE DEPARTMENT

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Abstract

Today, tabletop games and especially tabletop role playing games (TTRPGs) have seen a surge of popularity, with various pop culture media promoting such games and video streaming platforms exposing wide audiences to the hobby of tabletop gaming. Currently, there exist two categories of playing environments for such tabletop games. Firstly, locally, with all the players gathering around a table and utilizing physical components (dice, miniatures, board, terrain, etc). Secondly, through Virtual Tabletops, platforms created for digital remote play, that offer tools (virtual dice, board and miniatures) agnostic to any game system for facilitating any tabletop game session. Several of these platforms specialize in specific game rulesets to provide extended features like useful automations and complex calculations.

Some existing Virtual Platforms can provide a high level of integration in a rule system, but those platforms implement 2D graphics and with a very limited set of animations and audiovisual effects. On the other hand, more visually appealing 3D Virtual Tabletops provide very limited rule integration and as a result also limited animations and visual effects that would need to match specific character actions as dictated by the game's rules.

In this thesis, we present Arcane Tabletop, a platform for creating and experiencing multiplayer turn-based board games in Extended Reality. The novelty of , as our approach to a Virtual Table, is the combination of the digital and physical worlds, that allows for players to enjoy the aspects a physical setup provides, with the automations and immersive enhancements that a virtual table can offer. Additionally, the system presented in this thesis provides both a high-level of integration with any given game ruleset and the extension of such an inclusion to the game's mechanics and presentation. Each action and each character in the game is animated and has visual and audio effects, in 3D. This, in unison with the presentation of the game happening in extended reality, is our effort to "breathe life" into the tabletop.

Arcane Tabletop provides four distinct functionalities for creating, customizing and finally experiencing a tabletop game. Firstly, the creation of a custom turn-based board game rule set that can be imported in a board game scenario. Secondly, the loading of various assets such as 3D models, animations and visual and sound effects in order to create a template on which a game scenario can be made. Thirdly, the creation of a game scenario by utilizing a template and combining it with a game ruleset. Finally, the experience of a game scenario in Extended Reality through Microsoft's Hololens 2 holographic head mounted device.

Experiencing a game scenario requires players to wear the AR head mounted device, and to gather around the same space. The game consists of a holographic

3D model of terrain that serves as the board of the game, and characters that players control. Each character has a set of abilities that enable them to interact with other characters or the environment. The goal of the game and the nature of the interactions between characters varies according to the scenario and the game ruleset.

The resulting experience of playing the game should retain the tactile feeling and sense of community of a physical board game, and simultaneously utilize the virtual nature of the tabletop, which allows sound and visual effects to be incorporated in the gaming session, in order to provide a higher sense of immersion. In addition, the incorporation of various automations facilitates a gaming experience that is more guided, seamless, and conducive to a smooth flow for all players.

In conclusion, this thesis presents the research and development work performed on the topic of tabletop games and the digital platforms that facilitate them in the form of a literature review, a description of the design process followed for the *Arcane Tabletop*, a brief technical description of the system, and finally an evaluation that was conducted regarding the user experience of a particular game scenario created as a case study.

Arcane Tabletop: Πλατφόρμα για τη δημιουργία, προσαρμογή και διεξαγωγή επιτραπέζιων παιχνιδιών στρατηγικής, πολλαπλών παικτών σε περιβάλλοντα Μικτής Πραγματικότητας Περίληψη

Τα επιτραπέζια παιχνίδια και ιδιαίτερα τα επιτραπέζια παιχνίδια ρόλων, παρουσιάζουν το τελευταίο διάστημα μία σημαντική αύξηση παικτών. Αυτό οφείλεται σε πλατφόρμες διαμοιρασμού ζωντανού οπτικοακουστικού περιεχομένου, μέσω των οποίων τα επιτραπέζια παιχνίδια ρόλων διαφημίζονται και σε δημοφιλή μέσα ψυχαγωγίας, τα οποία προβάλλουν τέτοια παιχνίδια τόσο στη μικρή όσο και στη μεγάλη οθόνη. Οι υπάρχοντες τρόποι διεξαγωγής επιτραπέζιων παιχνιδιών ρόλων είναι δύο. Πρώτον, τοπικά, στον ίδιο χώρο, όπου όλοι οι παίκτες συγκεντρώνονται γύρω από ένα τραπέζι και χρησιμοποιούν τα υλικά εξαρτήματα του αντίστοιχου επιτραπέζιου (ζάρια, μινιατούρες, ταμπλό, κ.α.). Δεύτερον, ψηφιακά και εξ'αποστάσεως, μέσω ψηφιακών πλατφορμών για επιτραπέζια, δηλαδή ψηφιακών συστημάτων που δημιουργήθηκαν για τη διεξαγωγή ενός παιχνιδιού. Τέτοιες πλατφόρμες, παρέχουν ψηφιακά εξαρτήματα γενικής φύσεως (ψηφιακά ζάρια, ψηφιακό ταμπλό γενικής χρήσης, κ.α.) τα οποία μπορούν να εξυπηρετήσουν την πλειοψηφία των παιχνιδιών, με κάποιες από τις πλατφόρμες αυτές να εξειδικεύονται σε ένα ή παραπάνω παιχνίδια και τους κανόνες τους, παρέχοντας αυτοματισμούς και άλλες διευκολύνσεις.

Οι υπάρχουσες ψηφιαχές πλατφόρμες μπορούν μεν να προσφέρουν μεγάλο επίπεδο ενσωμάτωσης με τους χανόνες ψηφιαχών παιχνιδιών, παρέχουν όμως μόνο δισδιάστατη απειχόνιση με περιορισμένες επιλογές για χινηματιχή χαι οπτιχοαχουστιχά εφέ. Αντίθετα, υπάρχουσες ψηφιαχές πλατφόρμες με πιο ελχυστιχή παρουσίαση οι οποίες προβάλλουν το επιτραπέζιο παιχνίδι με τρισδιάστατα γραφιχά περιέχουν πολύ περιορισμένη ενσωμάτωση σε χανόνες χαι, ως αποτέλεσμα, περιορισμένη χινηματιχή χαι οπτιχοαχουστιχά εφέ, αφού δεν είναι χαταγεγραμμένες οι ενέργειες από τις οποίεςθα προέχυπταν, βάσει των χανόνων του παιχνιδιού.

Σε αυτήν την εργασία, παρουσιάζουμε το Arcane Tabletop, μία πλατφόρμα που επιτρέπει τη δημιουργία συνεργατικών παιχνιδιών και τη διεξαγωγή του δημιουργημένου παιχνιδιού σε περιβάλλον επαυξημένης πραγματικότητας. Η δική μας προσέγγιση για την ανάπτυξη πλατφορμών για επιτραπέζια παρέχει ένα συνδυασμό του πραγματικού και του ψηφιακού κόσμου: επιτρέπει στους παίκτες να διατηρήσουν τα κοινωνικά στοιχεία του επιτόπιου παιχνιδιού και το αίσθημα της αφής που παρέχει ένα τέτοιο επιτραπέζιο, με τις ενισχύσεις στην εμβύθιση, τη δυνατότητα προσήλωσης και την ευκολία διεξαγωγής του παιχνιδιού που παρέχουν οι ψηφιακές πλατφόρμες. Επιπλέον, το σύστημα που παρουσιάζεται σε αυτήν την εργασία, παρέχει μεγάλο βαθμό ενσωμάτωσης των εκάστοτε κανόνων, με την δυνατότητα αυτή να επεκτείνεται και στην παρουσίαση του παιχνιδιού. Κάθε ενέργεια και κάθε χαρακτήρας στο παιχνίδι έχει τη δική του τρισδιάστατη κινηματική και τα οπτικοακουστικά εφέ. Αυτό, σε συνδυασμό με το γεγονός ότι η εμπειρία του παιχνιδιού βιώνεται μέσω επαυξημένης πραγματικότητας,συντελείστην προσπάθειά μας να μεταδώσουμε το αίσθημα ότι το ταμπλό και οι χαραχτήρες του επιτραπέζιου παιχνιδιού "απέχτησαν ζωή".

Η πλατφόρμα Arcane Tabletop παρέχει τέσσερις διαφορετικές λειτουργικότητες στους χρήστες. Πρώτον, τη δυνατότητα δημιουργίας ενός συνόλου από κανόνες που θα διέπουν κάποιο σενάριο παιχνιδιού. Δεύτερον, τη μεταφόρτωση αρχείων που θα δημιουργήσουν ένα καλούπι για την οπτικοακουστική εμπειρία που θα παρέχει κάποιο σενάριο παιξίματος. Τρίτον, τη δημιουργία συγκεκριμένου σεναρίου παιξίματος ενός παιχνιδιού, μέσω του συνδυασμού ενός καλουπιού και ενός συνόλου από κανόνες. Τέλος, τη δυνατότητα σε πολλαπλούς παίχτες να παίξουν ταυτόχρονα ένα τέτοιο σενάριο σε περιβάλλον επαυξημένης πραγματικότητας μέσω της συσκευής HoloLens 2 της Μιςροσοφτ, μιας συσκευής η οποία μπορεί να προβάλει ολογράμματα στο χώρο. Για να παιχτεί χάποιο δημιουργημένο σενάριο, απαιτείται από τους παίχτες να φορέσουν τη συσκευή και να βρίσκονται στον ίδιο χώρο όπου μπορούν να απολαύσουν το παιχνίδι. Το παιχνίδι περιέχει ένα ψηφιακό ταμπλό το οποίο απεικονίζει τρισδιάστατα σχηνικά και χαρακτήρες τους οποίους χειρίζονται οι παίχτες. Κάθε χαρακτήρας παρέχει τη δυνατότητα για ένα σύνολο από ενέργειες μέσω των οποίων μπορεί να αλληλεπιδράσει με το ταμπλό ή/και με άλλους χαρακτήρες. Ο στόχος του παιχνιδιού και η αλληλεπίδραση μεταξύ των χαρακτήρων ποικίλει ανάλογα με το σενάριο και το σύνολο κανόνων που έχουν οριστεί στο σύστημα.

Η διεξαγωγή ενός τέτοιου σεναρίου θα πρέπει να διατηρεί σε μεγάλο βαθμό τοαίσθημα της αφής που διεγείρει η αλληλεπίδραση με τα εξαρτήματα ενός επιτραπέζιου παιχνιδιού και παράλληλα να εξυπηρετεί, όπως ένα επιτραπέζιο παιχνίδι, τις κοινωνικές ανάγκες των συμμετεχόντων. Ταυτόχρονα, αξιοποιώντας την ψηφιακή φύση του παιχνιδιού, πρέπει να παρέχει μεγαλύτερη εμβύθιση και ευκολότερη προσήλωση στο παιχνίδι μέσω οπτικών και ηχητικών εφέ και της κινηματικής των χαρακτήρων. Επιπροσθέτως, διάφοροι αυτοματισμοί και υπολογισμοί που γίνονται κατά τη διεξαγωγή του παιχνίδιού θα πρέπει να παρέχουν μια καθοδηγούμενη εμπειρία με καλύτερη ροή, απλοποιώντας την εφαρμογή περίπλοκων κανόνων και διευκολύνοντας τους παίκτες.

Εν κατακλείδι, αυτή η μεταπτυχιακή εργασία παρουσιάζει την έρευνα που επιτελέστηκε στη θεματολογία των επιτραπέζιων παιχνιδιών και των ψηφιακών συστημάτων για τη διεξαγωγή τους, εστιάζοντας κυρίως στα επιτραπέζια παιχνίδια ρόλων. Περιέχει τη διαδικασία ανάπτυξης της πλατφόρμας Arcane Tabletop μέσω μιας ανασκόπησης για τις υπάρχουσες σχετικές εργασίες, την περιγραφή της διαδικασίας σχεδίασης που ακολουθήθηκε και κατόπιν της ανάπτυξης του λογισμικού, μια σύντομης τεχνικής αναφοράς για την πλατφόρμα, και τέλος, μιας σύντομης αναφοράς της αξιολόγησης του συστήματος ως προς την εμπειρία των παικτών, η οποία πραγματοποιήθηκε πάνω σε ένα σενάριο παιχνιδιού που δημιουργήθηκε μέσω της πλατφόρμας.

Ευχαριστίες

Καταρχάς, θα ήθελα να ευχαριστήσω τον επόπτη καθηγητή αυτής της εργασίας και ακαδημαϊκό σύμβουλο κατά τη διάρκεια των μεταπτυχιακών σπουδών μου, καθηγητή Κωσταντίνο Στεφανίδη, ο οποίος πάντα υπήρξε υποστηρικτικός στην πορεία μου ως φοιτητής. Παράλληλα, θα ήθελα να ευχαριστήσω και τον επιβλέπων της μεταπτυχιακής εργασίας Δρ. Αστέριο Λεωνίδη, ο οποίος με πολύτιμες συμβουλές και πολλές ώρες ενασχόλησης, διετέλεσε αναπόσπαστα σημαντικό ρόλο στο αποτέλεσμα που παρουσιάζεται σε αυτή την εργασία.

Θα ήθελα να ευχαριστήσω αχόμα τους φίλους με τους οποίους τόσα χρόνια παίζουμε επιτραπέζια παιχνίδια χαι έχουν με το διχό τους τρόπο, εμπνεύσει τη θεματολογία αυτής της εργασίας χαι χαλλιεργήσει την αγάπη μου για το συγχεχριμένο αντιχείμενο.

Επιπλέον, είμαι ευγνώμων στους φίλους και τα αγαπημένα πρόσωπα που ήταν πάντα διαθέσιμα για συμβουλές και ουσιαστική βοήθεια κατά τη διάρκεια της εκπόνησης αυτής της εργασίας. Ονομαστικά και με αλφαβητική σειρά, θα ήθελα να ευχαριστήσω τους Αγαπάκη Μανόλη, Δουρουντάκη Όλγα, Κοπιδάκη Έφη, Μουτσάκη Γεωργία, Περβολαράκη Ζαχαρία και Χατζάκη Αλέξανδρο, για την πρακτική συνεισφορά τους στη μελέτη περίπτωσης που πραγματοποιήθηκε για το σύστημα.

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Τέλος, θα ήθελα να ευχαριστήσω την οικογένειά μου. Τους γονείς μου που υπήρξαν υποστηρικτικοί και στις πιο φορτωμένες μέρες ενασχόλησης, και τον αδερφό μου, ο οποίος με τη δική του πορεία στην επιστήμη υπολογιστών, έχει υπάρξει έμπνευση και κίνητρο να επιδιώκω πάντα το κάτι καλύτερο.

στους γονείς μου

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Chapter 1

Introduction

Tabletop Role Playing Games (TTRPGs) have seen a surge of popularity in recent years with an ever increasing player base. As a whole, such games have been researched to offer a variety of benefits to the players' health [27]. They have been studied to be beneficial to the players' creativity thinking and emotional creativity [23], [56], with a higher level of divergent thinking [56]. Also, strategic board gaming, which is heavily applied in tabletop role playing games, has been shown to offer lasting and significant enhancements to prospective memory and decision making [40]. Gaming in general has been suggested as potential treatment for specific medical conditions such as ADHD [42] and Alzheimer [52] with its application reducing the severity of the respective conditions' symptoms. Also, tabletop gaming has been associated with reduced risk of dementia and reduced declines in cognitive function [21] for the elders [2]. In this context, various organizations use tabletop gaming for mental health treatments with TTRPG groups for troubled teens to specific game rulesets created to aid psychotherapeutic purposes. There has been research focusing on the benefits of tabletop games from the angle of sociability as well. The social aspect of TTRPGs, can create self-confidence through the game sessions and act as a safe place to open up to other people, and create a community that is formed through the shared experience and enjoyment of the game [29]. At the same time, the cooperation and storytelling that are a core part of the TTRPG experience, lead to higher empathy levels for the players [79] [29].

Tabletop role playing games, are currently being played either around the same table with physical components or remotely through Virtual Tabletops (VTTs). The physical components such as dice, a board and miniatures that are utilized for the game, provide a feeling of tactility to the game that is enjoyed by many players and the locality of the experience enhances the social aspects of the game. Moreover, a physical board complete with painted 3D miniatures and terrain, looks much more impressive, and can help players get immersed in the game. On the other hand, VTTs provide automations and tools that make the more complex part of the game flow smoother, and with less cognitive load required from the players and especially the Game Master. Additionally, while VTTs generally look less impressive than a fully equipped 3D board, they offer a much larger variety of environments and visuals that are impossible or hard and expensive to replicate in a physical tabletop, such as running water and floating platforms.

Our system attempts to offer the best of both worlds, with extended reality holograms creating a synchronized digital tabletop, that can be interacted with by all the players that wear a head mounted device and are around the same table. Arcane Tabletop is part virtual table and part board game as it attempts to provide the benefits of both of the ways of enjoying a tabletop turned based game. Compared to other virtual tables, our system is the first we have encountered that incorporates holographic extended reality user interface and interactions. It also is the first such platform that combines 3D graphics with a complete control over the game's rule system, and the syncing of these rules with animations, user interface changes, sound and visual effects that make playing the game feel more akin to a video game. Compared to a physical board, our system provides new previously impossible affordances, from the game's components that range from atmospheric terrain (e.g. fog and smoke), to miniatures that can animate and move realistically, to visual effects as results of the player's actions (e.g fiery explosions and crackling lighting). Moreover, automations in various steps of the gameplay, provide an experience that is easier to enjoy for new players, and result to them feeling less lost in the game's mechanics. In the same context, experienced players don't need to make all the calculations manually and the game flows more smoothly.

This thesis presents in Chapter 2 some background theory that aims to provide an understanding of the basic concepts of this thesis. It also presents a literature review that was performed for tabletop games that are played in different platforms. In Chapter 3 we present the utilized methodology for designing and creating the system, and the functional requirements of the platform that were created using this process. A description of the system, its functionalities and the structure of its basic components can be found in Chapter 4. In Chapter 5, we elaborate further into each component, through a case study we prepared for this thesis. In Chapter 6, we describe a Cognitive Walkthrough evaluation that was performed with UX experts and the valuable feedback this evaluation provided us. Finally, in Chapter 7, we discuss some future work that we believe would enhance the functionalities of the system.

Chapter 2

Related Work

2.1 Background Theory

This section provides information about the basic topics that relate to the work presented in this thesis, and aims to serve as an aid into understanding the different domains that involve Arcane Tabletop. These topics include Extended Reality, different types of board games that contain virtual elements, Tabletop Role Playing Games and Virtual Tabletops. It will also contain a part of an extensive literature review that was conducted as part of this research that helped us determine the final system requirements.

2.1.1 Extended Reality and Mixed Reality

Extended Reality (XR) encapsulates Augmented Reality (AR), Virtual Reality (VR), and Mixed Reality (MR). Mixed Reality is a term with a heavily discussed meaning in the scientific community [71], but its popularity is ever increasing with companies utilizing the term to advertise a chain of related products and applications [71]. This research's focus is not on defining Mixed Reality. While the precise definition of Mixed Reality is debated, its positive effect on collaboration [61], [44], [45], narrative ([38], [3]) and immersion ([58], [46], [70]) are well researched and documented.

This research is concerned with Extended Reality as in recent years, the field of Extended Reality has seen significant advancements [57] with the emergence of more powerful mobile devices and improved software enabling the creation of more immersive and engaging extended reality experiences. Additionally, the development of standalone XR headsets, such as Microsoft HoloLens 2 [?] and Magic Leap 2 [54], and the imminent release of Apple's first extended reality headset Apple Vision Pro [34], has opened up new possibilities for creating more interactive and intuitive extended reality experiences. In this context, studying these emerging technologies in regards to board games and gathering existing research on this topic is a novel undertaking. Mixed Reality, can be achieved through multiple means, from general purpose smartphones and tablets [16], to specifically crafted head mounted displays and smart glasses. For this research, a choice has been made to focus on head mounted extended reality applications as they have been deemed more appropriate for the facilitation of a tabletop game experience as will be detailed further into the research.

