



**CHALMERS**  
UNIVERSITY OF TECHNOLOGY



UNIVERSITY OF GOTHENBURG



# Augmenting Board Games using Virtual Reality

Bachelor of Science Thesis in Information Technology and Industrial Design  
Engineering

Daniel Berndtsson, Martin Dehmer Östebo, Fredrik Eliasson,  
Hanna Römer, Alexander Sandberg

Chalmers University of Technology  
University of Gothenburg  
Department of Computer Science and Engineering  
Göteborg, Sweden, May 2017

Bachelor of Science Thesis

## **Augmenting Board Games using Virtual Reality**

Daniel Berndtsson  
Martin Dehmer Östebo  
Fredrik Eliasson  
Hanna Römer  
Alexander Sandberg

Department of Computer Science and Engineering  
CHALMERS UNIVERSITY OF TECHNOLOGY  
University of Gothenburg

Göteborg, Sweden 2017

## **Augmenting Board Games using Virtual Reality**

Daniel Berndtsson

Martin Dehmer Östebo

Fredrik Eliasson

Hanna Römer

Alexander Sandberg

© Daniel Berndtsson, Martin Dehmer Östebo, Fredrik Eliasson, Hanna Römer, Alexander Sandberg 2017

Examiner: Morten Fjeld

Department of Computer Science and Engineering

Chalmers University of Technology

University of Gothenburg

SE-412 96 Göteborg

Sweden

Telephone: +46 (0)31-772 1000

The Author grants to Chalmers University of Technology and University of Gothenburg the non-exclusive right to publish the Work electronically and in a non-commercial purpose make it accessible on the Internet.

The Author warrants that he/she is the Author to the Work, and warrants that the Work does not contain text, pictures or other material that violates copyright law.

The Author shall, when transferring the rights of the Work to a third party (for example a publisher or a company), acknowledge the third party about this agreement. If the Author has signed a copyright agreement with a third party regarding the Work, the Author warrants hereby that he/she has obtained any necessary permission from this third party to let Chalmers University of Technology and University of Gothenburg store the Work electronically and make it accessible on the Internet.

Cover:

Scene from the game BoardNight created in the project

Department of Computer Science and Engineering

Göteborg 2017

## **Acknowledgements**

We would like to thank our supervisor Staffan Björk and his co-worker Daniel Sjölie for their advice and continuous support. Big thanks to the people at Visual Arena for letting us use their equipment and lending their help when needed.

# Augmenting Board Games using Virtual Reality

Daniel Berndtsson  
Martin Dehmer Östebo  
Fredrik Eliasson  
Hanna Römer  
Alexander Sandberg

*Department of Computer Science and Engineering,  
Chalmers University of Technology  
University of Gothenburg*

Bachelor of Science Thesis

## ABSTRACT

Virtual reality, VR, is a relatively new technology which right now shows great commercial potential and garners the attention of many game developers. Even though many games and prototypes have been made using VR technology, few studies have been found which explore how VR could augment games of genres other than computer games. Identifying and characterizing the possibilities of virtual reality could help developers to more effectively incorporate new aspects in their applications, as well as allowing them to easier identify novel areas of different design spaces.

In this project, one such design space, *Virtual reality augmented board games*, is chosen as the subject for examination. Around this subject, two closely intertwined processes are done, one investigative and one developmental. Current games and literature are examined and several *elements of interest* are identified. Also, an original game, *BoardNight*, loosely based on an existing board game, is developed simultaneously as a compliment to the investigative effort, which allows for a more thorough examination of certain aspects of the design space.

The *elements of interest* that were identified highlights aspects of the studied subject which was considered interesting in relation to developing BoardNight. While not necessarily enhancing a gameplay experience, all identified elements of interest proved to be of interest when augmenting board games.

The resulting elements are not exhaustive and there are still elements within the design space which could be of interest to study further. Also, it would be beneficial to conduct user tests to get more objective results, which as of now could be considered to be somewhat subjective.

## SAMMANFATTNING

Virtual reality, VR, är en relativt ny teknologi som för närvarande visar stor kommersiell potential och som många spelutvecklare visar stort intresse för. Trots att många spel och prototyper har skapats för VR så har få studier gjorts som utforskar hur VR kan användas för att förstärka spel i genrer utanför datorspel. Genom att identifiera och karaktärisera möjligheter som tillhandahålls av VR så kan utvecklare inkorporera nya samt nyskapande aspekter av olika designområden i sina applikationer.