2.1.2 Augmented Reality

Augmented reality is a subset of Extended Reality [8] and is defined as the supplementation of the real world with virtual computer generated objects, that appear to coexist in the same space as the real world [4]. This supplementary computergenerated content can include multiple sensory modalities, such as visual, auditory, haptic, somatosensory and olfactory [9].

While augmented reality experiences present similarities with virtual reality experiences in regards to some interactions with the virtual objects, the implications of the inclusion of physical space in the experience warrant specific research on the topic of board games.

2.1.2.1 Types of AR Displays

AR displays can generally be categorized into monitor-based AR displays and see-through AR displays.

Monitor-based AR displays refer to augmentations that happen to a "distant" screen such as a smartphone or a tablet (can also be characterized as handheld AR). While such AR displays are the most accessible and easy to use for the public they also have limited interactions [51] and are deemed non-immersive [11]. Especially as the focus of this research is on board games, these AR displays are considered to be less suitable for playing an AR board game. As such, this research will focus on see-through AR displays, and any mention to affordances of augmented reality systems refers to systems developed for see-through AR displays.

See-through AR displays, allow users to see the augmented world from their own perspective. The most common way of achieving this, is through headmounted display devices (HMDs), by either providing a video of the real world through a camera system attached to the device that reproduces the viewpoint of the user's eyes, or by projecting virtual elements on a transparent surface in front of the observer. In the second case the HMD is referred to as an optical see-through [11].

Microsoft HoloLens 2

One popular head mounted device for augmented reality is Microsoft's HoloLens 2, an optical see-through headset that was developed and manufactured by Microsoft. Microsoft's HoloLens 2 compared to its predecessor Microsoft HoloLens,

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Figure 2.1: Four games for HoloLens2. Top-Left: Fragments [73]. Top-Right: HoloStudy [30]. Bottom-Left: RoboRaid [12]. Bottom-Right: Algorithmic Nature [15]

boasts higher hologram quality, better hologram interactions, faster response speed, more accurate hand recognition, and larger field of view, while simultaneously weighing less and achieving to be more comfortable [65]. This new version of Microsoft's HMD for extended reality, is equipped with enough processing and computing power to produce realistic holograms (as shown in Figure 2.1). Developed applications for this particular device, range from remote collaboration platforms, to education enhancing platforms for a variety of subjects, to relaxing decorating experiences, to AR video games and of course AR board games (Figure 2.1).

Tilt Five

Tilt Five [24] is a head mounted device that aims to provide a holographic experience for tabletop gaming. The system includes the Glasses, the Gameboard and the Wand (Figure 2.2). As the creators of Tilt Five describe their system, the glasses connect to a computer or an Android smartphone and through miniature projectors they send video images to the Gameboard. The Gameboard then reflects the video images through the Glasses creating the hologram 3D effect when looking through them. Finally, the Wand facilitates all the interactions with the holograms. The system offers satisfying hologram visual quality, stereo speakers and 3D spatial



Figure 2.2: The Tilt Five head mounted device

audio, a built-in microphone for hands-free voice chat and provides different ways of multiplayer in the form of either users in the same space with different Glass devices or through crossplay with computer or Android versions of the same game. Among other board games the popular board game Catan has been ported for Tilt Five.

2.1.2.2 The Mechanics of Interactions in AR

In augmented reality systems, the user can interact with both the physical world, and digital artifacts in the same experience [33]. While the physical interactions are of course instinctively understandable, the digital interactions as well as a harmonious combination of interactions between the physical and digital worlds, need to be detailed [10].

In AR systems these interactions can be categorized in three interaction models that suit most experiences, hands and motion controllers interactions, hands free interactions, and gaze and commit interactions [14]. These models are optimized for different situations and different needs, such as required convenience, complexity of task, and time affordance. The latter two models describe interactions that do not include any hand movements and as such do not concern this study of board games, where the tactile interactions and the physical involvement in facilitating play is so crucial.

The model of hands and motion controllers for interaction in an AR system requires users to use their hands to interact with the holographic world. If motion controllers are utilized, the interaction is reminiscent of the VR interaction control model and functions in the same manner. The more interesting models to study in the case of board game interactions for AR, are the point and commit with hands, and the direct manipulation with hands models for interaction with the digital world.

Direct Manipulation with Hands

The direct manipulation with hands (Figure 2.3), involves touching holograms

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Figure 2.3: The interactions of HoloLens 2

directly with the digital objects simulating their physical counterparts' properties. In this model, buttons would need to be pressed, and objects would get picked up by grabbing them with a realistic gesture. This type of interaction is the most user-friendly, as it is affordance-based with no symbolic gestures to learn and therefore no additional cognitive effort for any interaction [13]. This model is used for interacting with content within arms reach.

Point and Commit with Hands

The point and commit with hands (Figure 2.4) allows users to target, select, and manipulate out of reach 2D and 3D digital objects. For this interaction, a ray shoots out from the center of the user's palm and is treated as an extension of the hand. At the other end of the ray a cursor is located, that attaches the ray to objects it intersects with. A command is triggered by using the ray to "point", and a hand gesture (like pinch) to "commit" and perform an interaction such as the pressing of a button. This interaction introduces some cognitive effort from the user, as it is not an interaction that can be performed in the physical world.

2.1.3 Board Games and Tabletop Games

This section focuses on information about board games in general, and their various characteristics. These characteristics directed our research to the domain of



Figure 2.4: The Point and Commit interaction

tabletop games, and our approach to specific features that aimed to support and enhance these important characteristics of board games.

2.1.3.1 Tabletop Games

Tabletop games is a broad term, that encompasses many different styles of games that include card games, board games, dice games, miniature wargames, and tilebased games, with the requirement to be played on a table or similar flat surface. In this research, special focus is attributed to multiplayer tabletop games. The terms tabletop games, board games and tabletop board games will be used interchangeably, as different board games can contain cards, miniatures, tile boards and dice.

Tabletop games, are usually multiplayer but there also exist single player variations. The complexity of board games can vary vastly in both the rule system, as games can have single page rule books, or an entire library that spans hundreds or even thousands of pages in rules. Also, the components that are required to play a board game can range from dice, cards, board with 2D or 3D elements, miniatures, tokens and storage components. A similar variation exists in the duration of a gaming session for a board game, which we define as the time required to play the game one time, with sessions spanning from 20 minutes to 6 or more hours for different games.

Tabletop boards can range from the simple board components of most casual board games, to medium complex boards that may contain various tokens, to large detailed 3D boards that are populated with detailed miniatures for characters and monsters, and for the artifacts of the environment, in addition to traditional board game components such as dice and cards (Figure 2.5). Such complex boards are time-consuming to produce and expensive for both players and companies. Additionally, setting up a 3D detailed environment for a tabletop session is timeconsuming, and requires a lot of available physical space.



Figure 2.5: Tabletop game boards of different complexities

2.1.3.2 Collaborative, Competitive or Cooperative board games

There exist three categories in regards to how the players of a board game approach each other during the game session: cooperative games, collaborative games and competitive games [80].

Competitive games provide the players with opposing goals, that require strategies to defeat each other within the confounds of the rules.

Collaborative games are games in which all the players of the game work together as a team that shares the payoffs and outcomes of each player's decision. In these games, the team winning means all the players win, and the team losing means all players lose [80].

The third category, cooperative games, are games where the players have interests that are neither completely opposed or completely coincident [59]. This means that opportunities exist for the players to work together to achieve a winwin condition, but this cooperation may not be of equal benefit for all players that take part in it. Through either cooperating and facilitating negotiations and bargains with the other players, as the rules dictate, or by taking a more solo approach to the game, a winner is declared by an accumulation of points or similar achievement counting methods. In this kind of game, players may incorporate cooperative strategies, but as only one player wins the game in the end, deviations from cooperation like back-stabbing or free riding are sure to occur [80].

Depending on the category a board game falls into, the players need to deploy different kinds of strategies according to the rules to achieve the goal of the game and be victorious. According to previous research, a key part of the playtime in a tabletop game is the strategy, whether it involves a discussion of play before a move, or a more introspective process [79].

2.1.3.3 Narrative in Board Games

For this thesis, we will consider narrative as a series of related events and experiences [38]. Narratives are researched to be a powerful method for emboldening empathy characteristics in a person by cultivating perspective taking and emotional engagement, with a researched positive association between empathy and prosocial behaviors [37]. In traditional board games, the narrative is usually interactive, which means that the players have control over the story being told, in the style of choose-your-own-adventure [38]. The level of complexity of an interactive story, can vary from board games that present a few choices on how the narrative progresses, to tabletop role playing games that usually act like sandboxes where the player has agency in the world, and has limitless options in ways to influence the story. In tabletop role playing games, that narrative is often more important than any other aspect of the game, and core part of the experience.

2.1.3.4 Immersion in Board Games

Immersion is generally described as the sense of being transported by the power of sounds, words and/or images into a fictional world or space [46]. This general definition of immersion includes different levels and distinctions of immersion [46], that concern this study. Perceptual immersion, is the process of immersing the players in a completely different universe such as a medieval town or a boat in the middle of the ocean [55]. This immersion can be facilitated by targeting the senses with sounds, images and even smells that aim to transport the immersed player to a fictional world. Another distinction of immersion is Deep Emotional Engagement, which is the forming of an emotional connection to events that happen in the fiction of the game. For some board games, and for all tabletop RPGs, this multileveled immersion co-exists and is crucial to the experience of the players ([47], [43]). Many tabletop games, even those that are not specifically role playing games, are either designed to require, or are benefited by achieving the aforementioned varying levels of immersion.

2.1.3.5 Tabletop Role Playing Games

A Tabletop Role Playing Game (TTRPG) refers to the progressive creation of a type of collaborative narrative, by a typically small group of players, that is presented and experienced in the confounds and the context of a board game. The participants in this narrative building experience are the game master and the players. The players take a main role in the narrative, while the game master uses mostly verbal discourse to animate the narrative [20]. In such games, a game set will include a description of the world in which the action is set, the governing rule of the world, and tips on the general atmosphere [20]. The game is played

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on a table with all the players gathering around, and for its facilitation, there often exist props and components, such as character sheets, dice, game boards and miniatures that represent the player characters, their allies and their enemies.

TTRPGs fall in the collaborative category of board games, with the player roleplaying as characters that form a team that generally has goals that align with each other. The narrative for this type of game, is formed both by the Game Master (GM) and the players collaboratively, with the former providing descriptions of the environment, and each situation as well as roleplaying every Non-Player Character (NPC), and each player roleplaying a singular character that influences both the story and the fictional world created for the game. For this type of board games, there usually exists a plot that develops among several game sessions with the player characters (PCs) making decisions and impacting the way it progresses. While a central plot exists, the shared story is heavily improvisational in nature, with the GM responding in real time to the actions that players perform, and adjusting to situations and events according to the players' interests in the fictional world [1].

This type of board game has a heavily social profile, as the collaboration of the group is what creates the narrative and the immersion, and is crucial in the gameplay aspect. These types of games have been exploding in popularity in the last years, through various digital media depicting their play, and by content creators that livestream their game sessions, or provide content about TTRPGs.

2.1.4 Digital Board Games

This section is devoted to board games that have been digitized, and are played on devices with screens that do not use any kind of augmentation. These games usually are played with the players in different physical spaces, and basically function as an online video game. For this study, a digital board game, is a video game played on mobile, tablet, or a computer that has adapted the rules, gameplay, and general sense of play of an existing board game to the aforementioned digital media.

In the recent years, there has been a rise in popularity for digitizing board games with a prime example being the publisher Asmodee Digital [22], that since 2016 has released more than 10 popular board games for PC, mobile phones, and even the new generation of gaming consoles [22], and achieved financial success and positive reviews from critics in doing so. The games adapted in this manner, range from moderately simple board games like Ticket to Ride, to some of the most complex board games like Gloomhaven.

The purpose of studying the adaptation of of existing games into the digital domain, is beneficial for comparisons between the different versions of the game on the different platforms. Studying the same board game in its physical version, its digital version, and its extended reality version, provides valuable information about each platform's affordances and contributions to the game experience.

2.1.4.1 Affordances of Digital Board Games

The digitization of board games, functionally affects the board gameplay experience as digital systems provide new ways for interaction, and enable the development of novel features that are impossible, or too complex to be feasible, in a physical environment. Such features, include a more flexible way to display information, with minimizable and maximizable content that can be manipulated by the user, an non-intrusive way to incorporate atmospheric music into the game without requiring external tools, the streamlining of the board game actions, and an automatic enforcement of the rule system through the digitized system. These affordances can refer to any kind of digitization on board games.

Another novel feature of digitized games, is the ability to facilitate remote gameplay. This refers to the fact that players can enjoy their favorite board game from the comfort of their home with online game sessions. As such, in these games, there does not exist a "tabletop" in the literal definition of the word, as such digital games are played on a screen instead of a table. Removing the physical tabletop as well as the social locality from a board game, creates a new situation for play that presents its own advantages and disadvantages. These unique characteristics will be further explored in later sections of this chapter.

2.1.5 Virtual Tabletops

Virtual Tabletops (VTTs) refer to software that was created to support remote play of tabletop role playing games. While these tools have existed for years, they have seen a substantial surge of interest in the pandemic with players migrating from local games to virtual ones.

These platforms offer a digital board that is shared among the players that aims to replace the physical table on which the game is played upon. Each virtual table platform offers different features for players with most of them offering multiperson connectivity, dice rolling, the importing of custom tokens as images and their movement and annotation in the board.

More complex features come in the form of in-game distance calculation, sound or visual effects, and automations that are dependent on specific rule systems such as the automatic roll of the dice and subsequent relevant calculations of specific abilities of specific characters.

Various virtual tabletops also allow for the extension or even insertion rulesets, automations and calculations from the users. These extension of the system usually involve coding, either in the native language the VTT is written on, or in some custom language the system provides.

Virtual tabletops can either feature 2D graphics for the board and the characters or 3D graphics.

2D virtual tabletops are usually more flexible and customizable, and include better rule system integrations that allow for automations inside the game and for custom actions that are performed when specific in-game events occur.

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Figure 2.6: Tabula Sono, an in-browser, free-to-play 3D virtual tabletop.

3D virtual platforms have a more attractive and realistic presentation, with detailed characters and terrain that simulates a miniaturized world. On the other hand, they provide less flexibility and limited or non-existent rule dependent automations. As such, they fail to reach their potential of their 3D graphics, as the lack of rule system integration does not allow the actions of the characters to be animated or be accompanied by visual and audio effects or voice lines.

2.1.5.1 Tabula Sono

Tabula Sono is an in-browser, free-to-play 3D virtual tabletop [74], created for supporting tabletop role playing games. It provides tools for world building by creating end editing simple 3D environments that will act as the game's board. Lighting is also supported as well as the importing of 2D maps for the surface of the board. The VTT also contains a collection of 3D models to be used as representations of the characters that the players will control during the game. During the game the players can move and rotate their miniatures. Finally, the platform also provides some tools for the Game Master to hide elements of the map or characters that may need to be revealed at a later stage of the game. There are no rule integrations, or any automations during the game supported by the platform.

2.1.5.2 FoundryVTT

FoundryVTT [25] is a one time purchase virtual tabletop, that was created for online tabletop role playing experieces, and supports Windows, Mac and Linux as OS. It allows the players to self-host a game server which allows players to connect to a game session through a web browser. The platform is rule system



Figure 2.7: Foundty VTT, a 2D virtual tabletop that provides a lot of customization and rule integrations.

agnostic, providing a framework of features which can be used to play a variety of different tabletop role playing games. It provides 2D graphics for characters and miniatures, and sound effects that provide immersion to players. There exists a set of imported maps that can be used as a game board and a set of character art that can be used for characters. Dice rolling is enabled, and various automations such as automatic activation and targetting of specific abilities can be supported through the platform. In order to support these rule integrations, the system of FoundryVTT exposes an API that allows creators and players to code the automations and game rules they want to implement. A community supported by the creators for the virtual tabletop, has created partial rule integration for over 200 different role-playing game systems that are constantly updated and expanded upon. Foundry VTT provides a lot of functionalities that are common in other 2D virtual platforms such as Roll20 [68] and Fantasy Grounds [53].

2.1.5.3 Tabletop Simulator

Tabletop Simulator [26] is a 3D virtual tabletop that aims to provide a digital experience for any tabletop game. This is achieved by providing general tools that facilitate board games and interactions between them. This includes physicbased interaction for dices, cards an the board, and features for creating tabletop experiences. The system is fairly complex even for experienced users and programmers, as it provides a myriad of ways for creators to inject various rules and automations into a game session. Various creators have created modules that can be added to the platform, and users can download and combine these modules to simulate interactions of a physical tabletop. The system provides the possibility for more immersive features such as character animations and audio effects, but a complex rule implementation and inclusion for particular game system is complex,

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Figure 2.8: Tabletop Simulator, a 3D virtual tabletop for all kinds of tabletop games.

and the integration of such features in coordination with specific rules requires a vast amount of work that makes the task impossible even for the most experienced and determined creators.

2.1.6 Hybrid Games

Advancements in technology make the merge of digital and analog media an easier task than it was ever before [7]. In this context, hybrid games are continuously becoming more feasible for development, and are rising in popularity [28] with various educational board games being developed and utilized [18], and the adaptation of other physical games like Monopoly [62] and Bloodbowl [41].

While many definitions exist for the term "Hybrid Games", for this research, a hybrid game will represent a board game that combines digital and physical modalities to create an experience for players within the boundaries of a defined physical space, with most of the components of the game being physical, and the digital components being mostly small-scale enhancements to the board game experience. Such enhancements can range from mobile phone digital game additions for score counting, to physical game boards that can display digital information, to various sensors that trigger different effects according to their programming. The definition utilized in this study resembles the definition proposed by Marcello A. Gomez et al. [28], with the change of the emphasis in the physical aspect of the board game.

2.1.6.1 Affordances of Hybrid Board Games

The inclusion of digital components in hybrid board games, creates various advantages through the addition of novel interactions, possible artificial intelligence, and through the fact that a part of the game has been programmed and instructed to behave in a specific way.

Novel interactions refer to new game mechanics with which the player can interact with the system. These interactions can originate from sensors that track physical parameters, such as temperature, humidity, light or sound [28], and can produce feedback in a similarly varied way. Such varied sensory input and output, can also be utilized for making board games accessible to people with disabilities such as visual impairment [6], [17] and the elderly [77].

The accessibility of hybrid games is also enhanced by a reduction in the cognitive load required to play, since the inclusion of computational calculations can reduce the information that the player needs to process while playing [28]. Additionally, indicators that act as aid can be automatically set to appear on specific scenarios during the gameplay experience. Moreover, the integration of artificial intelligence in the analog gaming experience, can take the form of auto-activated game mechanics, that previously needed a meticulous study of the board game rule system by the players, to manually declare that the mechanic is activated [28]. As such, even in the small-scale integration of technology in physical board games, AI can create a better flowing gameplay experience.

Such games have been studied extensively, and hold significant potential if they are developed carefully to adhere to the aspects of play that players consider crucial to the board game experience. This includes, minimizing gameplay activities that are not perceived as empowering or emotionally captivating by the players [39], providing game mechanics that without technology would have been impossible or required vast player effort [39], supporting a level of social environment as non-augmented board games [39] and maintaining the materiality and the tactile interactions that are highly desired by board game players [66].

A further analysis and comparison of hybrid board games to different kinds of board games will be detailed later in this chapter.

2.1.6.2 Hybrid Game Implementations

The study of hybrid games and specifically hybrid board games, highlights two categories of researched hybrid game implementations. The first category concerns either board games that exist and are adapted into a new hybrid version of the game, and games that are entirely designed and created from scratch (Figure 2.9).

The Settlers of Catan is a multiplayer tabletop strategy game, that involves cooperation, negotiation, and logic and has been adapted in a hybrid form by Jessica Ip et al. [36]. This version, includes both tangible and digital components, with a projector being utilized to simulate the board. Various hints and reminders to the players, are given through this board, with task automations and enforcement


Figure 2.9: Hybrid Game implementations: Top Left: hybrid Catan. Top Right, hybrid Monopoly, Bottom: hybrid Embroidery

of the rule system, being performed through computers. Such task automations include the illuminating of specific areas, to remind players to collect resources depending on the result of the dice roll, each turn.