I detta projekt utforskas ett sådant designområde, brädspel förstärkta genom VR, det vill säga *Virtual reality augmented board games*. Kring detta drivs två tätt sammanlänkade processer varav den ena är utforskande och den andra utvecklingsinriktad. Genom utforskandet av aktuella spel och litteratur identifieras ett antal intresseområden, så kallade *elements of interest*. Ett nytt spel, benämnt *BoardNight*, vilket är löst baserat på ett redan existerande brädspel skapas också. BoardNight utvecklas parallellt med den utforskande processen och är huvudsakligen ett komplement till denna. Detta spel möjliggör mer utförliga studier av utvalda aspekter inom designområdet.

De intresseområden som har identifierats belyser aspekter av det studerade designområdet som ansågs vara intressanta i relation till utvecklingen av BoardNight. Dessa aspekter förbättrar nödvändigtvis inte spelupplevelsen, men alla identifierade intresseområden visade sig ha potential att förstärka brädspel.

De resulterande intresseområdena är inte de enda som finns inom designområdet, det finns fortfarande intresseområden som skulle vara intressanta att studera vidare. Det skulle även vara fördelaktigt att utföra användartester för att få fram mer objektiva resultat, som just nu kan anses vara något subjektiva.

**Keywords:** VR, virtual reality, augmented, board game, zombicide, multiplayer, unreal engine, chalmers, bachelor exam project, interaction

# Contents

1. Introduction.....	4
1.1 Purpose .....	4
1.2 Scope .....	4
1.3 Delimitations .....	5
1.3.1 Prototype.....	5
1.3.2 Target Platform.....	5
1.3.3 VR-sickness.....	5
1.3.4 Usability Tests .....	5
2. Background.....	7
2.1 Board games .....	7
2.2 Virtual Reality.....	7
2.2.1 Virtual Reality Systems.....	8
2.3 VR augmented board games.....	8
2.4 Related work.....	9
3. Methodology.....	10
3.1 Unreal Engine 4.....	10
3.1.1 Multiplayer.....	11
3.1.2 Artificial Intelligence .....	11
3.2 Workflow .....	12
3.2.1 Iterative Workflow .....	13
3.2.2 Documentation and Version Control.....	13
4. Process .....	15
4.1 Research.....	15
4.2 The Board Game Process.....	15
4.2.1 Selection process.....	15
4.2.2 Zombicide .....	16
4.3 Elements of Interest .....	17
4.3.1 To Act as a Game Piece.....	17
4.3.2 Multiplayer.....	19
4.3.3 Interaction Between Players.....	20
4.3.4 Asymmetric Information .....	22
4.3.5 Interaction With the Environment.....	22
4.3.6 Visualization of Information .....	23

4.4 Implementation & Design.....	24
4.4.1 Unreal Engine .....	24
4.4.2 Movement .....	24
4.4.3 Artificial Intelligence .....	25
4.4.4 Assests .....	26
4.4.5 Multiplayer .....	27
5. Results.....	28
5.1 Implementation .....	28
5.2 Elements of interest .....	32
5.2.1 To Act as a Game Piece.....	32
5.2.2 Multiplayer and Interaction Between Players .....	32
5.2.3 Asymmetric Information .....	32
5.2.4 Interaction With the Environment.....	33
5.2.5 Visualization of Information .....	33
6. Discussion .....	34
6.1 Result.....	34
6.2 Methodology.....	35
6.3 Validity .....	36
6.4 Future Work .....	37
6.4.1 Implementation .....	37
6.4.2 Elements of Interest .....	37
6.5 Ethical.....	38
7. Conclusion.....	39
References.....	40



# Glossary

<b>Action View:</b>	When the player is acting as their game piece, being on the board
<b>AI:</b>	Artificial Intelligence
<b>Augmented Board Games:</b>	Board games that are using computational power to extend functionality and gameplay
<b>Blueprints:</b>	A scripting language used in Unreal Engine 4
<b>Board View:</b>	When the player is not the game piece, rather standing around the board looking down at the game pieces
<b>Design Space:</b>	A defined area of design limited and separated by aspects such as interaction, input parameters and process parameters.
<b>Immersion:</b>	How strongly a player feels like the digital environment he is inhabiting is real
<b>LAN:</b>	Local Area Network
<b>Presence:</b>	The feeling of whether something or someone is actually there with the player in the virtual environment
<b>UE4:</b>	Unreal Engine 4
<b>VoIP:</b>	Voice over Internet Protocol
<b>VR-sickness:</b>	A state similar to motion sickness. Occurs due to the brain receiving different information from the eyes compared to the other senses
<b>WAN:</b>	Wide Area Network

# 1. Introduction

Playing board games is an old human phenomenon [1] but it is argued that, based on current sales patterns, we are currently experiencing what could be described as the golden age of board games [2]. Apart from traditional board games, following the digital age, board games have also been translated into computer games.

Attempts to make large scale virtual reality, VR, games are few, as can be seen by the supply of games in the Oculus Store [3]. Most games available are experimental and created by independent developers. The purpose of such games is often to showcase and investigate the question of what VR has to offer the gaming industry. It is a broad, currently unanswered, question which is also being investigated by several major game companies including Valve and Bethesda who are developing titles for VR [4], [5].

## 1.1 Purpose

It would be beneficial for a VR developer to have knowledge of how VR can be used to augment games in different design spaces. Because of the success of modern board games, it could also prove advantageous to base the research of such knowledge in board games. Therefore, the question which the project aims to answer is: Which are the possibilities provided by virtual reality to augment a board game experience and how can these be utilised?

## 1.2 Scope

S. Björk et al. [6] defines augmentation of board games as “using computational power to extend functionality and gameplay”. Different possibilities on how to achieve this will be identified and explored primarily through a VR board game created during the project. The project will also cover literature studies and examination of already existing games in order to gain more insight of what has previously been explored in VR. The implementation of the game will enable exploration of elements not present in other games and will allow testing of these in a controlled environment.

Elements of interest to the project are mechanics or aspects of gameplay that may augment the board game experience for players by the use of VR. One can with good assurance say that the number of such elements is very large and that it is also changing depending on the observer's point of view. The number of elements which the project consider will therefore be limited. Most elements which will be investigated were not known at the project's start, instead a part of the project's scope has been to identify these. Elements have been found by brainstorming [7], playing board and VR games, assimilating information about the subject and as a natural process in the creation of the VR game. Information on how each individual element was identified is found in the process chapter.

The elements which were known as the project started was either presented by the supervisor or thought of before the project work had begun. These elements were the ability to play multiplayer, how information should be visualized and the use of asymmetric information.

## 1.3 Delimitations

To further narrow the scope of the project several delimitations have been made. What is going to be implemented, which are the target platforms and what are usually important aspects of developing a game in VR but is outside of the scope?

### 1.3.1 Prototype

The main delimitation is to create one game, based on the concept of an already existing board game. A different approach would have been to create a platform, on which users could play different board games as well as create their own maps, rules and essentially their own game within the boundaries of the platform, much like Tabletop Simulator [8]. However, this would require the features to be relatively simple and generic for them to also be applicable to different kinds of board games and would therefore make it more difficult to deeper explore certain areas and features in which VR has potential to augment the board game experience. Alternatively, making every feature use VR to its full extent would cause the complexity of the project to exceed what is possible to accomplish within the given time. Another option would have been to design a completely new board game. This would require constructing a ruleset and other elements to make a proper board game, which was considered too time-consuming and not fundamental to the scope of the project.

### 1.3.2 Target Platform

HTC Vive [9] and Oculus Rift [3] are the VR-headsets available to the project during development and will be the target platforms for the game. Although the headsets are fairly similar there are differences which need to be accounted for when developing for both platforms. While using the Oculus, movement is more restricted due to the limited tracking space, usually set up to be used while standing or sitting in front of a computer. The Vive on the other hand uses a room-scale tracking space which gives the user the ability to walk around more freely.

### 1.3.3 VR-sickness

A major limitation in any VR application is VR-sickness [10]. To keep the effects of VR-sickness to a minimum, guidelines and research on the topic will be taken into account by following the recommendations given by Epic Games [11], [12], but a full study on the subject is outside of the project's scope.

### 1.3.4 Usability Tests

When developing a game or any other software that is going to be used by humans, it is important to conduct usability tests during the development cycle. The software is being

developed for the user and therefore it is important to get continuous feedback from users, so that developers know if they are heading in the right direction [13]. However, performing extensive usability tests are time consuming. It includes both creating the tests and executing them. This is the main reason usability tests will not be performed in this project. Using time to increase the number of investigated elements have been prioritised over creation and execution of usability tests. Additionally, by excluding usability tests, the implementation can be created in such a way that it promotes basic evaluation and finding of new elements without taking the additional time to also make it user friendly. Would the implementation be customized for usability tests this process would be slowed down.

## 2. Background

The background of board games gives a basic understanding of why and how board games have been made. The background of VR span a shorter time period but also presents some of the systems that are currently being developed. Related works gives an introduction to previous investigations in similar subjects in order to give inspiration and provide knowledge of what is already known.