The popular game Monopoly, has also been adapted to hybrid form [62] with the inclusion of an electronic board that can communicate with mobile devices. Monopoly, is a board game that has seen a lot of versions with the same rules, but different themes from pop culture. This hybrid version, allows for a selection of themes in the game through the board that displays various information including the theme of the game, tips for players, and the visualization of possible outcomes before the rolling of the dice. The hybrid board includes quality of life features, such as folding mechanisms, and charging through solar energy.

A gamified version of a Hybrid Embroidery Tool [49], utilizes image tracking for scanning the player's drawings on a canvas, and embroidering their designs. The game was created as a collaborative experience, where in players take turns to discuss their ideas and add their designs to the canvas and the final embroidering.

The second category of hybrid game implementations, includes hybrid game components and tools (Figure 2.10), that are designed to be functional for a variety of board games, and can be seamlessly utilized in a traditional board game, to transform it into a hybrid game.

The Truesight Battle Grid [64] is a board for the TTRPG Dungeons & Dragons, with LED lights for each cell of the grid that can be lit up in different colors, and blocks that can modify the board in a modular way. The coloring of each cell,



Figure 2.10: Hybrid game tools. Left: Tisch. Right: Truesight Battle Grid

can indicate different terrain, such as grass or water, and a virtual tracking of the pieces displays various information that regard the piece and the space of the board, such as movement range, and line of sight.

Tisch [32], is an application that runs on a Microsoft Surface, and aims to provide a board for digital tabletop activities through tangible interactions, by simulating a digital board and its capabilities in a flat touch screen.

2.1.7 Mixed Reality Board Games

For this research, the topic of extended reality board games will be explored through extended reality tabletop games with head mounted devices. The setting for these board games is a physical space with a table and seats, where digital components are projected through the HMD to both the table, and the rest of the space. Physical components like dice or cards can still be involved in the game, or become digital with the system either monitoring or being agnostic to them. For example, an extended reality tabletop game, may include digital dice for rolling or expect the players to roll the die physically, and then enter the result in the digital device.

As mentioned in previously, board games and specifically tabletop role playing games present unique characteristics, with some being fundamental to the experience, and others having a negative impact on the experience if they are absent. These characteristics as well as the affordances of AR, must be analyzed in order to make a complete study on AR tabletop games.

2.1.8 Affordances of Extended Reality Board Games

In this thesis, we present the affordances of extended reality in detail, as this research involves the creation of an XR platform for creating this specific type of board games, and therefore the affordances the technology provides need to be further explained.

2.1.8.1 Merging Physical and Digital Information

Extended reality tabletop games are characterized by the merge of the physical and digital worlds, which enables new interactions and affordances. Such games, can achieve the sense of materiality in the game that is so intimate to both casual players and board game enthusiasts [66], while mediating more arduous tasks like point tracking, and order of play to a seamless digital environment. In addition, the natural and tactile interactions that a tabletop board gamer expects, can be maintained even with digital game components for pawns and dice [70], and at the same time benefit from their digital nature. Interactions that were previously impossible, like rolling dice that don't fall at the edge of a table, are possible with an extended reality game. Another important digital component that enhances the gameplay experience takes the form of a holographic digital projection of 2D or 3D elements to the physical game board.

Additionally, large tabletop games that traditionally take up a lot of space and may require large tables, can be compressed in size, with the utilization of the z-axis, the division of personal components to each player's digital world and the display of the components only when they are needed.

Moreover, digital components, and in general the extended reality board game experience, can be much more easily and effectively designed to include accessibility features. These features can refer to visual impairments [6], [17] and cognitive disabilities [77].

This is enabled through the versitility of digital elements that can be achieved with minimal costs. Adjustment in color, text size or content can be implemented at runtime, and without requiring completely different components to be included in the game in the same scale as physical components would. Additionally, vocal content for people with visual impairments can be included in the game, and in a personalized manner for each player. The inclusion of such accessibility features does not alter the game flow for other players, thus allowing a gaming experience that does not sacrifice attractiveness, play engrossment and enjoyment. [17].

Another contribution of the digital part of an augmented game, is that the rules of the game, by being integrated in the system, can be explained in detail and be programmed to be automatically abided by the game, so that no constant rule checking is required. Notably, this feature can even be optional as some tabletop gamers enjoy the process of figuring out a board game ruleset and its systems [45]. This specific example of an optional feature in an augmented tabletop board game, encompasses the value of extended reality in tabletop gaming. As different people have different preferences on what they enjoy in a physical setting of play [45], with extended reality all these physical features can be retained while the rest of the features can be digitized for either ease of play, smoother gameflow, or for better immersion.

2.1.8.2 Narrative Interfaces and Extended Reality

The market for interactive digital narratives has been utilized for entertainment, education, tourism and training in the recent years, and has seen significant growth [38]. As such, there has also been research on interactions and the conditions where these interactions are optimal for interactive narrative in extended reality. It has been studied that natural user interfaces seem to be more suited for a narrative game, as they provide interactions that tend to distract the users less, and as a result a system utilizing them can achieve greater immersion in the game and as a result a heightened level of focus in the story [38], [49].

It also has been documented, that the inclusion of sounds as a response to player action provides an additional level of presence in a narrative [58]. This provides board games in extended reality with a unique opportunity previously impossible in a physical space: the inclusion of sound effects in various game components. This can occur in the form of narration of plot or cards that several board games include, in the form of immersive and plot related music and in the form of sound effects that correspond to specific player actions, for example lighting sounds played for the utilization of a card that casts a lighting spell. The inclusion of such sounds seems to be a way to immerse a player in a narrative [58].

2.1.8.3 Immersion In AR Board Games

In board games developed or adapted for extended reality, the immersion to the digital board game components, exists as another level of immersion that is crucial to the final gaming experience. In this section, three levels of immersion will be discussed for AR board games, perceptual immersion, deep emotional engagement and immersion in the digital board game components

Perceptual Immersion

To achieve perceptual immersion, AR video games, board games, and applications in general combine virtual holograms and spatial sounds, while still keeping the users connected to the real world [37]. The simulation of sounds through the HMD heavily impacts perceptual immersion as ambient sounds can create a sense of physical presence, music can be used to set the basic mood, induce specific feelings or encourage activity, and sound effects are the sounds that result from events in the physical world [58]. Holograms can be used for immersion to display background objects, characters, or scenes that create a different world inside the physical space. This virtual addition to the real world space acts as a not distracting background to the central focus point which is the board game [67].

Digital Board Game Components

For digital board game components that may be utilized in the augmented board game, such as cards and markers, two things must be considered. Firstly,

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if these components can look, sound and behave in a realistic manner. As discussed previously, state of the art holographic devices for extended reality have the graphical and processing power to produce realistic holograms. Moreover, the inclusion of physics simulation is achievable. Therefore, it is safe to assume that the creation of realistic seeming gaming components is possible in AR.

The second thing for consideration for extended reality tabletop games, is the feeling of the digital components. This concerns the immersion when interacting with them. For example, a virtual die, except from looking, sounding and rolling like a physical die, should also be grabbed and tossed in a manner that feels as natural as grabbing and tossing a physical die. Many AR games seem to have achieved such immersion, from simple interactions like pressing a button, to even as complex interactions as handicrafts [70]. If the folding and manipulation of paper can be designed to seem natural to users, the interaction mechanics that board games require should also be achievable.

Deep Emotional Engagement

Deep emotional engagement is the level of immersion that is the least affected by the technology of AR [81]. This is because emotional engagement is heavily dependent on the content of the board game, the character of the player and how compatible this character is with the emotional engagement the board game provides. However, the cognitive engagement through the gameplay mechanics that are facilitated by digital board game components, as well as spatial immersion aid the achievement of deep emotional engagement ([60], [81]).

2.1.8.4 Maintaining Locality

An important addition to the affordances of Augmented tabletop games, is that they present all aforementioned benefits while at the same time, gathering all the players in the same space.

The social aspect of gathering in the same space for a tabletop gaming session is at the core of the existence and continuing popularity of tabletop gaming. So it is really beneficial that extended reality allows for a "traditional" setting for tabletop gaming, while providing further enhancements to the gaming experience.

As a lot of board games have a collaborative aspect to them or a combination of collaboration and opposing goals, it is of value to note that extended reality does not hinder collaboration efforts but rather seems to enhance it [69], [44], [5], as information can be more easily shared or viewed in the same time in a digital format and as such, strategies can be more easily explained and be understood by everyone. Also, through enhanced immersion players show more interest in the game and are more likely to discuss and propose ideas [44].

2.1.9 Extended Reality Games Implementations

Mensch ARgere Dich Nicht [48], is a extended reality adaptation of the popular German board game Mensch Ärgere Dich Nicht developed for Microsoft's HoloLens, offering interactions with physical and digital game elements. This implementation contains both real and virtual components for the game, including the board, dice and pieces, each of which can be selected to function either in their physical form or through HoloLens.

Yingjie Song et al. utilize HoloLens, a Kinect V2 and a PC to create an extended reality storytelling system that enables the learning of handicraft in a storytelling environment [70]. The game utilizes the Kinect and the computer to improve upon the HoloLens' hand tracking and gesture recognition, and includes an Origami tutorial and modes for creating and sharing stories through handicraft. The game was found particularly stimulating for interactions between parents and their children.

Shozo Ogawa et al. created a collaborative tabletop extended reality game for ice breaking, that is facilitated through a special board with 4 physical levers and HoloLens 2 MR headsets [61]. The players manipulate the real levers to change the incline of a virtual board, with the goal of making a virtual piece move through the board in various paths. The behavior of the piece in regards to gravity can be altered for each level the players face, with this counter-intuitive behavior seemingly having a positive effect in the verbal communication between the players, and generating interest for the game.

CheckMate, [31] is an AR tangible interface for remote interactions. It includes 3D printed tangible pieces with a surface that detects their manipulation and relocation. This is done through conductive materials that can be tracked on any touch-enabled capacitive surface. In this setup, an extended reality head mounted device is utilized, to add a virtual dimension to the game. The pieces of the opponent as well as an avatar of the opponent are projected in the virtual table, with the various moves of the pieces and the interactions between them being animated. In this way, each player plays their pieces physically as they would in an analog game of chess, while they see in real time projections of their opponent's pieces and moves. If a player loses a piece, they must remove it from the physical board in order for the game to continue.

The games described can be seen in 2.11.

2.2 A study on important tabletop affordances

For the purpose of analyzing the aforementioned board games, 10 aspects that define the players' board game experience as well as the various interactions and the way the game is played have been selected. The results of this study can be summarized in Figure 2.12, where the 10 aspects are placed in the horizontal axis, and the board games analyzed in the vertical axis. For each cell of this table, there exists a representation of the scale that the corresponding board game implements



Figure 2.11: Extended Reality Board games. Top: Mensch ARgere Dich Nicht. Middle: Checkmate. Bottom: Origami Handcraft game



Figure 2.12: A summary of our scaling of the selected board games for each category.

the corresponding aspect, which can range from the absence of implementation to a full implementation, with 3 intermediate stages.

It is important to note, that while Figure 2.12 summarizes the results discussed below, it does not provide measurements of how good a board game or its implementation is. Some board games may not be designed to incorporate an aspect that is cataloged in this research, and this fact does not necessarily make that board game lesser in quality. For example, chess as a game does not aim to create or convey any narrative, and as a result its scale in the category Narrative will be the lowest possible.

2.2.1 The Selected Board Games

For the task of analyzing each platform's affordances a selection of 12 games has been performed. This includes games on which has been done scientific research that has generated data that can be utilized in this analysis, and games from which such data will need to be extracted from the gameplay, and various user reviews and evaluations. These games are selected for multiple reasons. Firstly, the variety of platforms that needs to be explored has led to the inclusion of physical, digital, hybrid and extended reality board games, with 3 exclusively physical, 2 exclusively digital, 3 hybrid and 4 augmented board games being selected.

The three versions of Monopoly were selected firstly because Monopoly is a simple and popular game, with which experienced and non-experienced players of tabletop games are familiar with, and because physical, digital and hybrid implementations exist. This aids the distinction of each platform's affordances, as in the same board game the differences in each aspect studied can be easier attributed to the implementation platform.

Gloomhaven is a really popular and highly rated game among the board game community that is highly complex. It is mainly a tactical combat game with a high emphasis on strategy and cooperation while including roleplaying elements although in a more limited way when compared to traditional TTRPGs like D&D. It has a physical edition, and a later developed digital edition that has been both critically acclaimed and done well financially. The study of a more complex game with physical and digital adaptations will be helpful in answering the research questions posed in this section.

For the hybrid and augmented board games the selection was made from research rather than industry, as such industry games tend to be more experimental and have a generally smaller playerbase with fewer reviews, and are played by people that are well trained in the use of the technology that is utilized. On the other hand, the selected games that were created in a research context, have been evaluated with players of all levels of experience, and their behaviors have been documented and recorded more accurately and objectively.

It is important to note, that Tisch for TTRPGs and Truesight Battle Grid are tools that when utilized in an analog tabletop game can transform it to a hybrid game, and as such the analysis on them will be based on their utilization on the TTRPG Dungeons & Dragons (D&D) as it is one of the most popular games of its genre, and both of the studies for the tools reference it as a game where their tool was tested upon. Both of these tools are created to be utilized for D&D's combat encounters, which can be estimated to amount for at least one-third of the time played.

The 10 aspects in which we analyze the selected are Collaboration, Accessibility Features, Sociality, Complexity, Tactility, Game Customization, Flexible Interaction Types, Narrative, Immersion and Spatial Requirements. Our findings for each aspect and each game follow.

2.2.2 Collaboration

As discussed in Section 2, while not all board games are collaborative, most TTRPGs [80] and a large quantity of other genres of board games, do contain collaborative elements, and as such it is important to study how each different platform enables and possibly enhances collaboration. The scale of collaboration for a game will be determined by two factors: whether collaboration is a part of

the experience, and by analyzing what affordances the game provides to promote collaboration between the players.

Monopoly, while being mostly competitive, with the last standing player being declared as the winner, includes some collaborative elements like the trading of assets. In the digital version of the game, there is not any special feature to further encourage collaboration, and the study published for the hybrid version of the game does not make any reference to such a feature or observation either. As a result we do not deem any difference in the cooperation aspect of the game in any of its versions.

The experience of Gloomhaven is highly important in cooperation and collaboration, as each player takes control of a character and the team the players form must survive multiple combat scenarios in order to progress in the game. This collaboration is on a strategic level as it is most optimal for a team to collaborate in order to achieve their goals rather than act in a solitary way. However, in Gloomhaven there also exist personal goals and most importantly several of the factors that lead to character advancement such as exp points and gold are not shared resources so there arise situations where a player may act independently of the group. The rules of the game in regards to cooperation stay the same for both the digital and physical versions of the game. It is important to note however that in order to achieve live communication the digital must be accompanied with a platform that supports voice calls. However, as such platforms are ubiquitous this study does not consider this accompaniment as a detriment to collaboration.

Dungeons & Dragons is a highly cooperative game with collaboration being a pillar in the co-creation of the narrative and game experience. However, a lot of times the communication between players is hampered by the amount of information each player has to process.

In the study for Truesight Battle Grid, aids to the gameplay of D&D are presented, making as a result each player better at understanding the current situation and options for both their character and the other characters. As a result, the tool manages to enhance the communication and collaboration between players.

The research on Tich does not mention anything about an effect on collaboration, but the system was found generally usable with one of its goals being to provide information to players. As informed players are usually more likely to cooperate, there can be inferred an enhancement on collaboration.

The Hybrid Embroidery game created by Yi-Chin Lee et al. [49], includes a collaborative mode where the players take turns adding new embroidered elements to a section for the final result of a co-created embroidering. As such, collaboration is being supported through the interactions with the system. While this collaboration is at the core of this mode, the interactions that facilitate it are simple compared to the more complex strategizing aspect of Gloomhaven and D&D.

Ice Breaking, is a game that is all about cooperation as the aim of the game is to stimulate communication between the players through the act of cooperation, and as a result collaboration is at the core of the game. However, because the gameplay is simple and the game is not meant to be overly challenging as it is designed for first time meetings, this collaboration is not as deep and complex as in other games.

he rest of the games selected for this study do not contain any collaboration elements in their gameplay.

2.2.3 Accessibility Features

The board game industry is beginning to acknowledge the importance of accessibility, with many publishers and designers making efforts to create games that are more inclusive and accessible to players with different needs. These efforts have included features such as larger text, clearer symbols, tactile components, and color-blind modes.

Additionally, there are organizations and initiatives dedicated to promoting accessibility in board games, such as the AbleGamers Charity [35], and the Accessible Games Database [19]. However, these efforts are currently small-scale, and much work is needed to ensure that all players can fully enjoy board games regardless of their abilities. In this context, the digitization of board games can aid the adoption of accessibility features by more platforms. Features such as colorblind modes, larger text and clearer symbols can be implemented with a fraction of the development effort and cost in a digital media, when compared to a physical one. Moreover, digital content can be updated to include further accessibility features with a simple download-and-install, that integrates the new features rather than needing a revision of the game or a separate publishing and distributing of accessible physical components.

The analog version of Gloomhaven does not include any accessibility features. The digital version, provides some accessibility features such as subtitles for all the content, the ability to play the game only with one pointing and clicking device, and a tutorial mode that teaches the game's mechanics and rules which in turn can reduce the cognitive load for players. However, other important features are omitted such as resizable text, a colorblind mode and high-contrast graphics.

Mensch ARgere Dich nicht, features the ability for the players to choose between virtual or physical components for the board, the pieces and the dice. The virtual components require simpler interactions with automatic calculations for dice, and the ability to automatically move the pieces. In this way, people with difficulties in hand movement can play the game.

Dungeons & Dragons does not feature any accessibility features. Truesight Battle Grid with its indicators that help structure the game, and the visualizations in the map can help players understand and learn various rules of the game that are complex. This can simplify the game for people with learning difficulties or mental disabilities to play and enjoy the game.

The rest of the games studied in this research do not include any accessibility features, as they do not seem to be designed to be accessible. Important omissions in this front are made by the digital version of Monopoly that could theoretically include a variety of accessibility features with minimal effort.

2.2.4 Sociality

Sociality in this context, will refer to how a board game manages to create a social environment for the players. This environment is formed naturally in an analog board game where the players gather together, while in digital games it can be formed through text or voice chat or a form of video or audio call. The digital solution to communication between the players is lacking compared to the feeling of a physical gathering [66]. Moreover, some social interactions that typically occur in a board game stem from features that are not, or cannot be implemented in digital games such as object maneuvering, manual bookkeeping, shuffling of cards and organizing the board. In general, the social experience of play is of core importance to players, and can even be more important in a tabletop gameplay session over the particular board game that is played [66]. As a result, it is of great value to this study to analyze which platforms that tabletop games are played on can facilitate and support a high level of sociality.

The physical version of Monopoly, enables social interactions as it is expected in any analog board game. All players gather around the same table to play the game, and interact with each other. The digital version of Monopoly has not integrated any kind of social communication inside the game, either through text, voice or simple emoji-type reactions. This can be circumvented however through the use of a third party online platform that supports video and/or audio calls. An omission however that hampers the capabilities for social interactions in the game is the lack of accessibility features in the game.

The hybrid version of Monopoly supports social play in the same manner as analog board games, enabling players to sit around in the same physical space and play the game. While the hybrid board could theoretically support accessibility features, no such mention is made by the authors, and as a result in the Sociality category, the hybrid version of Monopoly is ranked in the same scale as the physical version, not higher.

In the same scale of sociality stands Mensch ÅRgere Dich Nicht as a board game that can be played with up to 4 players. The augmented version of the game provides some new tools and interactions that can spark social interactions and the locality of the analog game is maintained.