### 2.1 Board games

Board games have emerged from a range of different cultures around the world throughout human history. Examples can be found among the ancient Egyptians who played the board game Senet [1] or the Chinese who invented Go [14]. Ever since its origin and continuing today board games are used as a way of entertainment and social interaction. Board games are currently more popular than they have ever been and the market keeps growing [15]. The internet has encouraged the growth of board games by making the purchase of games more accessible and by giving players means of easily finding information about games. Naturally following the digital age board games have also been produced as computer games. The game Settlers of Catan, one of the most popular board games of our time [16], alone has at least twenty different digital titles [17]. Creating a board game on a digital platform offers a new set of tools for the designer of the game to work with but also impose new limitations. Wartile [18] is a modern digital board game which uses the digital environment of computers to do calculations, keep track of statistics and enhance the games aesthetics.

Augmented board games consist of a third category of board games which are a combination of classical and digital games [6]. In such a game the core mechanics are presented as a traditional physical game but these are also augmented by a digital medium [19]. Early games of the genre such as Space Alert [20] often use the digital enhancement only in minor aspects of the game, such as generating a scenario. One of the first fully augmented board games that uses digital augmentation for many critical parts of the game is XCOM: The Board Game [21].

### 2.2 Virtual Reality

VR was given attention by the game industry in the early 1990s [22], [23] but it was deemed to be a general failure and was mostly abandoned until a new upswing in the mid-2010s [24]. It is a technology that lets the user interact with a virtual environment in a more tangible way than regular computer interfaces like a monitor, keyboard and mouse. VR is usually experienced through a VR-headset that is strapped onto the user's head. The headset provides two slightly different images of what is being displayed, one for each eye, which causes the virtual environment to appear in three dimensions to the user. By looking in a certain direction the headset will display that part of the environment.

Certain headsets are also accompanied by motion controllers which track the movement of the user's hands. By pressing a button or in some other way interacting with the motion controller the user can pick up and move objects inside the virtual environment, further enhancing the immersion.

### 2.2.1 Virtual Reality Systems

There are currently several ways to experience VR for private use. The cheapest and most accessible way to experience VR is to buy a headset that uses an attached phone to track head movement, like Gear VR [25] or Google Cardboard [26]. For a greater, more immersive experience, there are computer connected headsets with motion controllers and motion tracking. The most commonly used computer connected headsets are Oculus Rift and HTC Vive. Playstation VR [27] is another alternative to the Vive and Oculus. It connects to a PlayStation 4 [28] and is cheaper than its computer connected counterparts.

### 2.3 VR augmented board games

VR can be used in numerous novel and not so novel ways to augment both digital and physical games. In the computer game Tabletop Simulator [8], which is a physics-based sandbox [29] where the users can play a wide variety of traditional tabletop games in a virtual multi-user environment. Interactions with board pieces are performed using a mouse and interaction with other players is handled through a chat window or by using Voice over Internet Protocol, VoIP. Tabletop Simulator supports use of VR-equipment and handles it by giving the users an avatar in the virtual environment in the form of floating in-game controllers and a floating head, tracking the motion controllers and the VR-headset. This provides users with the possibility to play board games in a setting that could be seen as more traditional, with avatars tracking the users, which gives a sense of physical presence. Handling virtual board game pieces using motion controllers with haptics more closely mimics handling a physical board game and could thus arguably provide a more tangible experience than what could be achieved using a mouse as input.

Another example of VR being used to augment a board game, but arguably in a more novel way, is the game Mask of Anubis [30]. In Mask of Anubis players take turn wearing a VR-headset and through it receiving visual information about a maze. This information is then conveyed verbally to the other players who in turn tries to mimic the informed player's instructions by assembling a physical maze using gameboard tiles. The VR-headset is then passed on to the next player and the process is repeated until the whole maze is built and the players win if they managed to communicate the maze's design successfully. Another variant of the concept with a single VR-headset is the game Keep talking and nobody explodes [31]. Here the VR-headset wearing player is presented with an armed bomb which can only be defused by solving several puzzles. These puzzles require a manual to be solved which is held by the other participant(s), and the game can only be won through successful communication between the players.

## 2.4 Related work

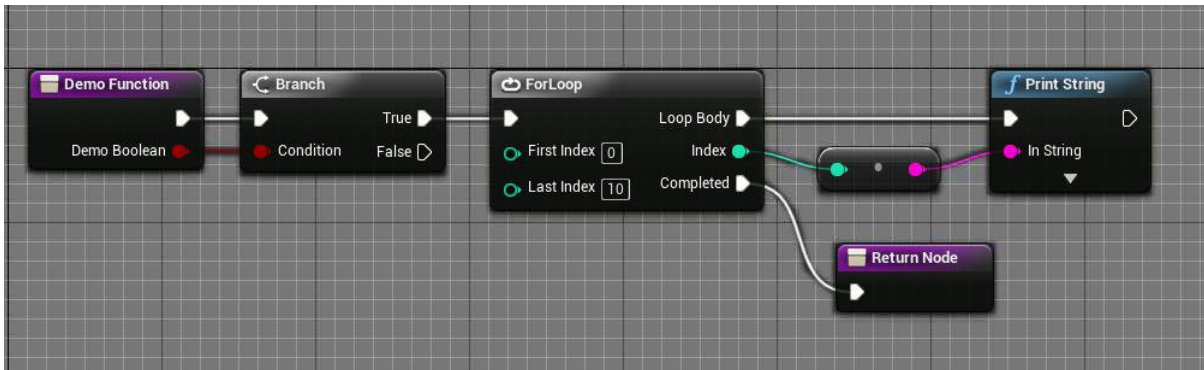
Not much work about VR-augmented board games have been found. Therefore, the major sources of information for an analysis of the field comes from games that is believed to inhabit VR augmented board games design space as well as similar studies done in fields that lie in close proximity to the subject. One such study is carried out by S. Björk et al. [6] who investigates the field of augmented board games in a structured manner. Through specifying a few gameplay aspects to focus on and performing a survey of games using methods and concepts from earlier research they seek to identify some of the characteristics of this particular design space. Presenting different variations of game designs helps define the design space and could aid in the identification of novel designs.

### 3. Methodology

In this chapter, the tools and methods used during the project are presented. This includes the tools used for implementing the game prototype and editing game assets. Also, the methodology used to govern the way in which the project was undertaken is presented, together with the tools used to facilitate a smooth workflow.

#### 3.1 Unreal Engine 4

Unreal Engine 4, UE4, is a game engine developed by Epic Games [11]. The engine focuses on bringing powerful development tools to as many people as possible. Epic Games does this by continuously updating the engine while providing it for free in return of a percentage of the income, would content created with the engine be sold. As a complement to traditional coding the engine also provides visual scripting in the form of Blueprints in order for people not familiar with more than the basics of coding to still be able to make advanced content. In addition, the engine provides support for most big gaming platforms including VR.



**Figure 1:** A function in Blueprints which checks if a boolean is true. If it is, prints numbers 0 to 9. Note that the background is brighter than it is presented in the engine for clearer visualization.

Another way of programming in UE4 is using the programming language C++, which is considered the industry standard for creating games and applications with high performance demands. Using C++ with UE4 allows programmers to create new gameplay elements which, since UE4 is open-source, can be altered to fit almost any need that a developer might have. If highly performant compiled code is not required for certain things, such as for scripted gameplay events, these can be implemented using Blueprints. The code is not written in text, instead it is built by nodes visually connected by lines. The developer creates code by adding nodes and dragging lines from one node to the other with the line having different meaning depending on its colour. Blueprints are not precompiled like C++ code, but instead runs on a virtual machine during runtime. This causes some overhead and is therefore probably not appropriate for handling computation-heavy systems such as rendering or physics-calculations.



### 3.1.1 Multiplayer

Unreal engine uses a server/client model for networking [32]. In this model there exists a server, which keeps the authoritative game state, and clients which maintain their own approximative game states. Communication between the server and its clients are done through either implicit replication, which is UE4's standard method of updating the client game states with the authoritative game state, or through explicit remote procedure calls, RPC, where the programmer chooses exactly what data to send where and when, and what is to be done with it. In order to keep game states synchronized across a networked session the standard approach is to let all important calculations and decisions take place server-side. That is, clients send RPC's to the server which handles the requests, updates the authoritative game state and replicates the updates to all clients. Things such as health counters, positions, physics calculations and more should be kept and updated server-side to ensure correct synchronization, or else inconsistencies can start to show among clients.

To facilitate session management, allowing for hosting and joining games remotely, external third party services can be used, such as Steam [33] or Xbox Live [34]. If online multiplayer is not required, UE4 supports local area network, LAN, play without any external services by default.

Networking can be implemented using either C++, Blueprints or a combination of both. Since networking is a performance-sensitive area, where delays can hinder a nice gameplay experience, writing as fast code as possible is generally preferred. It is however possible to create basic networking using only Blueprints [35].