Gloomhaven is a game that incorporates and supports social interactions in a more direct manner, because players need to communicate and discuss strategies in order to win any encounter. The digital edition of the game suffers similarly in the social aspect of play as the digital version of monopoly when compared to its corresponding analog version.

Dungeons & Dragons as a tabletop RPG is a game that is based on the social interactions between players as they assume different characters and interact with each other, with the characters forming relationships with each other and with the fictional world of the game. As such, it achieves the maximum scale in the Sociality category.

The digital enhancements provided by Tisch for TTRPGs and the Truesight Battle Grid may create new social interactions as new interactions with these platforms are inserted into the game. However they are tools utilized for the combat encounters of D&D where sociability is of secondary importance when compared to social encounters, and as such their overall benefits to sociability are not important enough to elevate further the game in this category.

While a game of chess is usually played between two human opponents, the rules of the game and the way the game flows does not promote social interactions between them, especially when compared to other board games. In only digital remote implementations of chess, the two players are usually separated entirely with no social interactions between them. Checkmate was created for remote play and through its augmented board and opponent as well as the tactile interactions with the pieces was reported to closely emulate the analog gameplay of chess being able to achieve the limited sociality that a physical game of chess provides.

The Hybrid Embroiderment game adds a social aspect in the process of embroidering through its collaborative mode where 2 players collaborate to create an embroidery. The workshop that was conducted in the research in order to study the scale of this collaboration and social interactions between the players reportedly only showed subtle social interactions contrary to the authors initial expectations. The AR game for creating Origami is focused mostly on story creation and storytelling rather than social interaction, but a user study was conducted that aimed to study if the game could foster parent and children interactions and was found to positively affect them, adding a social aspect although small to the game. Finally, the Ice Breaking game was created to facilitate social interactions between people that are just meeting and was recorded to be able to support social interactions in ways expected of a tabletop game played in a local setup.

2.2.5 Complexity

What is considered a complex game can be interpreted in many different ways. For this thesis, the complexity of a game will refer to how many rules the game possesses, how easy it is for new players to learn how to play, and how many components it utilizes. For example, chess can be considered a complex game that requires a high level of strategy with few people that have come close to mastering and possess extraordinary skill in it. However, for this research chess is considered a simple board game, as its rules are relatively simple to understand and a new player can begin to play shortly after being introduced to the game, even if truly mastering the game is exceptionally hard.

The value of recording the complexity of the board games studied, is to measure the effects of the different platforms where games are developed to both simple and complex games. This will serve to more accurately determine the benefits and challenges each platform provides to each type of board game depending on its complexity. All versions of Monopoly analyzed in this study feature more or less the same amount of complexity in their rules and gameplay and are considered simple. It is noteworthy to mention that the digital implementation of Monopoly, includes tutorials that further simplify the process of learning the game's rules and offers varying difficulties of AI opponents in case a player wishes to practice before facing real players. The hybrid version of Monopoly displays extra information in its electronic board, such as display of the desired goals for a player, and information about possible outcomes before the rolling of a die, that further simplify the game and help with building game strategies. In this context, any new mechanics introduced by the hybrid board are not recorded to facilitate interactions that are viewed as complex by players. As a result, both the digital and hybrid implementations of Monopoly manage to reduce the complexity of the game.

Gloomhaven is a tabletop game that incorporates a large quantity of options for the creation and advancement of a character as well as for the control of these characters. The rules for combat, and the strategy that is required in order to proceed in the game, further add to this complexity. In the analog version all of the non player characters (NPCs) are controlled by players according to specific rules. These factors, make the analog version of Gloomhaven a game that is notoriously difficult for newcomers to get into, due to its complexity. The digital version of the game attempts to offer the same experience in a more digestible form for new players, by including a variety of tutorials, in-game pointers, and help options, that aim to teach newcomers how to play the game. Also, the inclusion of AI control for NPCs removes a task that players would need to undertake in the traditional version, further simplifying the game.

Dungeons & Dragons offers a game experience similar to Gloomhaven in terms of complexity. A gridded battle board depicts the environment, and is utilized to measure distances for the movement and the various abilities characters have. Each player controls a character with a quantity of unique abilities, and has to make various strategic decisions each turn for movement, attacking, or different actions. For the depiction of the environment, most often drawings or everyday objects are utilized as to represent parts of the terrain. The rules that facilitate combat in D&D, the need for measurements in this gridded board and the amount of options each player has each turn creates a system that can be daunting for new players.

Tisch for TTRPGs, and the Truesight Battle Grid, are both tools that display information that would typically have to be imagined or calculated by the players or the DM, and as a result manage to reduce the cognitive load of D&D combat. However, even after this reduction in complexity, the game remains highly complex as the DM still has to control every character that is not a player character, and the players, while being more informed about the current battlefield situation, still have to know a large amount of general combat rules and character specific abilities in order to play.

The Origami handicraft game created by Yingjie Song et al., and the Hybrid Embroider Game, both include interactions that are characterized as intuitive and simple, with a small cognitive load, as they focus on creativity and storytelling, rather than any kind of strategy or complex gameplay interactivity, and as a result they can be characterized as pretty simple games.

The Ice Breaking game was created to be simple enough as to not be frustrating, but also be challenging enough to create social interaction between the two players.

Mensch ÄRgere Dich Nicht incorporates the rules of its corresponding analog game in a manner that does not include any interactions or added rules that complicate the experience, with simple rules for new players to manage to play without being lost on what is happening.

Checkmate adds a feature that colors the board tiles with regard to possible moves and an indication on whether a player can attack a piece of the opponent. These additions can act as an assistance to inexperienced players in learning the rules of the game.

2.2.6 Tactility

Tactility for this research, will be referred to as the feeling of a board game's components in regards to their physicality. This refers to both the physical characteristics of a component such as their texture, smell, colors and art depictions, and additionally to the interactions with these components, such as the setting up of the game, the moving of the pieces [45], the interaction with the board, the manual rolling of dice and the storage box where the components are safeguarded [66]. This tactility, can offer a feeling of satisfaction and is part of the experience of playing a board game. As a result, such an implementation and adaptation in different platforms should be studied. The scaling in this category will also consider how important to the experience is the tactility for each tabletop game.

The analog version of Monopoly contains dice, a board, player pawns, tokens for the houses and hotels built, a form of currency that is usually paper money, cards, and small miniatures for the hotels and homes built by the players. An important characteristic of Monopoly as a game is that it has a very large number of versions that range from real world locations, to fantastic worlds from pop culture. In this way, it is highly thematic as each version comes with different themed components, which is a major selling point of the game. The digital version of the game offers a variety of selectable 2D and 3D components and provides the option to create custom ones too. However, a lot of the interactions in tactility are lost, with a major one being the feel of the money handling of Monopoly. The hybrid version of Monopoly developed by Jae Wan Park, also offers a selection of different boards and themes for the location that the game takes place in, as well as the currency and theme of the digital money and interface on the players' smartphones. By having a physical board with and physical pawns, but utilizing digital interactions for the game's currency, the intensity of the feeling of tactility in hybrid Monopoly falls between the analog version and the digital implementation of the game.

The box of the tabletop game Gloomhaven weighs more than 9kg with the tactility of the game having been heavily considered in the development of the

game. The physical components are too many to individually mention, and they range from miniatures for player characters, stand-ins for monsters, various maps, boards for various different campaigns, sealed envelopes, town records, and even achievement badges. While this variety of content is also available in the digital edition of the game, the feeling of tactility is lost in the mouse and keyboard interactions.

In the game Dungeons & Dragons tactility comes into play when rolling dice in social and exploration scenarios, and becomes more central to the experience in any combat scenario. In a typical D&D combat scenario a board will be set up with physical representations of the environment, the player characters and the rest of the NPCs. These can range from character miniatures and physical terrain, to 2D drawn elements for the terrain or dice to represent the characters, depending on the budget and space constraints of the group that plays the game. The feeling of tactility in these scenarios comes from the visual of an accurately represented board as players see a gigantic dragon that dwarfs their own character miniatures, or a horde of goblins that surrounds their characters. Also, moving and manipulating their character inside the terrain can provide a feeling of satisfaction.

Truesight Battle Grid provides a modular board that provides various information. The physical walls, rooms and corridors that can be created in this way are better than a 2D battle grid where these terrain components would be drawn by a marker, but are a step down from the realistic terrain with textures and minute details that can be found in shops.

Tisch for TTRPGs provides the best possible form of 2D terrain as any map can be put on the screen and be used as a game board. However, a 3D detailed physical board still provides an elevated level of tactility.

The Origami handicraft game created by Yingjie Song et al. utilizes its systems to perform accurate hand tracking and provide an experience with folding and manipulating digital paper that the study mentions was highly satisfactory to the players that tested the game.

Hybrid Embroidery as a hybrid game utilizes the physical interaction of drawing that is then digitally processed to create an embroidering. In addition to the physical interactions during the game, there is also the feeling of tactility after its end as a custom embroidering is produced with its colors and designs being the creation of the player.

The Ice Breaking game developed by Shozo Ogawa et al. uses physical levers for control of a digital hologram that is rendered through a extended reality device. This tactile interaction and its results is what motivates and supports the communication between the players that the game was created to facilitate.

In Checkmate the players utilize physical pawns and pieces for their moves as a result achieving the same tactility as the analog game of chess. However, tactility is not a highly important aspect of the game with the primary focus lying on the strategy aspect.

Mensch ARgere Dich nicht provides both physical and virtual components, allowing the users to select digital or physical dice, pieces and board. The analog Mensch Argere Dich nicht has only simple interactions, with its components with very minimal tactility. In the AR version of the game, even when the digital versions of components are selected, the holograms and the interactions through HoloLens provide natural interactions and customizability in the board and the pieces colors.

2.2.7 Flexible Rule System

All board games have a set of rules. However, in many cases, different groups of players modify these rules for their game sessions. These additions, removals or changes of existing rules are most commonly referred to as "house rules". Additionally, there exist games that have a rule system that either intentionally or not, does not cover all the scenarios that can happen during the game. This is most prevalent in tabletop role playing games, where improvisation is a core element of the experience. This section mostly concerns digital games, as in analog games there is no system in place to enforce a set of rules and as a results the physical games can be played in an way the players want. Another facet of flexible game rules that will be taken into account for this category, is how often do players of the respective board games modify the game's rules.

The analog version of Monopoly is such a popular board game, that usually, the first time a person plays, they don't read the rules, but play with a group of people that lead the experience. This situation has created house rules that are so widespread amongst the community that most players don't even know that they are not playing according to the rules. Monopoly Plus, the digital version of the game has selected some of these house rules and has implemented them in the game as optional rules that can be enabled for a game. This includes 6 new rules that modify the game, covering the most common house rules but does not provide a large amount of flexibility to the game's rules. In the hybrid version of Monopoly studied in this research, the currency and bank are digital with no mentions of the being able to modify their function in any capacity, but most of the rules are not enforced by any digital system, and as such they can be modified.

Gloomhaven is another game in which players often introduce their own house rules to create a more enjoyable experience. These house rules are less widespread than those of Monopoly, and are mostly tweaks to the numbers of the original game rules that serve to balance the game in a way that serves a particular game group. The digital version of Gloomhaven has gathered some of the most popular house rules that have been circulating among the board game's community and has updated the originally released game to include the possibility of enabling them. The digital game, also features some variant rules that can change the game's difficulty, making it easy for players to select if they want a specific campaign to be more or less favorable to the players. While the choices for these rules are bound by what the programmers of the game have implemented, there are benefits to the digital means of game customization as the variants offer a generally balanced experience compared to some arbitrary house rules that players come up with. Additionally, there is no requirement for further cognitive effort by the players when trying to enforce these house rules as the system implements these modifications automatically and tracks the changes.

Dungeons & Dragons and TTRPGs in general, are the genre of tabletop gaming where the need for game customization and rule flexibility is most important. Because the narrative highly depends on improvisation, and because most narratives feature a complete freedom of choice and immersion in a fantastical world, the possible situations that can arise are endless. In this context, it is impossible to account for every scenario that can occur, both in terms of designing the game and in terms of understanding and studying the rules as a player. As a result, a lot of these games except from a lot of specific rules, also provide a lot of general rules that aim to cover the majority of scenarios that will occur. Due to this generality and the quantity of possible situations that can arise, some of these rules can be applied in ways that don't make sense in the context of a particular scenario. One such scenario that highlights this problem, occurs in D&D 5th edition, where two creatures that fight each other without the ability to see are equally unaffected by this inability instead of being equally affected. For such situations, the designers of tabletop role playing games, often mention that the most important rule of the game is that the dungeon masters are in control of any situation, and can enforce their own rules on specific situations as they see fit. In this way, game customization is by design integrated into D&D's rules.

The tools that can be utilized for D&D play, Tisch for TTRPGs and Truesight Battle Grid do not constrict the game's flexibility.

In a physical game of chess, customization to the rules is most usually applied in the form of the time constraints for each player, and some less popular game variations (e.g the Fischer random) that are designed to be played with the equipment of regular chess. Checkmate does not restrict players into any time constraints allowing them to track time manually. However, it does not provide any freedom of customization in the gameplay and on the contrary enforces the rules of classical chess.

The rest of games studied for this research do not provide any game customization as the digital systems have not been designed with such flexibility in mind.

2.2.8 Flexible Interaction Types

This subsection refers to the hybrid and augmented board games, and measures whether a game offers both analog and digital interactions for the same purpose, for example the ability to mark a board in both a physical and a digital way. This measurement, aims to catalog how often do games of this type include flexible interaction types.

The creators of Hybrid Monopoly support both completely digital play, through smartphones, and a hybrid approach, through a custom board. However, there does not seem to be an option to mix the two, with a portion of the players playing on their smartphones and others on the board. In both modes, the dice and the bank are digital, while the board and player pieces are physical while playing on the hybrid version, and digital while playing on a smartphone. As these different interaction types do not coexist in the same game session, Hybrid Monopoly is not considered to include flexible interaction types.

Checkmate aims to provide a tactile experience to its players trying to emulate the analog experience of playing chess with players in different physical locations. As such, it only includes tactile interactions with the pieces without offering alternatives. Similarly, the hybrid game for creating Embroidery created by Yi-Chin Lee et al. only features a single type of interaction

Mensch ARgere dich nicht features complete flexibility in the interaction with its components. The game's components are the dice, the board and the pieces all of which can be selected individually to be either physical or digital. When possible, the augmented versions of the components also contain features only possible in a digital system such as an automatic setup for the board and "Auto-Move" for the pieces. For the physical components, image tracking software is utilized to acquire information such as the number rolled by the dice or the position of the pieces.

The extended reality game for storytelling through Origami, features two ways of creating this handicraft; Either through HoloLens with digital interactions, or in the traditional way of creating Origami by utilizing a piece of paper with the digital model of the Origami being created at the same time through hand tracking.

2.2.9 Narrative

Narrative in board games has been previously touched upon in this chapter of the thesis. When studying board games and the platforms they are played on, it is important to take into consideration which games are created with a narrative in mind. In chess for example, and as a result also in Checkmate, there does not exist a narrative meant for experience for the players.

The same applies to Mensch Argere Dich nicht and the extended reality version of the game studied in this research as well as the Ice Breaking game, as the focus of has been given to the experience in regards to the mechanics and the rules of the game, and there is no narrative present.

In the Hybrid Embroidery game the players have a choice that is supported by the game's mechanics to try and co-create an embroidery within the context of some narrative.

In the analog version of Monopoly there is a minimal presentation of a narrative, with each thematic version of monopoly offering different descriptions to the various cards depending on the setting of the game. The digital and hybrid versions of the game provide the same kind of narrative with no notable additions or omissions.

Gloomhaven offers a narrative that accompanies the combat gameplay scenarios of the game. While the narrative is not as deep as in role playing games, it is more permanent and meaningful in the game when compared to typical tabletop games. It presents the players with an introduction, some intermediate narrative bits, and a conclusion. There also exist Events (or Encounters in the digital version), where the players are presented with a description of a situation outside of the normal combat scenarios, and two choices on how to respond in this situation. Depending on their answers various effects can occur that alter their next combat scenario and build the narrative. The digital version of Gloomhaven presents the same narrative in a more cohesive way, with drawn images accompanied by audible narration that make it easier to pay attention, follow the plot, and understand the setting end events that transpire.

In Dungeons & Dragons narrative is paramount to the experience. This narrative is supported mostly through descriptions by the Dungeon Master, and the interactions between players' characters, or with various NPCs the DM portrays. This narrative, in the form of a fantastical world and a plot, has been created beforehand in parts, but is fluid enough for the players to act their characters without restrictions, and in the end shape a unique collective narrative. The narrative is at the forefront mostly in social and exploration encounters, and less focused on combat scenarios. Truesight Battle Grid does not contain any features that affect the narrative during such scenarios. An accurate representation of the battlefield that has been described by the DM can provide a visualization that aids the players to form a clearer image of the narrative. This can be achieved by Tisch for TTRPGs, although in two dimensions, and therefor losing some details and a sense of realism. While the tool is created for facilitating combat scenarios, it does not offer enhancements to the narrative during those scenarios.

The Origami extended reality tabletop game focuses on storytelling through the interactions, and the process of creating handicraft. It is specifically aimed for children and parents to design, create and then tell stories. As such, narrative takes a center role in the game, with the system being satisfactory in the user testing performed by the researchers.

2.2.10 Immersion

Immersion in the context of this research has been defined in previous sections of this chapter. For this section, immersion to the digital components in the case of hybrid and extended reality board games will not be taken into consideration, as it is studied in the subsection Tactility.

Not all board games make immersion a major part of the intended experience they offer. Chess and as a result Checkmate does not contain any narrative in any form, or a fictional world to immerse the players in. The same holds true for the Ice Breaking Game and the Hybrid Embroidery game that place their focus in the gameplay experience and the mechanics of the game.

There also exist board games that try to achieve immersion to a minimal degree. Such a game is Monopoly with its various components that are thematic, such as the board and its locations, the buildings that represent the hotels and houses the players build, and the players' pawns. While Monopoly does not aim to completely immerse the players in the world of its theme, the variety and success of these various editions of monopoly, shows that players enjoy playing a game with the same rules in the fantastical world or real world location of their preference. The digital version of monopoly enhances this immersion factor by including ambient music and sound effects of the corresponding theme. The hybrid version does not take any steps to further immerse the players in the selected setting of the game.

As it has been discussed Gloomhaven features some light role playing elements, and as such immersion is a component of the experience, although secondary to the mechanics and gameplay of the combat scenarios. Descriptions of the world and the current whereabouts of the adventuring party, aim to immerse the players in the story and the current situation, while the character backstories provide understanding for the motivations of the characters. This immersion is enhanced in the digital version of the game, where the locations, player characters and enemies are rendered and animated with detailed 3D graphics and effects. Sound, also plays an important role with music and sound effects for narration and for various abilities and interactions.

In D&D as with all tabletop role playing games, being immersed in the story and characters is a core part of the experience. In D&D, immersion is achieved through the DM's description of the world and characters, and is heavily based on each player's imagination and willingness to immerse themselves. As with the narrative, immersion takes a central role in the social and exploration encounters with combat encounters relying more on strategy and the mechanics of the game. As such, the tools that are created mainly for combat encounters, Tisch for TTRPGs and Truesight Battle Grid do not affect the immersion of the players in any way.

2.2.11 Spatial Requirements and Storage

This section will detail what kind of space does each game require of the players, in order for a game session to be facilitated. Analog board games with many players and large or many components may require big rooms and storage spaces, as many homes of fanatic board gamers have rooms specifically configured to host the gameplay of just one board game. In the space requirements, except for the board game components, objects such as bottles and glasses for water or soft drink, snacks and food should also be considered.

On the other hand, as digital board games are usually played with players in different locations, they require the space that the hosted device (usually a mobile phone, tablet or computer) covers. Hybrid and augmented board games, fall between the aforementioned spaces, as the digitization of some physical components, the elimination of others and the possibility for an overlap of physical and digital components clears up much space. However the gameplay session is still facilitated in a table with all the players gathered in the same space.

The analog version of Monopoly needs a moderate amount of space in order to play. The game utilizes a medium sized board and the players have their own cards and money to manage. There is enough space to play Monopoly in most tables but with the addition of snacks and drinks bigger tables are required to host the game. The game can be stored in its box. Hybrid Monopoly is created to be more compact with its board being much smaller and the currency and cards for the players being digital.

Gloomhaven on the other hand, has many different components that need to be readily available for the players to use. This includes different maps, battle boards, storybooks and rule-books, and for each player various cards, character sheets and more. As such, the game requires a large table to lay out all these components, and space for the players to lay out their specific components. If drinks and snacks are included in the game session, comfortable gameplay would require a large space designed for Gloomhaven and other board games. Storing the game does not present a problem in regards to space, as all of the components fit in the game's box.

Dungeons & Dragons as a game is very fluid in regards to spatial requirements. A board may be used for combat, or the combat may be facilitated in the players imagination through description. Players may need for the gameplay character sheets, pencils, dice, dice tray or dice towers, or may utilize their mobile phone for all this. Because of this fluidity for this research we will consider the most common setup that players utilize, that is also considered by a consensus of the community to be the intended and most fun way to play the game. The dice are physical rather than digital. Combats are played on a tiled board with miniatures or other stand-ins for characters and the environment. Each player stores their character's information in paper, a laptop or a tablet. The DM has their own space where they have their notes hidden from players in whatever form they prefer. Dice trays or dice towers may be utilized although they are not central to the experience. Snacks, drinks and water are a must, as gameplay sessions can last from 3 to 8 hours. With the number of people participating in a session (DM and players included) ranging usually from 4 to 7, it is understandable that all these components require a large amount of space for players to be comfortable. Storage can also be demanding in space if physical miniatures and terrain are utilized by the group. The Truesight Battle Grid does not provide any means to decrease the space requirements of D&D. Tisch for TTRPGs on the other hand, can function as multiple battlemaps eliminating the need for multiple battle boards, but this solution means that terrain will be flat, and does not address in this context the most desirable way of playing, which is with miniature terrain.

The Ice Breaking game developed by Shozo Ogawa et al. requires a table for the MR device to project the virtual board that will be manipulated with levers. The hologram provides flexibility for placing other things on the table as it can move easily in the space of the table and other physical objects can exist in the same space as the projection.

Mensch Argere Dich nicht is a game that has a board and can be played with a maximum of 4 players, thus requiring a modest amount of space to be played. The extended reality version created by Younes Lakhnati et al, provides flexibility to the space required by providing hologram alternatives to all the games' components.

In this way, is there is no room for a board everything can be made digital, with physical objects taking the same space, or if there is no space to roll the dice only this component can be made digital, maintaining the tactility of the game.

Checkmate also utilizes an HMD for projection of the opponent's pieces, but the board is physical and as such the space required to play is similar to analog chess.

The Origami game is played with 1 or 2 players that create a story through their handicrafts. The space required for the creation of handicraft is little, but the storytelling mode creates landscapes like mountains and forests. A physical version of such 3D terrain, would require both space for the story scenery and space for the storage of the various different terrain pieces that comprise the scenery. The MR device in which the game is played defeats the need for such space with the utilization of holograms.

The hardware setup for the Hybrid Embroiderment game includes an embroidery machine, a laptop and the swatch scanner where the player draws. While these components take up a modest amount of space, the fact that the game is played with one or at most 2 players doesn't make the game particularly demanding in terms of spatial requirements for gameplay, while storage may be more demanding with the machines needing special care when compared to boxes of typical board games.

All digital versions of games played on computers or smartphones require no special space or storage as they are played in devices that are also utilized for other purposes. Also regarding storage, in the context of data storage for digital games, such board games are not demanding when compared to modern computer disk sizes.

2.2.12 Discussion

From analyzing the above categories and the results, the development team came to the realization that creating a platform for experiencing tabletop games and tabletop role playing games in extended reality is a valuable undertaking.

Games that are played in the same space for all players, enable better collaboration between the players and create a better social environment. Accessibility in board games as a feature, can be implemented easier and in a more thorough manner when digital components come into play. The complexity of the game can be managed through digital systems. Tactility, while not in an absolute scale, can be supported in a satisfactory level by extended reality technology. Flexible rule system types can be implemented in a digital environment, but it is more complex when compared to completely physical board games. Mixed reality environments can provide flexible interaction types that keep players interested and engaged in the experience. Narrative and immersion are enhanced by virtual components, but are also highly dependent on locality. Finally, spatial requirements are generally much smaller with the involvement of digital components, especially in complex games. With these results in mind, we understood that extended reality presents a unique blend of affordances that are ideal for experiencing games that have large boards, are multiplayer and collaborative, contain tactility as a part of their experience, can be complex in their rule systems, and aim to provide immersion in a narrative. This part of the research is what led to *Arcane Tabletop*'s game scenarios being experienced in extended reality.

Chapter 3

Methodology

This chapter explains the application of the AmI Design Process in designing *Arcane Tabletop*. A list of the functional requirements that were extracted by utilizing this process is also presented.

3.1 Design Process

The process followed for the designing of *Arcane Tabletop* is the AmI Design Process [72] which can be summarized in Figure 3.3.

Experience with tabletop games, and especially tabletop role playing games and virtual tabletops, research interest in virtual and extended reality, and interest in video game development led to the initial idea of creating a virtual tabletop that can be enjoyed by many players in the same space. Due to personal experience with the TTRPG Dungeons & Dragons, the first idea was to adapt this particular system in an extended reality experience. A series of meetings that involved the development team, and discussions with people that engage in tabletop gaming both digitally and physically, expanded the existing concept to include a variety of possible tabletop systems that will be able to be experienced. In this step of **Understanding** in the first iteration of the design process, the general idea of a platform that enables the creation, customization and experience of tabletop games was finalized. At the same time, for the **Define** step of the process, from the conductive meetings and through communication, several high-level requirements for the platform were created, that described the desired functionality of the system.

After defining the requirements, the development team conducted meetings to brainstorm solutions and interactions, that can facilitate the functionality of the platform. In this **Ideate** step, the ideas were catalogued without taking into consideration the complexity, cost or feasibility of their application. Such ideas, included the possible devices that can be utilized for the platform, and the manner in which the digital world will interplay with the physical.

In the Filter & Plan step of the AmI design Process, this catalog of solutions



Figure 3.1: The AMI design process [72]

was processed with critical thinking by the development team and people that are highly involved in tabletop games. Though this scrutinizing process, some ideas were deemed unfeasible for the scope of the platform, some ideas were expanded upon with meaningful comments insights and suggestions and some ideas were modified. Generally, the focus for this filtering of ideas, was to prioritize a combination of innovation, research interest, feasibility of application and end-user experience that feels meaningful. During this process, it was identified that the user should be able to interact with the user interface and especially the board, both by touch and with point & commit interactions. Touch is useful for precision, enabling the user to select a specific spot in the terrain or digital object, and when the player is near the interactable object. Remote interactable object, which is a common occurrence in the large board that digital Virtual Platforms usually provide and an enhancement over physical boards where such interactions are impossible.

The **Design** stage of the Arcane Tabletop started by taking several images of a real game board, in the perspective of the end user in extended reality. Then, low-fi designs were added on top of these images to get a first visualization of the system. Some of these low-fi prototypes can be seen in Figure 3.2. These designs were created as a first concept to help visualize the interactions for both the development team and for evaluators, with each design providing a solution to one or multiple functional requirements, as they were defined in earlier steps of the process.

These solutions were then developed in Microsoft's Hololens2, where the interactions could be tested in their completion. With the augmented space available, both touch and point & commit methods for interaction were practically tested with these low-fi designs, and it was in this step of **Integrate & Test** that both

3.2. REQUIREMENTS



Figure 3.2: Low-Fi designs for Arcane Tabletop



Figure 3.3: Top: Initial low-fi designs. Bottom: High-fi designs.

types of interactions were confirmed to be of value for the interactions required by *Arcane Tabletop*.

After testing this solutions in the actual environment that they would be utilized, the designs and their functionality were put subject to evaluations. In this **Evaluate** step, many suggestions were catalogued for later implementation, and a basic structure for the user interface was created. This structure would be refined in the iterations of the design process that followed. Some of the Hi-Fi later designs are presented in Figure 3.3.

3.2 Requirements

3.2.1 Functional Requirements

The functional requirements of this platform can be divided into four separate, but highly correlated and comprehensively integrated sections, each representing a different phase in the Design and Evaluation workflow, as Protovision proposes.

3.2.1.1 Creating a ruleset

Any game experienced in Arcane Tabletop has an integrated rule set that governs how the game is played. For this purpose, users can create the rules for their own game.

- **FR-1.** Users should be able to describe custom abilities that can be utilized in the game. For each ability the user should be able to define:
 - a. The name of the ability.
 - b. The effects of the ability.
 - c. The type of the ability.
 - d. The success conditions of the ability.
 - e. The area of effect of the ability.
 - f. The targeting parameters of the ability.
 - g. The effect of the ability according to the game's rules.
 - h. The animation of the ability.
 - i. The visual and audio effects of the ability.
- **FR-2.** Users should be able to create character presets that are utilized for easier character creation. Each character preset, users should be able to define:
 - a. The preset's name.
 - b. Statistics that will be attributed to any character that has the particular preset.
 - c. Abilities that will be attributed to any character that has the particular preset.
- **FR-3.** Users should be able to create characters that have set of abilities and character presets.
- **FR-4.** Users should be able to inject into the game specific action rules that change the way the game usually works.

3.2.1.2 Game Templates

In order to create a game scenario, users utilize game templates, a set of assets that govern the game's presentation.

- **FR-1.** Users should be able to import 3D character models that can be animate and animated in game scenarios.
- **FR-2.** Users should be able to create a set animation controllers that can be used in various character models
- **FR-3.** Users should be able to import a set of animations that can be added to animation controllers
- **FR-4.** Users should be able to import a set of visual effects
- **FR-5.** Users should be able to import a set of models that can be utilized for the creation of the virtual board.

3.2.1.3 Game Scenario Creation

Users should be able to create a Game Scenario. A game scenario reperesents one session or one level of a specific board game and it combines a rule set with a game template.

- **FR-1.** Users should be able to select specific 3D models from a game template and place them in the scenario in order to create a board
- **FR-2.** Users should be able to select 3D models of characters from the a game template and place them in the scenario
- **FR-3.** Users should be able to assign animation managers from the game template to characters that contain all the animations required.
- **FR-4.** Users should be able to assign animations to abilities that are defined by the ruleset. These animations are utilized by the characters when an ability is activated.
- **FR-5.** Users should be able to assign audio and visual effects from a game template to abilities from a game ruleset.
- **FR-6.** Users should be able to assign characters from the ruleset to character models from the game template.
- **FR-7.** Users should be able to assign characters to be controllable by specific players

3.2.1.4 Tabletop Experience in Extended Reality

Users should be able to play a created game scenario through an extended reality device.

- **FR-1.** Players should view the created board and characters in the physical space.
- FR-2. Players should only be able to control the characters assigned to them.
- **FR-3.** Players should be able to minimize and adjust the user interface's rotation, position and scale in the physical space.
- FR-4. Players should be able to view information about any character.
- **FR-5.** Players should be able to move their characters inside the board when it is their character's turn.
- **FR-6.** Players should be able to activate any ability of a character they control if its the character's turn.
- FR-7. Players should be able to review any activated ability's effects.
- **FR-8.** Players should be able to end their turn.

Chapter 4

The Arcane Tabletop System

This chapter provides a comprehensive outline of the features available in Arcane Tabletop. The system's objective is to offer users a platform where they can create their own turned-based strategy board game rules, or import pre-existing ones. Additionally, they can import the game's visual and audio components, and immerse themselves in the experience of the created game, in extended reality.

The process of creating a game is split into three steps that are seperate both in terms of implementation and in terms of user experience. In the first step, the creator of a board games creates the basic rules of the game, with the final result being JSON files that can be parsed by the system in later steps, to create the systems for playing the game. The second step, includes importing 3D models, animatons, effects and other assets, for creating a game template that acts as the visual and audio presentation of the game. These two steps, can be done in any order, and by different people. The third step, is combining the first two steps to create a specific game scenario, through the Unity Editor. The creator of the game in this step creates specific characters that will be assigned to players, and the 3D arena of the game. In this step, they also match animations with abilities and visual effects.

The final functionality *Arcane Tabletop* offers, is experiencing game scenarios in extended reality through Microsoft's Hololens 2. These categories as well as the architecture of the system is presented in Figure 4.1.

4.1 Creating a Rule System

To create a platform that can build and adapt rule systems for turn-based strategy games, it was crucial to identify key traits of such board games. From our research in board games and the literature review presented in Chapter 2, we have identified five core concepts that combine and interact, to create a playable turned-based board game.

To explain it briefly, Character refers to the agents that the players are controlling, and that can affect other characters or their environment. Character Stats



Figure 4.1: The architecture of ARcane Platform

contain the data of the character. Effects, describe ways that Character stats or the environment can be affected. Abilities contain a set of Effects, and a cost that needs to be expended in order to activate the ability's effect. Character Presets as a concept, act as aid for the creation of a Character and are a set of Abilities and Character Stats that can be attributed to one or multiple characters. Finally, Turn Economy is a resource that refers to the set of actions that are available for a Character to activate each turn.

4.1.1 Character Stats

As explained briefly above, Character Stats describe the Character's attributes. They have a numeric value and are identified by their names.

Character Stats are the core of the flexibility of the created system for creating different board games rules. Character stats vary greatly in purpose from data that refers to the health of a character, to the points a character has for casting certain abilities, to statistics that influence the damage or possibility of success of abilities, to the distance a character can move in a turn, to even more obscure and game specific uses, for example, for games that each Character that players control is a number unit of soldiers, a Character Stat can act as the number of units remaining in this Character.

The formula for calculating a Character Stat's value at any given time of the game is as following:

Current Value = Static Value + Stat Relations Value + Permanent Effects Value + Temporal Effects Value - Damage

This formula suggests that the value of a Character Stat is dependent on several variables, which will be explained below.

- **Current Value**: Current Value refers to the value of a Character Stat at any given time. It can be affected with various different ways, and its calculation happens often during a game.
- Static Value: An integer that acts as a base value for a Character Stat. This value never changes during the game.
- Stat Relations Value: The sum of the current values of other Character Stats that affect a specific Character Stat. A multiplier may affect each added value of the related Character Stats.
- **Permanent Effects Value**: The sum of a set of integers that each represents a Permanent Effect. These effects do not change in value and can only be removed directly by abilities.
- **Temporal Effects Value:** The sum of a set of integers that each represents a Temporal Effect. Temporal effects can change in value between the turns of a game and have a duration also counted in turns. They are removed either directly by abilities or when their duration expires.

• **Damage**: A natural number that represents the damage dealt in a Character Stat and is subtracted from the stat's value as part of the calculation.

Depending on the rule system created or adapted Characters can have a small or great number of Character Statistics that can be connected in a simple or complex manner.

4.1.2 Effect Stats

Effects represent ways to affect Character Stats, and are separate entities from the Permanent Effects and Temporal Effects that are contained in Character Stats. An Effect Stat defines a way to affect a Character's Character Statistics. An Effect stat describes the types of characters that it can affect, the number of characters it can affect, the way to select which characters will be affected, the way to calculate how this effect succeeds or fails, and finally the effect on the Character Stats.

The field "type" of Effect Stat defines how the effect affects a target. The three types that are currently implemented include "Damage", which increases the *damage* variable of a referenced Character Stat of the target, "Healing", which decreases the *damage* variable of a referenced Character Stat of the target to a minimum value of 0, and "Temporal" which creates a *Temporal Effect* in a Character Stat that either increases or decreases its value for a set duration of turns.

The system of Effect Stats supports the way that various tabletop games and especially tabletop role playing games calculate for an effects success and the amount of damage or healing it deals. Dice rolls may need to be made, and their results are affected by both the stats of the character that activates the effect and the character that receives the effect. Targets and activators of effects may need to make a roll and pass a specific number, or the effect may succeed automatically. This whole system is supporting by enabling dice rolls with dice of any sides and the ability to include any Character Stat into the calculations for success, damage or healing of an effect.

4.1.3 Ability

Abilities are differentiated by their names and represent the actions that Characters can make, usually during their turns. They are the medium that ultimately allows the players to affect other Characters.

Abilities contain a set of Effect Stats that represent the result of their activation that are defined by the creator of the rules. An ability's activation can cause multiple effects with a distinction made to effects that are entirely different and effects that are followups to previous effects. For example, an ability that describes a slash with a poisoned weapon may have one effect that deals slashing damage and a following effect that deals poison damage to the same target that was slashed. On the other hand, the casting of a specific spell may describe the selection of two

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Figure 4.2: Effect Data model

characters for healing, and then the selection of two characters for damaging, with the characters selected for damage possibly being different than the characters that were selected healing.

Abilities, also contain a description that the creators of the rule system fill, usually meant for describing the way the ability works or to provide a narratively flavorful description of its effects.

Additionally, they contain a set of tag that can be used to group abilities into categories. This grouping can be utilized both for user interface purposed and for mechanical purposed of games, as it is common in rule systems for abilities to present idiosyncrasies according to their types (for example "fire" abilities not affecting characters with the "Fire Child" preset).

Finally, abilities contain data that relates to the resources that their activation will cost. The cost of an ability can be of two different resources that a Character possesses. First, a set of Character Stats. For each such cost entry, a stat is selected by name and a defined value is subtracted when the ability is cast. The second resource is a set of *Turn Economy* variables. These variables, in brief, represent what a Characters can do on their turn and will be explained in a more detailed manner in this chapter in the Character section. If the Character does not possess one of the costs required, they cannot cast the ability.

4.1.4 Character Presets

Character Presets are differentiated by their names and contain a set of Character Stats and Abilities and can be assigned to Characters. A Character that is assigned



Figure 4.3: Ability Data Model

Character Preset			> statistic	
			name	string
name	poolean		staticValue	int
statistics	statistics[]			
abilities	string []		statRelations	string []

Figure 4.4: Character Preset Data Model

a Character Preset gains the abilities and stats that are described in the preset. Additionally, Character can get Permanent Effects (as they are described in the Character Stats) to specific stats through Character Presets. The existence of Character Presets serves two purposes.

First, to group abilities and stats, in a manner that makes character creation an easier process, with the creator of the rules being able to create general types of traits that Characters can have, and then combine different presets to create specific Characters.

Second, to accommodate for the very common existence of these presets in turned based games and especially tabletop role playing games. Such games describe Classes (in D&D and Pathfinder), Occupations (in Call of Cthulhu), Careers (in Star Wars TTRPG), and various other names in different game systems. These different names describe the idea of Characters Presets and define what the characters can do. *Arcane Tabletop* can adapt these character features with Character Presets and allow for the creation of custom made such presets.

4.1.5 Characters

Characters are the agents that players control in the game. A creator of a system of rules of a board game in *Arcane Tabletop*, defines the ways in which a character can affect other characters. The animations, models, sound effects and technical details of the presentation of characters do not belong in the step of creating or adapting a rule system.

Characters are identified by their names and contain a set of Abilities they can possibly activate and a set of Character Stats that describe them. They contain
4.1. CREATING A RULE SYSTEM

Character					
name	string				
player	int				
turnEconomy	turnEconomyType []	⇒ turnEcon	turnEconomyType		
abilties	string []	name	string		
basePresets	string []	number	int		
additionalPresets	string []				

Figure 4.5: Character Data Model

the names of the Character Presets that are assigned to them as it is common in turn based strategy games to contain rules that present idiosyncrasies according to what *Arcane Tabletop* describes with Character Presets (for example "fire" abilities not affecting characters with the "Fire Child" preset).