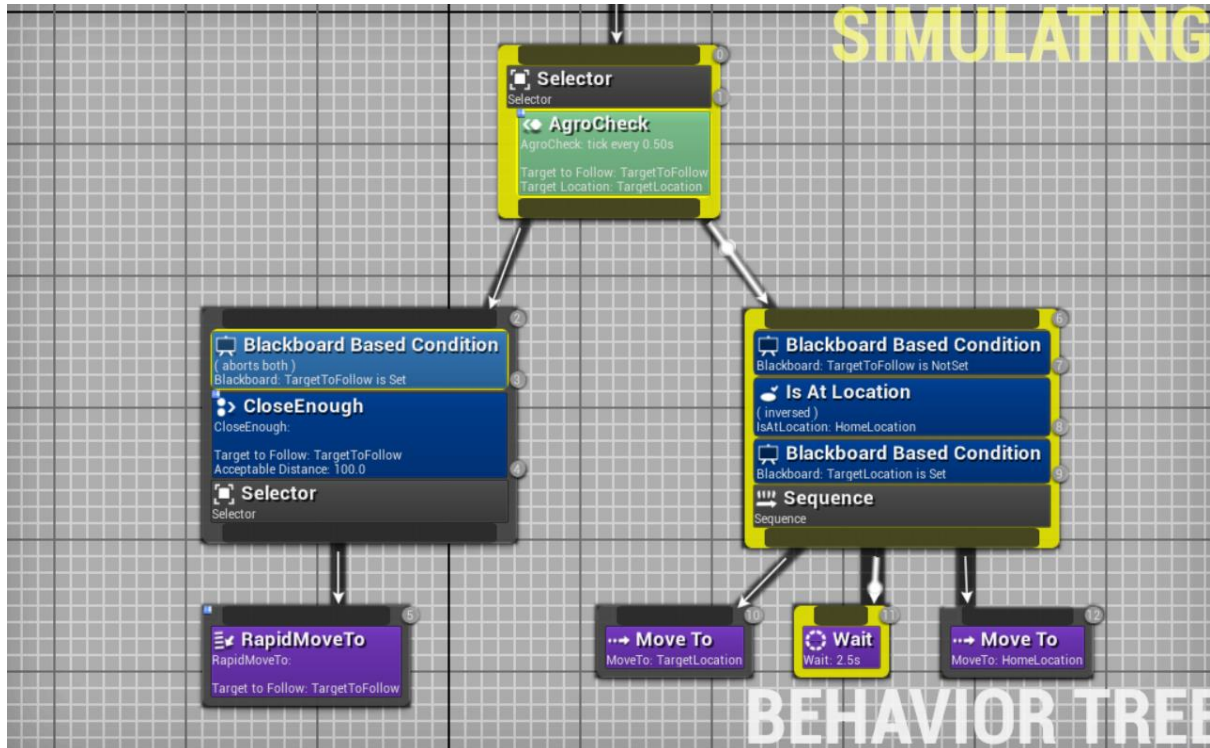
Although designing and implementing new gameplay features might be quick and intuitive with a single player experience in mind, several factors substantially increases the effort of converting the same features into something multiplayer-ready. To maintain synchronized game states everything that has an effect on game state has to be done through the server. This can cause problems with responsivity since things like movement requests has to be sent from a client to the server where the movement is calculated, the authoritative game state is updated and then replicated back to the client. This can take a substantial amount of time depending on network capacity and congestion.

When it comes to testing and debugging multiplayer games, UE4 has a feature that allows for running a server and zero or more client instances on a single computer, which allows for fast setup of testing sessions. Unfortunately, this feature does not work properly when multiple instances needs to be tested in VR, rendering this method unfit for testing multiplayer features. Instead, at least two computers with VR-setups are needed to allow for proper testing to be done.

### 3.1.2 Artificial Intelligence

UE4 uses its own artificial intelligence, AI, which can be created with customized Blueprints called Blackboards and Behavior trees [36].

The Blackboard is the memory bank of the Behavior tree in which all key values are stored. It is also where data is written and read for decision making purposes inside the Behavior tree. A Blackboard can also be used in any situation where it's convenient to have a central place to store relevant data. Blackboards are commonly used in combination with Behavior trees but you could also make a Behavior tree which does not use a Blackboard.



**Figure 2:** A Behavior tree as visualized in UE4's Blueprints. Note that the background is brighter than it is presented in the engine for clearer visualization.