Additionally, Characters contain a set of Turn Economy Actions. A Turn Economy Action represents a type of action that a character can perform on their turn, and is represented by its name and an integer that is the available amount for each turn. In most games, on each turn a character has an available set of actions they can perform that cost the same or different resources. Whether a character depleted this pool of possible actions or not, in their next turn, they have the same set of possible actions available for use. For example, in a game a character on their turn may be able to do three things: Move, Attack and Defend. Attack and Defend may contain a lot of different abilities that can be activated utilizing these actions. Whether the character moves, uses an Attack ability and/or uses a Defend ability, on their next turn they will have these three types of actions available for use again. As the concept of Turn Economy is core for tabletop role playing games and strategy board games in general, it is described separately in its own section of the data models, even though its functions are a subset of the Character Stats concept, and it could potentially be implemented in this way as well.

4.1.6 Rule System Creation Process

To create such a rule system, a user of *Arcane Tabletop* creates JSON files with specific names that correspond to specific rules. Templates and documentation for these JSON files explain the fields that need to be filled and how each field affects the rules.

Different files exist for Abilities, Character Presets and Characters. For abilities, the Effects Stats of the ability need to be filled, as well as the name and its cost. For Character Presets, a set of Character Stats and the names of abilities are filled as well as the name of the preset. A user that creates or adapts a rule system does not need to create any characters, as this generally concerns the creator of a game scenario.

4.2 Creating a Game Template

The term *Game Template* in the context of *Arcane Tabletop*, means a set of prepared assets that can be utilized by a user to create a game scenario. These assets include character models that may be rigged or not, animations, audio effects, audio files of dialogue, visual effects, terrain models, ability icons and general user interface icons and backgrounds.

Since, the platform described in this thesis supports the creation and playing of multiple board games there also exists a variety in potential fantastical and historical settings for these games. As such, the Arcane Tabletop needs to be able to implement a game set on a fantasy world as well as one set in space, or a historical location of ancient Greece. For this purpose, game templates can be implemented. A game template is created by a user of the system and it is meant to house a set of assets, as they were catalogued in the paragraph above, that fit a specific setting. For customizing the user interface, the user can upload images that can represent new backgrounds, fonts, borders and icons for the various buttons and pages with the layout of pages remaining mostly the same between different templates. Some customization for the display of character information has been implemented, as a creator of a template can choose what character information wants to be displayed and in what form, select the priority of the information and group a selection of character information that will be helpful for players.

For the integration of a game template the assets uploaded need to be uploaded in specific locations inside the project as indicated by the documentation of the platform. From there, a user that creates a game scenario can utilize them to create a board game experience. A user template is created through the Unity Editor [75] using its system for file imports. To export a template a user exports the folder and its sub-folders with names that have been assigned and are catalogued in the documentation for this particular purpose. Similarly, to import a template a user imports the assets in this documented folder structure. A game template is agnostic to any rule system and is combined with such system in the process of creation of a game scenario. The next section describes briefly the process of creating a game scenario, and how a template is utilized by the creator of the scenario. Chapter 5 provides further detailing of this process.

4.3 Creating a Game Scenario

A game scenario for this thesis is defined as an encounter of particular board game. It contains Abilities Character Stats and Character Presets that have been assigned to specific Characters. These characters have been placed in a created 3D environment. The characters have 3D models that are animated for each action they make. Sound and visual effects have been assigned to the characters' abilities and voice dialogues have possibly been assigned as reaction to events that happen inside the game. Characters have been assigned as controllable by specific players.

4.3. CREATING A GAME SCENARIO

For the user interface, icons for the buttons that activate each ability have been selected, borders and backgrounds that fit to the theme of the game are set and the user interface that displays a character's information has been customized for each character individually or in a general manner.

It is in the creation of a game scenario that a rule set that contains information about the Abilities, Character Stats, Character Presets and Characters are combined with a game template that contains information about the visual and audio presentation of characters and abilities to create a game that is ready to be played. In this step, a user must be familiar with the rule system and the template they utilize. The integration of the rule system in a game template happens by filling various fields in JSON files for which templates are provided by the documentation where these fields are also explained.

4.3.1 Environment

The terrain of the game scenario is the space where characters can move and the space where abilities are activated in. It acts as the physical game board of a tabletop strategy game, depicting a 3D terrain that is decorated with scenery. The 3D models that combine to form the environment of the game are drawn from the game template. As the 3D models can contain animations and can represent anything this form of a digital board enables situations that are impossible in a physical board. The running of rivers, lighting falling from the sky, floating terrain and complete control of the verticality of the board are just a few examples of the extension in capabilities this virtual board provides.

4.3.2 Characters

The characters that players control are the combination of two different aspects of the game. The first aspect refers to the data the Characters utilize during the game which are described as Character Stats, Character Presets and Abilities. This is the backbone of the game with the dataflow proceeding according to the rule system that was created. Characters in the context of the rule system are created by filling fields in a JSON template that is described in the documentation. The fields are filled with information provided in the rule system creation process such as the names of abilities and the names of Character Presets. In this step of the user selects the created character's Turn Economy, as it has been described in the section about creating a rule system.

The second aspect is the presentation of the characters and their placement inside the space of the game. It refers to the models of the characters, the animations of this models for each action they take, the audio that triggers on specific interactions, their position, rotation and scale within the game's world. Characters in the context of the presentation are created by inserting the character template prefab inside the game scenario scene. The character template prefab contains the functionality for animating, moving and selecting the character inside the game, and is provided by the platform of Arcane Tabletop to be universally used in all game templates and rule systems. Inside this prefab the user inserts a 3D model from the game template that will be used to represent the particular character. From this prefab the user selects the animation system of the game template that will be used to animate this character.

In order to bridge the rule system and the presentation of the character in the game world, the user simply enters the name of the character created in the rule system in the character prefab that has been assigned for the character.

4.3.3 Abilities

The abilities that characters possess act as the audiovisual and rule based medium for players to affect the game world. These abilities interact in the data aspect of the game by affecting Character Stats and in the presentantion aspect of the game by controlling the animation of characters, visual and audio effects that aim to bring the effects of the abilities to life, and the altering of the position, rotation and scale of the characters.

In the rules aspect of the game, the Effect Stats included in an ability, as they are explained in the section about Creating a Rule System, define the way that an ability is activated, the targets it selects, the way this selection is made, and the final effect its activation causes. These characteristics of the ability extend beyond the the data plane, through integrated systems of the Arcane Tabletop platform that will be briefly mentioned in the next section and then explained in a more detailed manner in the Chapter 5.

In the presentation aspect of the game, each ability defines the kind of animation that the character activating will make, the animation that the targets of the ability will make if the ability succeeds and potentially a different animation if the ability fails, one or more visual or audio effects that will be played during the ability's activation and at its completion. These animations, audio and visual effects come from the game template.

To combine the presentation aspect and rules aspect of abilities, the user creating the game scenario fills in a JSON template that is provided by the platform. The user fills for abilities entries that connect the ability as defined in the rule system through the ability's name with values that correlate to the names of assets such as animations and sound effects that are included in the game template. In this way a new Ability data model is created that includes the rule system related data and the data from the game template that are to be used in the experience of the game scenario.

4.3.4 User Interface

User Interface in *Arcane Tabletop* can be easily customized in its visuals, in order to be able to fit the many different styles of worlds that board games take place into. With the loading of custom assets for fonts, backgrounds, buttons, character portraits and other user interface components, the UI can adapt to traditional fantasy, modern, futuristic or any kind of style of board game. For these changes to occur, the creator of the game scenario must import the images of their unique user interface style and the font they intend to use. Alternatively, they can select one style that is included in a Game Template.

4.3.5 Multiplayer Features

As the game scenario is meant to be experienced in multiplayer, the creator of the scenario has the responsibility of assigning specific characters to specific player ids. A player may control one or several characters or even no character, in which case they act as a spectator to that scenario.

Additionally, for each scenario loaded by the players, there exists a lobby where the players select their id to enter the game and be able to control their players. This lobby has a simple default form of simple user interface for selection but can be customized in any way the game scenario's creator wishes. For the use case of Arcane Tabletop created for this thesis the lobby also acts as a narrative interaction to the game scenario.

4.4 Experiencing a Game Scenario

Experiencing a game scenario is a multiplayer experience in extended reality through a Microsoft's holographic device Hololens2. The head mounted device projects holograms to its user's vision and allows interaction with them inside the space.

Games created by Arcane Tabletop all have the same game flow as they all are turn-based strategy games. Players take turns controlling the characters that have been assigned to them. On their turns the players move their characters inside the environment and activate abilities that affect other characters or the environment, and observe the results of their abilities through audiovisual effects, changes in character statistics and character animations. The specifics of the game as well as the trigger that ends the game depend on the game rule-set and the game scenario.

4.4.1 Beginning the Scenario

Each scenario begins with players in a lobby room where they select their player id. The players select their id and they see the game board spawning in front of them. The players can see the board with the 3D terrain and the characters performing their idle animations also waiting for the game to start. The game begins when all the players required have connected.

When the game begins, the system decides in which order will character take their turns. This decision is at random by default but users in either the game scenario creation process or rule creation process can inject their own custom way to calculate the order of turns. This is necessary, as in most tabletop games, dice rolls with modifiers affected by specific Character Stats are made to decide the order of turns for characters, or different rules apply.

4.4.2 On Others' Turns

Each player can move around the space and survey the board that remains stationary on the place it was spawned. They watch as their allies and opponents take turns with their characters moving in the board, activating abilities and creating visual and audio effects, and expressing voice lines depending on the situation that evolves.

While they await for the turn of a character they control, players can also survey the current situation of the characters of the other players, see their Character Stats and any relevant to the game information. This is done through the customizable character user interface. All the user interface that has the form of floating holographic panels can be moved, rotated, minimized and scaled in the space of the player.

4.4.3 On Player Turn

When the turn of a character that a player commands comes, new window spawns. It shows the actions that the character can perform. A series of menus categorize the different abilities of the character according to their Turn Economy cost and the tags of the abilities. The character can navigate through this menu and select an ability to try to activate. Additionally, from this menu the player can end their turn whenever they choose to.

When the turn of a character a player command comes, the player can perform some additional actions. They can move their character, select and cast abilities and finally end their turn. The actions described in the section above are also available.

4.4.3.1 Activating an Ability

The player can navigate a series of menus in a holographic panel either through touch or by point & commit in order to activate an ability. Abilities are categorized according to their tags and the Turn Economy cost they have. After selecting an ability to cast, the player can review the abilities effects as well as the way for selecting targets for it. In this step, the player can cancel this activation of the ability to select a new one.

After selecting the targets, the player can activate the ability and watch it play out with the animations, visual and audio effects they have defined for it. They can review the calculations that were made to check whether the ability succeeds, and the effect result that was performed to the targets, if any.

4.4.3.2 Moving a Character

Moving in the terrain is a special kind of ability that all characters possess. On a character's turn, the controlling player can try to move the character. Usually, characters on games have some limitations on how much they can move each turn and in which areas they can move. Because these limitations are usually heavily rule dependant, the platform provides ways for users to inject rules for moving a character. These rules can refer to Turn Economy or any Character Stat of the character that attempts to move, or even be an independent value.

The selection of destination for a character is done through either touching on a spoti in the terrain or by the point & commit interaction at the desired destination.

4.4.3.3 Multiplayer

As mentioned above, before the game scenario begins, the players enter a lobby where they select their id and wait for the other players to join in. After all players have joined the game begins. In game time, players only see their own User Interface and windows that they open. Animations for characters and abilities, the position of characters and visual and audio effects are all synchronized among players.

This is performed with done with Remote Procedure Calls through the Photon [63] state synchronization networking library for Unity. Through this calls, the player game instance that currently controls a character whose turn it is, sends data about the actions they perform that need synchronization.

Chapter 5

The Forest of Ariandel and the Godling: a Game Scenario

In this chapter, we will present some details about the software architecture and the implementation of *Arcane Tabletop*. We will analyze the most important components and explain the functionality and use within the system, in order to provide a comprehensive understanding about the platform and the process of creating and experiencing a tabletop game. This analysis, will be performed in the context of a case study of a board game that was created through *Arcane Tabletop*. Our case study contains custom rules, a game template that includes character models, animations, visual and sound effects, and its own specific characters and story.

Arcane Tabletop is implemented in Unity [75] with the steps of creating a Game Template and creating the Game Scenario being performed in the Unity editor. To experience a game scenario, the Unity Project is built on a Hololens2 device.

5.1 The case study

The board game created as a case study for the platform, is titled *The Forest of Ariandel and the Godling*, and splits the players into two groups. The first group, controls the three created characters of the "Godling Party", and the second group, the four created characters of the "Heroes Party". Any character can be assigned to any player before the game, and as such, the game can be played with a minimum of 2 people, if each player controls one party of characters, to a maximum of seven, if each player controls a single character.

The board game was created with the intention to be simple enough to learn and to explain, but complex enough to utilize multiple features that the platform provides. The specifics of the game, such as the rule system, the game template, and the game scenario will be explained in detail in the next sections of this chapter.

The game rules can be summarized as follows: All Characters have different Character Stats and different Abilities according to their Character Presets. Each character has a Turn Economy of 2 Action Points, that can be utilized for activating abilities. Each character, has some weaker abilities called "Normal Abilities", that have no Character Stat cost, and some stronger abilities called "Special Abilities", that require the use of a specific Character Stat named "Power Points". Another important characteristic of abilities in this rule system, is whether an ability is a "Physical Ability" or a "Magical Ability". This distinction refers to what Character Stats are utilized for the calculation of the abilities' success and damage.

In their turn, the characters can move and use their abilities. The activated abilities' effects, affect other characters in different ways, damaging them, healing them, impeding some of their other stats or enhancing some of their stats. The goal of the game, is for one team of characters (either the "Godling Party" or the "Heroes Party") to reduce all of the other characters' Character Stat named "Hit Points" to 0. The first group of players to achieve that win the game.

5.2 Rule System Implementation

To create the rule system for the case study presented in this thesis, the JSON file templates that are provided by the platform for Character Presets and Abilities were filled. The JSON file of Character Presets creates a number of possible combinations for Abilities and Character Stats that can be utilized in later steps to create unique characters, while the Abilities JSON file describes how each ability works according to the rules. A short description of these components that make up the rule system of the game is included below.

Creating a rule set is independent of the Unity game engine, as it only contains JSON files, that will later be parsed and translated by C scripts to create the data classes that are utilized by the platform.

5.2.1 Character Stats

The idea for the rule system implementation, is for all characters to share the same type of Character Stats in different values. Below, follows a list of the stats that the characters share with a short description for each one, that explains its purpose.

- 1. **Hit Points:** Represents the character's vitality. When this stat's Current-Value becomes 0 the character dies. All characters begin with their HP full at different values according to their Character Presets.
- 2. Power Points: A Character Stat that is utilized for the activation of Abilities. All characters begin with 0 power points at the start of their turns, and each turn they gain 1 power point.
- 3. **Speed**: Defines in measurement of feet, scaled to the game world, how far a character can move each turn. When a character moves an amount of

5.2. RULE SYSTEM IMPLEMENTATION

feet in game, Speed is damaged for the same amount. At the start of each character's turn, all Speed damage dealt to them is healed and the character can move again.

- 4. Attack: Is utilized in calculations to measure if a "Physical Ability" succeeds. It also affects the Damage Character Stat.
- 5. **Damage**: Is utilized in calculations to measure how much damage a "Physical Ability" deals. Its value is calculated by a base amount, and is increased by 0.3 times the CurrentValue of the "Attack" Character Stat.
- 6. Magic Attack: Similar to the "Attack" Character Stat but referring to "Magical Abilities".
- 7. Magic Damage: Similar to the "Damage" Character Stat but referring to "Magical Abilities". Its value is calculated by a base amount, and is increased by 0.3 times the CurrentValue of the "Magic Attack" Character Stat.
- 8. **Defense**: Is utilized in calculations to measure if a "Physical Ability" succeeds. It also affects the "Physical Negation" Character Stat.
- 9. **Physical Negation**: Is utilized in calculations to measure how much damage a character blocks from a "Physical Ability". Its value is calculated by a base amount, and is increased by 0.2 times the CurrentValue of the "Defense" Character Stat.
- 10. Magic Defense: Similar to the "Defense" Character Stat but referring to "Magical Abilities". It also affects the "Magic Negation" Character Stat.
- 11. **Magic Negation**: Similar to the "Physical Negation" Character Stat but referring to "Magical Abilities". Its value is calculated by a base amount, and is increased by 0.2 times the CurrentValue of the "Magic Defense" Character Stat.

5.2.2 Character Presets

One base Character Preset was created for the game which is named "Character". It includes all the 11 stats explained above in their basic values. It represents a base template upon other presets will expand. Three Additional Character Presets were created that will be utilized for general categorization of the characters, depending on whether they use "Physical Abilities", "Magical Abilities" or both kinds of abilities. These presets are named "Physical Fighter", "Magical Fighter" and "Hybrid Fighter". The three presets do not contain any Abilities or Character Stats, and they are utilized for the generation of unique User Interface for the Characters as it will explained later in this chapter.

Another 6 Additional Presets have been created that are specific to the 7 characters. One of these presets is shared by two Characters. These Additional Presets

Character					
HP	30				
Speed	30				
Defense	10				
Physical Negation	0,2 * Defense				
Magic Defense	10				
Magic Negation	0,2 * Magic Defense				
Attack	5				
Damage	0,3 * Attack				
Magic Attack	5				
Magic Damage	0,3 * Magic Attack				
Power Points	3				

Figure 5.1: The "Character" Base Character Preset

Paladin		Godling		Rogue	
HP	20	HP	30	HP	15
Speed	10	Speed	10	Speed	20
Attack	5	Defense	5	Defense	5
Defense	5	Magic Defense	15	Magic Defense	5
Magic Attack	5	Magic Attack	15	Attack	10
Magic Defense	5	Power Ponts	1	Power Ponts	1
Sorcerer		Elemental		Warrior	
HP	10	HP	50	HP	30
Speed	10	Defense	10	Speed	10
Magic Defense	10	Magic Defense	10	Defense	5

Figure 5.2: The Additional Character Presets

10

10

Magic Defense

Magic Attack

Power Ponts

15

15

1

contain the Character Stat values and Abilities that differentiate the characters of the game.

5.2.3 Abilities

10

1

Attack

Magic Attack

Magic Attack

Power Points

For this rule system, close to 40 abilities have been created. All of these abilities have unique names, descriptions and effects. The abilities are diversified by the amount of damage, healing or other effect they perform, the way that they select targets and their cost in Turn Economy and Character Stats. Some abilities have multiple effects. Generally, for this study case and the rules of the created board game, we have utilized the "Tag" field of an Abilities to categorize them according to their effects.

Almost half of these abilities have the tag "Physical Abilities", while the other half of have the tag "Magical Abilities". Abilities with the first tag, have as a condition to succeed a comparison for attackers to roll a d20 die and add their "Attack" Character Stat, and for defenders to roll a d20 die and add their "Defense" Character stat. If the attacker's roll is higher, the ability succeeds, and otherwise it fails. Such abilities, usually add the attacker's Character Stat "Damage" to their damage, with this damage amount being reduced by an amount equal to the defender's CurrentValue of the Character Stat "Physical Negation". Abilities with the tag "Magical Abilities" usually have similar rules for succeeding and damaging but with the stats "Magic Attack", "Magic Defense", "Magic Damage" and "Magic Negation" replacing their counterparts.

Additionally, there exist abilities with the "Heal", "Buff" and "Debuff" Tags. "Heal" abilities heal a Character Stat reducing its Damage property by an amount. "Buff" abilities raise one or several Character Stats of their targets for an amount of time measured in rounds by creating a Temporal Effect. "Debuff" abilities reduce one or several Character Stats of their targets by creating a Temporal Effect. "Heal" and "Buff" abilities succeed automatically as they have exclusively positive effects. "Debuff" abilities, usually also have the tag "Physical Abilities" or "Magical Abilities", and their success is calculated with the rules described above.

The last kind of tags that describe abilities created for the case study, are the "Normal Abilities" and "Special Abilities" tags. "Normal Abilities" tagged abilities have no cost of the Character Stat "Power Points" while "Special Abilities" tagged abilities, cost an amount of "Power Points" and have generally stronger effects.

5.3 Game Template Implementation

Creating a game template for *Arcane Tabletop*, is arguably the hardest step of creating a board game through the platform. It requires the collection of various assets like animations, visual and audio effects, models for characters and terrain, and the integration of animations to animators for rigged models. The importing of the assets and the integration of animations is done in Unity's editor.

For the terrain assets, a set of almost 200 different models was created. These models primarily serve the setting of a forest, as the game scenario that was created for this thesis requires. For each one of these models, Unity C# scripts were added, which enable the recording of a touch or point and commit action by a player, and the output of the precise world position of the area that was selected on the model. These scripts are essential for player movement and the targeting of abilities, as it will be explained in a later section of this chapter.

For visual effects, a set of almost 60 effects are included, that can serve a variety of purposes such as weather phenomena, magic spells, party fireworks, modern warfare effects and much more. Additionally, these effects can be customized and combined to create different and more complex effects, potentially expanding the library of visual effects of the template. This variety makes the visual effect library suitable for board games that take place in both medieval and modern settings.

The set of character model assets for the game template, includes the 7 rigged



Figure 5.3: Some terrain models

models that are required for the created story of the game scenario. These seven character models have their own custom created animators and rigs, created using the Mixamo platform. For each character a set of about 20 animations is included, bringing the total animation count to about 140. This animation set includes animations for idle states of the characters, for moving, for reactions such as dodging, blocking and taking damage, and for activating abilities such as punches, kicks, weapon swings, spell gestures and more. These animations and their animators, can be also be utilized by models of similar dimensions that are rigged through the Mixamo platform. The animators we created serve as template for archetypes of characters that are frequently present in fantasy settings, such as a wizard, a warrior with a sword and a shield, a warrior with a two-handed sword, a giant and an assassin. With the animators and animations ready, new character models can be imported, rigged, and be animated with low effort.

For the sound that the game template provides, we collected a pool of sound effects with the intent to use them for the custom board game created as a case study for the platform. We collected a set of almost 60 sound effects, that include spell casting sounds, slash and impact sounds, charging ability sounds and other audio clips that can be utilized by any board game set in a fantasy world with spells. Additionally, 2 audio clips that loop perfectly are included that serve as background sounds aiming to enhance immersion to the game world for the players. One includes music, and the other ambient sounds of a forest.

For the user interface, only the visuals that are utilized for this scenario are included into the template. This includes custom icon and window backgrounds, and various general use icons that can be utilized in any board game, such as magic effect icons and health icons. The design choices for the user interface in this study case, are inspired from the style of cRPG video games (classical Role Playing Games), which are digital games with gameplay that presents similarities, or even a direct adaptation to the the gameplay of tabletop role playing games.

5.4 Game Scenario Implementation

For the implementation of the game scenario we followed the following process. We created lore for the board game and a way to present it to the player. We created the digital game board where the action will take place from the game template asset. From the JSON templates, we created the files for the characters and their user interface. Similarly, from these provided JSON templates, we created the files for the characters inside the board in their starting positions. We assigned the characters that form the "Godling Party" and the characters that form the "Heroes Party". These steps are analyzed below.

5.4.1 Game Lore

The lore for this game scenario is presented in the form of a narrator reading a fairy tale from a storybook. This story, is narrated before the start of the game and aims to immerse the player in the scenario and the story that the board game takes place. The storybook is complete with images. The synopsis of the game's lore is that the characters of the "Godling Party" have caused trouble in the forest of *Ariandel* with the fire spirit *Ifrit* setting fire on the forest, and the ice spirit *Nisse* freezing parts of the forest. The characters of the "Heroes Party" have entered the forest in order to stop this destruction.

5.4.2 Game Board Creation

The terrain that serves as the game board, was created from the assets that are included in the game template. This board represents the forest of Ariandel. As the lore suggests, parts of the forest are on fire, while others are frozen. The scale of the terrain matches the 28mm scale that the majority of tabletop games utilize, and its size is larger than what most game boards are. Its size is a little bigger than 400 square meters in-game, and about 1.6×1 meters in real life measurements.

5.4.3 User Interface

For the user interface, as creators of a game scenario, we selected the theme that is provided in the game template. To create a custom user interface for the characters, we edited the JSON file for character user interface in a way that the Base Preset "Character" displays the stat "Hit Points" as a bar in a red color, and the stat "Power Points" as a bar in a blue color. Then, to organize groups of characters' information in the User Interface of the board game we utilize the Additional Presets "Physical Fighter", "Magic Fighter" and "Hybrid Fighter". Characters



Figure 5.4: The Game Board



Figure 5.5: Character Information User Interface

that contain these Character Presets, have different base stats displayed and different groupings for their other stats prioritizing the most important Character Stats for each character.

For the character's portraits, images of that display them were generated utilizing Microsoft's Bing Image Creator AI for image generation with a text prompt. The images were created to fit the 3D models of the characters.

5.4.4 Abilities Presentation

In order to define the visual and audio effects of each ability, we filled the JSON template file named "AbilitiesPresentation". For each ability, we entered the names of the animations that characters will perform when they activate the ability. Additionally, we entered the names of the animations that the targets of an ability perform, when the ability succeeds or fails.

Following that, information was filled about the visual effects that instantiate for the activation of the ability. Such effects can instantiate while the ability is activating, and/or in the impact frame of the animation and the visual effects that instantiate on the characters that get affected by the ability. For the audio presentation of the ability, we define which sound effects will play during the activation of the ability, and when the impact frame of the animation is played. Additionally, character dialogue is selected to play on some abilities. All these fields are optional, with the casting of an ability being possible without any visual or audio effect playing. The JSON data model for an Ability Presentation is displayed in Figure 5.5.

5.4.5 Characters

For the seven characters of the game, in the JSON file, for each character we included the "Character" Base Character Preset, and one of the Additional Presets that can be seen in Figure 5.2. We also added for each character one of the three Additional Character Presets from "Physical Fighter", "Magic Fighter", "Hybrid Fighter", that are utilized for the custom user interface of each character. In the same file, the Turn Economy for each Character is also filled.

After filling the JSON file with all the templates, we inserted the Character Unity Prefab in the scene for each character. This prefab, includes various scripts such as the Animation Manager which handles all the animation transitions of the character, the Select Unit Manager that handles the states of selection for characters, the NavMesh Agent Unity script that handles the path-finding for the characters, and a CharacterScript that contains the CharacterStats and Abilities of the character.

The Character Unity Prefab does not contain the character model. To finalize the creation of a character in the game scenario, we insert the model of the character in the prefab, and enter the name of the character in the CharacterScript through Unity's Editor. The models for the characters are displayed in Figure 5.6.



Figure 5.6: Ability Presentation data model

5.5 Gameplay Experience

The gameplay experience refers to the experience of a prepared game scenario in extended reality through Microsoft's Hololens2. The players wear the head mounted device and can start playing the board game. Firstly, they enter a "lobby room" where they can join for multiplayer, and await for the other players to join. After they and the other players join the game, the digital board with the characters, as they were created and placed in the game-scenario creating process, spawn in front of them and the game begins.

5.5.1 The Lobby Room

In the "lobby room", the only digital objects players can see are a projected podium with a closed floating book on top of it. The title of the book reads "Begin Story". After selecting the book, it opens, and narration begins as the pages of the book unfold. The written words in the pages match the audible narration, and images complete the fairy tale aesthetic of the story book. The narration explains the lore that was written for this case study, and explains the objective of both parties that will be playing the game. The player can turn the pages of the book, or skip to the end of the narration. The book contains 20 pages with 9 pictures, that relate to the events of the story. These pictures were generated utilizing Microsoft's Bing Image Creator AI for image generation with a text prompt.



Figure 5.7: The Characters of the game Scenario. Top: "Heroes Party". Bottom: "Godling Party"



Figure 5.8: Lobby. Left: The closed book. Right: The open book during narration

After the narration's end, the book closes, and its title is replaced with the words "Connect to Game". Selecting the book now, connects the player to the game.

5.5.2 Entering the Game

When the player connects to the game and the game starts, the player sees the digital hologram of the game board and the characters performing their idle state. On the far end of the board, the player can see a digital holographic panel that displays the characters of the game in the form of portraits. Each portrait has the name of the character written on the top, and a health bar on the right side of it. An 3D token is also displayed at the top of the character whose turn is.

The character portraits are interactable, either through touch or point & commit. Selecting a portrait in this way, spawns a holographic panel that displays information about the character of the portrait. This window can also be spawned by selecting a character's model. The information displayed for each character, has been customized to highlight the important Character Stats of the particular character during the creation of the game scenario.

A holographic panel that spawns by default on the right of the player with the label "Action Logs", shows the history of all the abilities activated, complete with the targets they affected, whether they succeeded or not, and the calculations that were made for success and the amount of effect. Character names and numbers are color-coded for readability.

5.5.3 Moving a Character

For the game implemented as a case study for Arcane Tabletop, a Character Stat has been created named "Speed" and each character can move a distance equal to this number in feet on their turn. This stat is replenished to its max value at the start of a turn.

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Figure 5.9: Player view when the game starts.



Figure 5.10: Player view when it is their turn.



Figure 5.11: Some of the game's UI. Top: Character Portraits. Bottom left: Character Information. Bottom Right: Action Logs

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Figure 5.12: Moving a character

If a player tries to move a character to a place that is not allowed they will be informed with the correspondent error message. If the player selects a legal destination a line will form in the game's terrain that shows the path that the character will follow, and a ray will indicate the final spot of the character at the end of their move. At this final spot, a menu will spawn through which the player can either confirm or cancel the move. If the player confirms the move, the character will perform the move animation assigned to them, and move to the selected destination.

5.5.4 Activating an ability

When the turn of a character a player controls comes, an additional holographic panel spawns. It has the label "Turn Economy", and contains buttons that read the playing character's Turn Economy, also showing the number of each Turn Economy. For the case study prepared where the character has only on Turn Economy with the name "Action Points" the player sees one button that reads this name.

Selecting this button either through touch or point & commit, leads the player to another menu, where they can see buttons that read the names of the Abilities' Tags that the playing character has. Selecting a category of Abilities the player can see the abilities of the selected category.

From this holographic panel, the player can try to activate an ability. Selecting an ability that the character can not cast, either because of a Turn Economy cost or a Character Stat cost, leads to no result, and the player is notified through an error message.



Figure 5.13: Selecting targets of an ability. Left: Line Selection. Right: Sphere Selection

Selecting an ability that can be activated spawns the ability activation menu. There, the player can see the selected ability's information, and review the ability's cost, the range and radius of its effects, the lowest and highest amount of damage or healing the ability will deal (calculated according to the specific character's Character Statistics), a description of how this ability succeeds or fails, and a description of what happens if the ability fails. In case that the ability has a duration, (for example in case the ability adds a Temporal Effect to a character) this duration is also displayed.

The player then, can select targets for the ability according to its description. On the digital terrain, the range of the ability is displayed and if the ability has a particular shape for the selection of targets, (eg. fireball has the shape of *sphere*) this shape is also spawned in 3D, and in a place from where it can be moved within the range of the ability. In case the ability requires the explicit selection of characters, the player can touch or point and click at the characters' models in order to select them. Re-selecting a character cancels their selection.

When a character is selected for the activation of an ability, a 3D token is spawned above their head to indicate that they are selected by the current activation. During this selection, the system will inform the players of any errors they make in the target selection process. Examples of such errors, include the player attempting to target more characters than the ability allows, attempting to target a player that is outside of the range of the ability, and the player attempting to target allies while the ability specifies that it can only target enemies or vice versa. The use of these error messages, are for players to correct and become able to activate the ability, and also to teach the mechanics of the game and the rule system intricacies for new players.

Finally, after having selected the targets, the player can activate their ability. When the player activates a character ability, two separate things happen. On the



Figure 5.14: Ability Information before activation

data plane of the game, calculations are made in the form of dice rolls, taking into consideration any Character Stats of the Character detailed in the Ability's Effect Stats. These calculations refer to both the possible success and possible failure of the ability.

In the game's presentation, the character's model plays the animations, sound effects, and visual effects that have been assigned to the ability and the character in the process of the creation of the game scenario. At the same time, the characters that have been selected as targets for the ability, play different animations and audio and visual effects depending on the success or failure of the ability, which is calculated behind the scenes utilizing the rules system created.

A detailed explanation of the targets of the ability, the activator and the rolls and other numbers calculated for both the success and damage of the ability, are then printed on the action logs window.









Figure 5.15: Selecting which ability to activate

Chapter 6

Evaluation

For this thesis, we wanted to evaluate the system's learnability, to compare it to a traditional physical tabletop game. For this purpose, we performed a Cognitive Walkthrough experiment for the case study created utilizing *Arcane Tabletop*. A cognitive walkthrough is well researched usability inspection method that focuses on evaluating a design for ease of learning through exploration [78]. The process of the Cognitive Walkthrough has been documented to identify a large percentage of the usability problems of a systems, utilizing much less resources in comparison to a full scale system evaluation. [50]. While the value of a full scale evaluation is undeniable, for the purposes of this thesis, and in the interest of collecting some first results about the system's usability, we conducted this cognitive walkthrough as a precursor to a more detailed evaluation.

For the facilitation of the evaluation five User Experience experts acted as *evaluators* of the system. The experts that were selected had prior experience to extended reality technologies, and were familiar with Microsoft's Hololens 2 technologies and interactions. Additionally, they had experience with board games and/or video games and role playing games. One person from the development team acted as the *facilitator* for the process.

The evaluation through Cognitive Walkthrough was conducted as follows. A set of task-based scenarios were prepared, and the facilitator, that has experience with the system, completed them. These scenarios were completed in computer monitor, because Hololens 2 does not offer a way to conduct such an evaluation. The evaluators observed the completion of the tasks and scenarios, and offer their interpretation of how a user that knows the created game's rules but has never played it in extended reality, would perceive the interface and behave in the given situation. The user that the evaluators take the role of, are also assumed to have experience with the technology of Hololens 2 and the interactions it provides.

To extract the interpretation of the evaluators, there is the need to gauge whether this imaginary user would succeed at each task of each scenario. For this purpose, the facilitator stops after performing each task, and 4 key questions are made to the evaluator, in order to uncover potential causes for failure for each

1 - Will users try to achieve the right result?		
2 - Will users notice that the correct action is available?		
3 - Will users associate the correct action with the result they're trying to achieve?		
4 - After the action is performed, will users see that progress is made toward the goal?		

Table 6.1: Key questions for the Cognitive Walkthrough

interaction. This set of questions is displayed in Table 6.1. Finally, a person is given the role of recorder, documenting the answers found for each question, and the probable success or failure of the overarching task or scenario. At the end of this process, the users wore the extended reality head mounted device and were given time to experience the game. After this brief gameplay, they were asked if the real perspective of the extended reality experience would change any of their answers they made while observing the facilitator playing in a traditional computer monitor.

6.1 The Evaluated Scenarios

The selected scenarios were chosen to cover the complete functionality of the game. The scenarios include the actions players would make during their turn and during the other player's turns.

- Scenario #1
 - 1. Task 1: Listen and read the story presented in the Lobby Room.
 - 2. Task 2: Connect to the game.
- Scenario #2
 - 1. Task 1: Identify whose character turn it is.
 - 2. Task 2: Move the character one time by touching the board and one time through the point and commit interaction.
- Scenario #3
 - 1. Select for activation an ability of the character playing that selects its targets through a line.
 - 2. Understand what the ability does and how it succeeds or fails.
 - 3. Activate the ability.
- Scenario #4
 - 1. Select for activation an ability of the character playing that selects its targets through a sphere.

- 2. Activate the ability.
- 3. Review what happened through the action logs.

• Scenario #5

- 1. Select for activation an ability that Heals its targets through explicit unit selection.
- 2. Activate the ability.
- 3. Observe the results of the activation through the logger and the character portraits.
- Scenario #6
 - 1. Open a character information holographic panel.
 - 2. In this panel, review the selected characters' current Character Stats.
- Scenario #7
 - 1. Try to perform an invalid move for the character playing.
 - 2. Observe and review the result

• Scenario #8

- 1. On an ability that allows the selection of up to 1 target, try to select 2.
- 2. Observe and review the result

• Scenario #9

- 1. On an ability that selects targets within a specific range, try to select a character that is out of this range.
- 2. Observe and review the result

6.2 Results

The evaluators responded positively to the system, and noted that there were not major issues with the system that would make a task's or scenario's completion impossible. However, there were observations about issues that make the completion of certain tasks more time consuming or requiring more cognitive effort than they should. In this section of the evaluation, we detail the most notable issues identified through the process of Cognitive Walkthrough, and propose possible solutions that can be implemented to resolve these issues.

For the first scenario, 3 of the evaluators indicated that the book also serving as a button can possibly confuse some users. The users will eventually understand that they need to click on the book as there doesn't exist any other digital element in the scene, but it may take them a little bit of time. To solve this issue, we would create an element under the book or on the podium that is clearly a button that will start the narration.

For the second scenario, in its first task, 4 of the evaluators indicated that while the indicator of the portraits is enough to recognize who is playing, finding the character that plays in the 3D board could prove difficult. The solution we propose for this issue is to add an indication in the 3D character model as well that will capture the player's attention at the start of the character's turn,

For the third scenario, in the task of selecting the targets through a line and specifically in the positioning of the line, 2 evaluators noted that the user would not be unsure at first on how to move the line, but would find it eventually as the interaction is natural. To remove this uncertainty, and similar uncertainties that were reported for abilities that require explicit selection of their targets, some tutorial labels could be added, to guide a first-time user into the correct interactions. These labels could take the form of short text messages like the error messages that are displayed, with the user being able to disable them.

For the fourth scenario, in the task of examining the logs, 3 evaluators reported that while the information is presented, users may find difficult to backtrack to previous ability effects in the previous rounds through scrolling. To solve that, we would change the way the information of the abilities is presented, adding a log when the logs for ability starts and a log for when logs for an ability end. Additionally, we could make the information more concise by making the logs for each ability activation minimizable.

In the sixth scenario, and specifically in the task of reviewing the character information, all evaluators reported the same issue. While the information for stats of the character exists, there exist no indication of how these stats have been modified compared to their starting values. Moreover, the duration of any Temporal Effects a character's stat possesses can only be found in a roundabout way through the action logs. To solve these problems, we could add next to the current value that is displayed in the character information, the starting value. Moreover, we could create a new section of information in this panel that details the Temporal Effects, which stats they affect and their duration. Finally, in the portraits and/or the 3D models of the characters we could icons match different temporal effects and are added and removed accordingly.

Chapter 7

Conclusions and Future Work

This thesis presents Arcane Tabletop, a platform for creating, customizing and experiencing board games in extended reality. In the experience of the board game, the player can see their characters animating and their actions producing visual and sound effects. This platform presents novelty in the fact that it allows a extended reality tabletop experience in a scale that has not been done before, enabling tabletop role playing game session in a local physical environment, while also providing digital augmentations and enhancements to the experience, such as audiovisual effects, automatic calculations, and the application of rules that can be difficult to remember in a physical analog setting. In comparison to virtual tabletops, Arcane Tabletop offers tight integration of system and the rules, while also including 3D graphics, animations and effects, something that has not yet be implemented in other such systems.

The scope of the platform is large, and as such we have identified various points for future work. In this thesis, we present the idea and an implementation of the system, having put emphasis in the players' experience. The extended reality element in such tabletop games in this scale is uncharted territory in terms of both research and industry, our primary goal was to create a realistic and polished experience in a game scenario, in order to first evaluate the end product that the platform produces. As such, our main planned future work focuses on making the steps of creating a board game a smoother more user friendly process.