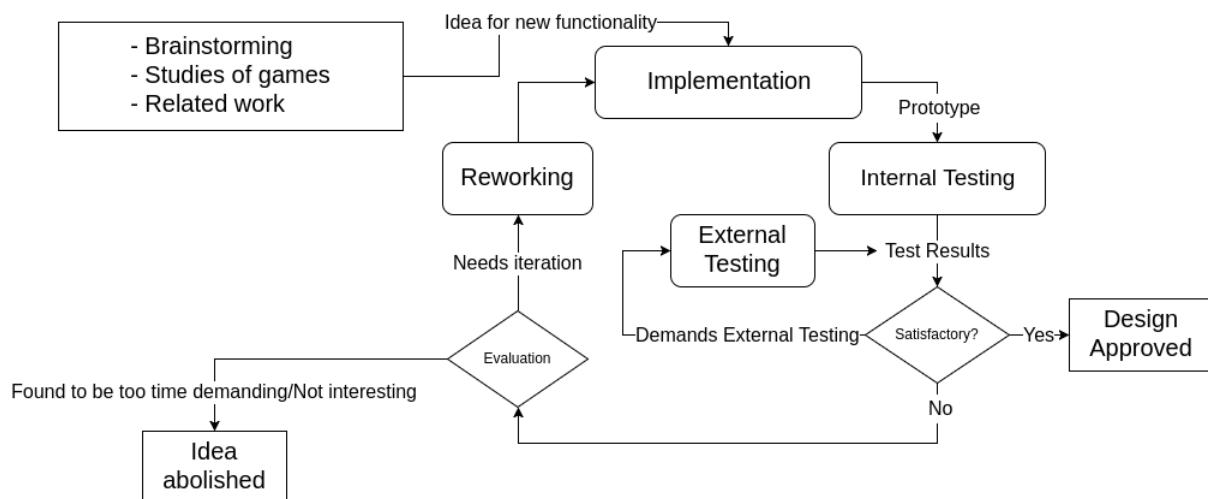
UE4's Behavior tree is event-driven, meaning that it does not run at all times. Instead it executes only when relevant information for the entity controlled by the Behavior tree is changed. Conditionals are used to control which nodes of the tree is executed. The main benefit of UE4's Behavior tree is the use of Decorators. Decorators are used to further enhance the logic capabilities of Conditionals. The way the Behavior tree is visualized makes the system easier to read and a programmer can easily debug if a node in the tree is not reached. In a traditional Behavior tree [37], Conditionals could be problematic because informations stored in leaves have to be manually managed to know which information is stored in each leaf. The Behavior tree used in UE4 can differentiate the information in the leaves quite easily. This is crucial when observing Decorators on critical nodes, especially when used in a system that is event-driven.

### 3.2 Workflow

Project work has to be planned, distributed and executed. It is also important to be able to share work between members of the project to enable work on different tasks simultaneously.

### 3.2.1 Iterative Workflow

An iterative workflow is usually designed as a loop which starts with the creation of an idea. The idea is implemented into a prototype which is tested internally. Tests are then done to show if the idea is satisfactory. It may also be necessary to test the implemented idea externally before it can be decided if the idea is valid or not. If the idea is valid it is finished; if it is not, the idea is evaluated. The evaluation finds if the idea should be discarded or iterated, i.e. reworked into a new idea. If the idea is iterated the process is repeated for the reworked idea. Theoretically, an idea can repeat this loop indefinitely until a satisfactory implementation has been created.



**Figure 3:** An iterative workflow.

### 3.2.2 Documentation and Version Control

A way for multiple people to simultaneously write different parts of the same text is to use online services, one such service is Google Drive [38]. Google Drive allows users to create documents which are shared online with other members of the project via Google Docs. Any number of people who has access to the document are able to edit it simultaneously. In Google Docs one may also add comments and suggestions about the text.

When sharing other types of work, such as code and images, an alternative is GitHub [39]. GitHub keeps a repository of shared files which each person whom the files are shared with keep a copy of on that person's computer. After a change is made locally a “commit” is created, this commit may be “pushed”, making it available in the GitHub repository. The repository keeps a timeline of pushed commits, enabling the possibility to revert back to an earlier version. People with access to the repository can “pull” changes which downloads it to that person's local files; what makes this efficient is that only the differences between the local files and the files in GitHub are downloaded, not the entire repository. GitHub also supports the use of “branches”. The branch which contains the agreed upon ‘correct’ version of the shared files is called the “master branch”. Creating a new branch from the master creates an individual version of the stored files in the repository. No changes made in a branch affect other branches until those are merged into a common branch. The use of

branches allows members of a project to have the same original files from which they make changes independently.

## 4. Process

This chapter presents how the project was realized. It describes the workflow of each individual part of the project such as how the board game, on which the created VR game is based, was selected. The content of each subchapter is described in a chronological order but as many of these chapters overlap each other in time the order of the subchapters is not chronological.

### 4.1 Research

Academic work has been acquired through searching in Google Scholar [40], Chalmers library [41], Semantic Scholar [42], IEEE Xplore [43], DIGRA [44] and ACM [45]. This search has been about the subject in general as well as finding specific information about board games. Finding information on VR and game interaction in academic reports and articles has proven difficult, specific information has instead been found in news articles on the internet and on webpages. These sources have in turn been found by following references from remotely related work and other web pages, as well as from using Google.