In the rule creation process, a visual editor would provide a much better user experience. Instead of filling the JSON template files for the various rules, a user could utilize this editor that can be an independent web-based system, in order to create a rule system. This system would eliminate errors that occur because of typos, because the system would keep reference to any created Ability, Character Preset, Character Stat, Effect, Character, etc. and would only allow the creation of rules that will work in the final system. The end result of the editor would be exporting the created rule system to the JSON files the system currently utilizes, so no further changes to the other functionalities of the platform would be required.

In the later steps of creating a tabletop game, we could eliminate the need for

the Unity Editor. This would require a large amount of work, but the idea for the end result, would be a custom editor where the user can load the 3D and 2D assets for characters, terrain and UI, create and attach the animators, import visual and audio effects, and create the board of the game. Also it could have the added functionality of importing and exporting game templates. This would make the steps of creating a game template and a game scenario easier for people that do not have any experience with the unity editor, and would provide flexibility during the creation of the game scenario.

For the game experience, the issues that were highlighted during the evaluation, and the solutions we provide in this thesis could be addressed. Furthermore, we have considered enhancements to the experience such as resizing, moving and rotating the game board, that could be implemented to the digital platform. Furthermore, we are considering allowing physical interaction to affect the digital game, such as enabling rolling of physical dice instead of the automatic rolls that are currently made by the system, in order to further preserve the tactility that is traditionally an important aspect of tabletop gaming.

Another important future direction we could take the system into, would be accessibility features. The potential for it already exists, as the scaling of windows can help people with impaired vision, remote interactions allow people with mobility impairments to experience the game completely, and the guided experience that is offered by the game would make the system approachable to people with cognitive disabilities. However, these features have been implemented organically, and much further research would need to be done in order to create a truly accessible game.

Additionally, a large, full scale evaluation of the system, especially after resolving the issues proposed through the cognitive walkthrough evaluation, would provide valuable feedback and new directions upon which we could expand the platform.

Finally, we would like to develop some game scenarios that add an educational aspect to the tabletop experience. For example, creating a game scenario for the Battle of Marathon [76], could create a tabletop experience in extended reality where the incline of the board is of high importance and can be simulated through 3D graphics, with the battle itself becoming a fun and educational game.

Bibliography

- Devi Acharya, Michael Mateas, and Noah Wardrip-Fruin. Story improvisation in tabletop roleplaying games: Towards a computational assistant for game masters. In 2021 IEEE Conference on Games (CoG), pages 01–08. IEEE, 2021.
- [2] Drew M Altschul and Ian J Deary. Playing analog games is associated with reduced declines in cognitive function: a 68-year longitudinal cohort study. *The Journals of Gerontology: Series B*, 75(3):474–482, 2020.
- [3] Ruth Aylett. Interactive narrative and story-telling. In The Handbook on Socially Interactive Agents: 20 years of Research on Embodied Conversational Agents, Intelligent Virtual Agents, and Social Robotics Volume 2: Interactivity, Platforms, Application, pages 463–492. 2022.
- [4] Ronald Azuma, Yohan Baillot, Reinhold Behringer, Steven Feiner, Simon Julier, and Blair MacIntyre. Recent advances in augmented reality. *IEEE computer graphics and applications*, 21(6):34–47, 2001.
- [5] Michaela Benk, Raphael P Weibel, Stefan Feuerriegel, and Andrea Ferrario. " is it my turn?" assessing teamwork and taskwork in collaborative immersive analytics. *Proceedings of the ACM on Human-Computer Interaction*, 6(CSCW2):1–23, 2022.
- [6] Adrian Bolesnikov, Jin Kang, and Audrey Girouard. Understanding tabletop games accessibility: Exploring board and card gaming experiences of people who are blind and low vision. In Sixteenth International Conference on Tangible, Embedded, and Embodied Interaction, pages 1–17, 2022.
- [7] Saverio Cavicchini, Ilaria Mariani, et al. Hybrid board game: Possibilities and implications from an interaction design perspective. In *GHItaly19. Games-Human Interaction 2019*, volume 2480, pages 1–6. CEUR, 2019.
- [8] Jack CP Cheng, Keyu Chen, and Weiwei Chen. State-of-the-art review on mixed reality applications in the aeco industry. *Journal of Construction En*gineering and Management, 146(2):03119009, 2020.

- [9] Pietro Cipresso, Irene Alice Chicchi Giglioli, Mariano Alcañiz Raya, and Giuseppe Riva. The past, present, and future of virtual and augmented reality research: a network and cluster analysis of the literature. *Frontiers in psychology*, page 2086, 2018.
- [10] Sara Colombo. Merging Digital and Physical: Tangible Interactions, pages 21–30. Springer International Publishing, Cham, 2016.
- [11] Adrien Coppens. Merging real and virtual worlds: An analysis of the state of the art and practical evaluation of microsoft hololens. *arXiv preprint arXiv:1706.08096*, 2017.
- [12] Microsoft Corporation. Roboraid. "https://www.microsoft.com/en-us/p/ holostudy-demo/9nblggh51rhx?activetab=pivot:overviewtab", 2016.
- [13] Microsoft Corporation. Microsoft's hololens 2. "https://www.microsoft. com/en-gb/hololens/hardware", 2017.
- [14] Microsoft Corporation. Introducing instinctual interactions. "https: //learn.microsoft.com/en-us/windows/mixed-reality/design/ interaction-fundamentals", 2022.
- [15] Prefrontal Cortex. Algorithmic nature. "https://prefrontalcortex.de/ en/projects/algorithmic-nature/", 2017.
- [16] Alan B. Craig. Chapter 7 mobile augmented reality. In Alan B. Craig, editor, Understanding Augmented Reality, pages 209–220. Morgan Kaufmann, Boston, 2013.
- [17] Frederico Da Rocha Tomé Filho, Bill Kapralos, and Pejman Mirza-Babaei. Exploring current board games' accessibility efforts for persons with visual impairment. In *Recent Advances in Technologies for Inclusive Well-Being: Virtual Patients, Gamification and Simulation*, pages 487–501. Springer, 2021.
- [18] José Nunes da Silva Júnior, Dávila Zampieri, Marcos Carlos de Mattos, Bruna Ribeiro Duque, Antonio Jose Melo Leite Junior, Ulisses Silva de Sousa, David Macedo do Nascimento, Mary Anne Sousa Lima, and André Jalles Monteiro. A hybrid board game to engage students in reviewing organic acids and bases concepts. Journal of chemical education, 97(10):3720–3726, 2020.
- [19] Inc. DAGERSystem. Accessible games database. "https://accessiblegamesdatabase.com/", 2023.
- [20] Stéphane Daniau. The transformative potential of role-playing games—: From play skills to human skills. *Simulation & Gaming*, 47(4):423–444, 2016.
- [21] JF Dartigues, A Foubert-Samier, M Le Goff, M Viltard, H Amieva, JM Orgogozo, et al. Playing board games, cognitive decline and dementia: a french population-based cohort study. bmj open. 2013; 3: e002998.

- [22] Asmodee Digital. Asmodee digital. "https://www.asmodee-digital.com/ en/", 2023.
- [23] Scott Benjamin Dyson, Yu-Lin Chang, Hsueh-Chih Chen, Hsiang-Yu Hsiung, Chien-Chih Tseng, and Jen-Ho Chang. The effect of tabletop role-playing games on the creative potential and emotional creativity of taiwanese college students. *Thinking Skills and Creativity*, 19:88–96, 2016.
- [24] Tilt Five. Tilt five, inc. "https://www.tiltfive.com/", 2023.
- [25] LLC Foundry Gaming. Foundry virtual tabletop. "https://foundryvtt. com/", 2023.
- [26] Berserk Games. Tabletop simulator. "https://www.tabletopsimulator. com/", 2020.
- [27] Andrea Gauthier, Pamela M Kato, Kim CM Bul, Ian Dunwell, Aimee Walker-Clarke, and Petros Lameras. Board games for health: A systematic literature review and meta-analysis. *Games for health journal*, 8(2):85–100, 2019.
- [28] Marcello A Gómez-Maureira, Giulio Barbero, Maria Freese, and Mike Preuss. Towards a taxonomy of ai in hybrid board games. In *Proceedings of the 15th International Conference on the Foundations of Digital Games*, pages 1–6, 2020.
- [29] Anne M Goodall. Magic, Adventure & Social Participation: Tabletop Role-Playing Games and Their Potential to Promote Social Inclusion and Citizenship. PhD thesis, Université d'Ottawa/University of Ottawa, 2021.
- [30] Holo Group. Holostudy demo. "https://www.microsoft.com/en-us/p/ holostudy-demo/9nblggh51rhx?activetab=pivot:overviewtab", 2016.
- [31] Sebastian Günther, Florian Müller, Martin Schmitz, Jan Riemann, Niloofar Dezfuli, Markus Funk, Dominik Schön, and Max Mühlhäuser. Checkmate: Exploring a tangible augmented reality interface for remote interaction. In Extended Abstracts of the 2018 CHI Conference on Human Factors in Computing Systems, pages 1–6, 2018.
- [32] Ulf Hartelius, Johan Fröhlander, and Staffan Björk. Tisch digital tools supporting board games. In *Proceedings of the International Conference on the Foundations of Digital Games*, pages 196–203, 2012.
- [33] Eva Hornecker. The role of physicality in tangible and embodied interactions. Interactions, 18:19–23, 03 2011.
- [34] Apple Inc. Apple vision pro. "https://www.apple.com/apple-vision-pro/ ", 2023.

- [35] The AbleGamers Foundation Inc. Ablegamers. "https://ablegamers.org/ ", 2023.
- [36] Jessica Ip and Jeremy Cooperstock. To virtualize or not? the importance of physical and virtual components in augmented reality board games. In Entertainment Computing-ICEC 2011: 10th International Conference, ICEC 2011, Vancouver, Canada, October 5-8, 2011. Proceedings 10, pages 452–455. Springer, 2011.
- [37] Yunshui Jin, Minhua Ma, and Jiachen Li. Immersive storytelling in augmented reality: Witnessing the kindertransport. In *Joint International Conference on Serious Games*, pages 17–33. Springer, 2020.
- [38] Yunshui Jin, Minhua Ma, and Yongning Zhu. A comparison of natural user interface and graphical user interface for narrative in hmd-based augmented reality. *Multimedia tools and applications*, 81(4):5795–5826, 2022.
- [39] P Johan, E Daniel, and B Staffan. Augmented board games-enhancing board games with electronics. In DiGRA & # 3905-Proceedings of the 2005 DiGRA International Conference: Changing Views: Worlds in Play, 2005.
- [40] Wi Hoon Jung, Sung Nyun Kim, Tae Young Lee, Joon Hwan Jang, Chi-Hoon Choi, Do-Hyung Kang, and Jun Soo Kwon. Exploring the brains of baduk (go) experts: gray matter morphometry, resting-state functional connectivity, and graph theoretical analysis. *Frontiers in Human Neuroscience*, 7:633, 2013.
- [41] Ville Kankainen. The interplay of two worlds in blood bowl: Implications for hybrid board game design. In Proceedings of the 13th International Conference on Advances in Computer Entertainment Technology, pages 1–7, 2016.
- [42] Se Hee Kim, Doug Hyun Han, Young Sik Lee, Bung-Nyun Kim, Jae Hoon Cheong, and Sang Ho Han. Baduk (the game of go) improved cognitive function and brain activity in children with attention deficit hyperactivity disorder. *Psychiatry Investigation*, 11(2):143, 2014.
- [43] Geoff King and Tanya Krzywinska. Tomb raiders and space invaders: Videogame forms and contexts. IB Tauris, 2006.
- [44] Sreeram Kongeseri and Christopher Coley. Design of a collaborative tabletop game for civic engagement: Serious games in rural india. In *International Conference on Videogame Sciences and Arts*, pages 86–98. Springer, 2019.
- [45] Mehmet Kosa and Pieter Spronck. What tabletop players think about augmented tabletop games: a content analysis. In Proceedings of the 13th International Conference on the Foundations of Digital Games, pages 1–8, 2018.
- [46] Tanya Krzywinska, Tim Phillips, Alcwyn Parker, and Michael James Scott. From immersion's bleeding edge to the augmented telegrapher: A method for
creating mixed reality games for museum and heritage contexts. Journal on Computing and Cultural Heritage (JOCCH), 13(4):1–20, 2020.

- [47] Samuli Laato, Sampsa Rauti, AKM Najmul Islam, and Erkki Sutinen. Why playing augmented reality games feels meaningful to players? the roles of imagination and social experience. *Computers in Human Behavior*, 121:106816, 2021.
- [48] Younes Lakhnati, Raphael Springer, and Jens Gerken. Mensch argere dich nicht: a board game testbed for mixed reality interactions. In Proceedings of the 18th International Conference on Mobile and Ubiquitous Multimedia, pages 1-5, 2019.
- [49] Yi-Chin Lee and Lea Albaugh. Hybrid embroidery games: Playing with materials, machines, and people. In *Designing Interactive Systems Conference* 2021, pages 749–762, 2021.
- [50] Clayton Lewis, Peter G Polson, Cathleen Wharton, and John Rieman. Testing a walkthrough methodology for theory-based design of walk-up-and-use interfaces. In *Proceedings of the SIGCHI conference on Human factors in computing systems*, pages 235–242, 1990.
- [51] Ming Li, Reza Seifabadi, Dilara Long, Quirina De Ruiter, Nicole Varble, Rachel Hecht, Ayele H Negussie, Venkatesh Krishnasamy, Sheng Xu, and Bradford J Wood. Smartphone-versus smartglasses-based augmented reality (ar) for percutaneous needle interventions: system accuracy and feasibility study. International journal of computer assisted radiology and surgery, 15:1921–1930, 2020.
- [52] Q Lin, Y Cao, and J Gao. The impacts of a go-game (chinese chess) intervention on alzheimer disease in a northeast chinese population. front aging neurosci [internet]. 2015 [cited 2022 nov 15]; 7: 163, 2015.
- [53] SmiteWorks USA LLC. Fantasy grounds. "https://www.fantasygrounds. com/", 2020.
- [54] Inc. Magic Leap. Magic leap 2. "https://www.magicleap.com/ magic-leap-2", 2023.
- [55] Alison McMahan. Immersion, engagement, and presence: A method for analyzing 3-d video games. In *The video game theory reader*, pages 67–86. Routledge, 2013.
- [56] Maxence Mercier and Todd Lubart. The effects of board games on creative potential. The Journal of Creative Behavior, 55(3):875–885, 2021.
- [57] Tadatsugu Morimoto, Takaomi Kobayashi, Hirohito Hirata, Koji Otani, Maki Sugimoto, Masatsugu Tsukamoto, Tomohito Yoshihara, Masaya Ueno, and

Masaaki Mawatari. Xr (extended reality: virtual reality, augmented reality, mixed reality) technology in spine medicine: status quo and quo vadis. *Journal of Clinical Medicine*, 11(2):470, 2022.

- [58] Marija Nakevska, Anika van Der Sanden, Mathias Funk, Jun Hu, and Matthias Rauterberg. Interactive storytelling in a mixed reality environment: the effects of interactivity on user experiences. *Entertainment computing*, 21:97–104, 2017.
- [59] John Nash. Two-person cooperative games. Econometrica: Journal of the Econometric Society, pages 128–140, 1953.
- [60] Victor Nell. Lost in a book: The psychology of reading for pleasure. Yale University Press, 1988.
- [61] Shozo Ogawa, Kodai Ito, Ryota Horie, and Mitsunori Tada. Development of a board game using mixed reality to support communication. In HCI International 2021-Late Breaking Posters: 23rd HCI International Conference, HCII 2021, Virtual Event, July 24–29, 2021, Proceedings, Part I 23, pages 451–458. Springer, 2021.
- [62] Jae Wan Park. Hybrid monopoly: a multimedia board game that supports bidirectional communication between a mobile device and a physical game set. *Multimedia Tools and Applications*, 76(16):17385–17401, 2017.
- [63] Photon. Photon engine. "https://www.photonengine.com/", 2017.
- [64] Bas A Plijnaer, Daisy O'Neill, Eloisa Kompier, Günter Wallner, and Regina Bernhaupt. Truesight battle grid-enhancing the game experience of tabletop role-playing through tangible data visualization. In *Extended Abstracts of* the 2020 Annual Symposium on Computer-Human Interaction in Play, pages 103–107, 2020.
- [65] Alicia Pose-Díez-de-la Lastra, Rafael Moreta-Martinez, Mónica García-Sevilla, David García-Mato, José Antonio Calvo-Haro, Lydia Mediavilla-Santos, Rubén Pérez-Mañanes, Felix Von Haxthausen, and Javier Pascau. Hololens 1 vs. hololens 2: improvements in the new model for orthopedic oncological interventions. Sensors, 22(13):4915, 2022.
- [66] Melissa J Rogerson, Martin Gibbs, and Wally Smith. " i love all the bits" the materiality of boardgames. In Proceedings of the 2016 CHI conference on human factors in computing systems, pages 3956–3969, 2016.
- [67] Melissa J Rogerson, Lucy A Sparrow, and Martin R Gibbs. More than a gimmick-digital tools for boardgame play. Proceedings of the ACM on Human-Computer Interaction, 5(CHI PLAY):1–23, 2021.
- [68] LLC Roll20. Roll20. "https://roll20.net/", 2023.

- [69] Mickael Sereno, Xiyao Wang, Lonni Besançon, Michael J Mcguffin, and Tobias Isenberg. Collaborative work in augmented reality: A survey. *IEEE Trans*actions on Visualization and Computer Graphics, 28(6):2530–2549, 2020.
- [70] Yingjie Song, Nianmei Zhou, Qianhui Sun, Wei Gai, Juan Liu, Yulong Bian, Shijun Liu, Lizhen Cui, and Chenglei Yang. Mixed reality storytelling environments based on tangible user interface: Take origami as an example. In 2019 IEEE Conference on Virtual Reality and 3D User Interfaces (VR), pages 1167–1168. IEEE, 2019.
- [71] Maximilian Speicher, Brian D Hall, and Michael Nebeling. What is mixed reality? In Proceedings of the 2019 CHI conference on human factors in computing systems, pages 1–15, 2019.
- [72] Constantine Stephanides, Asterios Leonidis, Maria Korozi, Vasilis Kouroumalis, Ilia Adami, and Stavroula Ntoa. Design for Intelligent Environments. In HUMAN COMPUTER INTERACTION: INTERACTING WITH INTELLIGENT ENVIRONMENTS, HUMAN-COMPUTER INTER-ACTION: FOUNDATIONS, METHODS, TECHNOLOGIES AND APPLI-CATIONS. CRC Press, 2024.
- [73] Asobo Studio. Fragments for microsfot hololens. "https://www. asobostudio.com/games/fragments", 2017.
- [74] LLC Tabula Gaming. Tabula sono. "https://tabulasono.com/", 2023.
- [75] Unity Technologies. Unity. "https://unity.com/", 2017.
- [76] Michael Ray The Editors of Encyclopaedia Britannica. Brittanica. "https: //www.britannica.com/event/Battle-of-Marathon", 2023.
- [77] Li-Lan Wang and I-Jui Lee. A preliminary study on application of tangible user interface and augmented reality technology with table game and handeye coordination operation tasks in the fields of memory and visuospatial perception for the elderly. In *International Conference on Human-Computer Interaction*, pages 277–289. Springer, 2022.
- [78] C Wharton, J Rieman, C Lewis, and P Polson. The cognitive walkthrough: a practitioner's guide. usability inspection methods. *ed: John Wiley, New York*, 1994.
- [79] Yan Xu, Evan Barba, Iulian Radu, Maribeth Gandy, and Blair MacIntyre. Chores are fun: Understanding social play in board games for digital tabletop game design. In *digra conference*, 2011.
- [80] José P Zagal, Jochen Rick, and Idris Hsi. Collaborative games: Lessons learned from board games. *Simulation & gaming*, 37(1):24–40, 2006.

[81] Chenyan Zhang, Andrew Perkis, and Sebastian Arndt. Spatial immersion versus emotional immersion, which is more immersive? In 2017 Ninth International Conference on Quality of Multimedia Experience (QoMEX), pages 1–6. IEEE, 2017.

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