Methods used to learn how to use UE4 has included reading the engine's documentation [46], watch videos, both live and recorded on Twitch [47] and YouTube [48], and also by searching for answers about specific questions on the official forum [49]. This information has been enough to learn the basics of how to use the engine. To gain knowledge of ways other developers have implemented elements similar to those of interest to the project and to gain a general understanding of the gaming platform and its potential, VR games have been played and examined. These games have been made available to the project through its supervisors.

### 4.2 The Board Game Process

As a means to test elements of interest to the project in a controlled environment, a VR board game has been created. This game was based on an already existing board game, but was in no way intended to be a complete VR version of the chosen board game. In this chapter, it is explained which board game were chosen and how the choice was made.

#### 4.2.1 Selection process

One of the first stages of the project was to select what type of game was going to be created to help address the scope of the project. The process began with a brainstorming session resulting in several different ideas, which could be roughly divided into three different groups; sandbox [29], completely new games and already existing games. The concept of creating a sandbox game as well as the idea of creating a new game was discussed but, as explained in chapter 1.3.1, it was assessed to be outside of the project scope. The already existing games which were suggested to be the base of the implementation were of different types and genres. Some of the board games were: Concept [50], a creative picture game in

which you describe the characteristics of something without saying anything but keywords. Ascending Empires [51], a game set in space in which the player flick game pieces representing spaceships to new destinations. Zombicide [52], a board game where a varying number of players work together to complete an objective, while fighting endless waves of zombies.

The suggested board games were researched and tested before it was decided which game the created VR based implementation would be of. In this phase, it was defined which elements were important for the chosen game to include. These elements were:

- Cooperation
- Player vs. AI
- A tile based board
- Replayability
- Customizable ruleset

An important aspect of a VR board game was believed to be the interaction between players. Creating a game in which players cooperate to win over an AI rather than each other had the potential to increase this interaction. A game with a tile based board could use the limited tracking space of VR in a beneficial way by letting tiles be restricted by this limited area. Replayability, the value for the player to play the same game several times, is desired of a game to increase its longevity. This is often achieved by including random elements that affect the core gameplay. The game was also required to have rules which were easily customizable without altering its core elements. This would enable testing of new elements in VR by removing or adding rules. Among the games considered, Zombicide was the game which best met these requirements. Thus, the VR implementation created in this project, named BoardNight, is based on the already existing board game Zombicide. However, the intention was not for BoardNight to be a VR version of the game Zombicide, it was only supposed to be based on the same concept and game mechanics.

#### 4.2.2 Zombicide

Zombicide [52] is a board game in which up to six players work together to complete an objective while fighting endless waves of zombies. There are several different scenarios the player can engage in with different objectives and map sizes. The maps are tile based and players take turns completing actions such as moving, attacking zombies or searching for items. Players can choose from a range of different characters, all with varying abilities and attributes that can directly affect the outcome of the game. By killing zombies, the characters are awarded with experience points which eventually increases the character level and unlocks further abilities and attributes. As a character level up the zombies will spawn in greater numbers and tougher zombies will also start to appear. A full description of the rules can be read in the rule book [53].



**Figure 4:** The box of Zombicide and its associated game pieces. From: [54]. CC-BY-SA-4.0

### 4.3 Elements of Interest

Each element of interest has had its own way from discovery, investigation to conclusion. An explanation of the process of how these were discovered and investigated are therefore described individually. Some elements were given to the project as it started but most were found during the execution of the project. The main way of investigating an element has been to implement it within BoardNight.

#### 4.3.1 To Act as a Game Piece

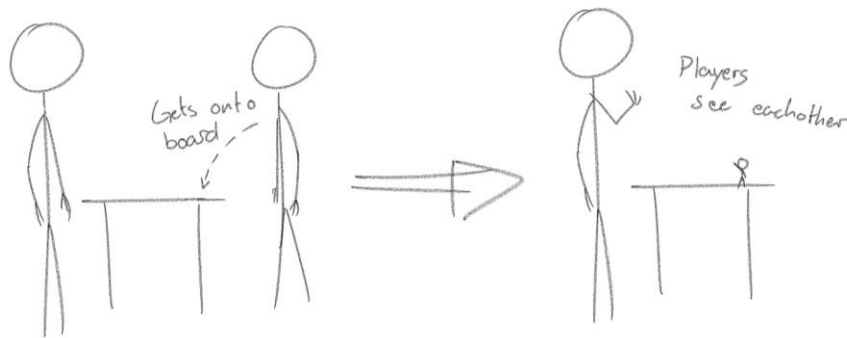
In a board game, the player is often represented as one or several game pieces on a board. The game piece may represent different things depending on what game is played. In Chess, the player is represented by multiple game pieces all which are controlled by the player, while in Snakes and Ladders [55] the player is only represented by a single board piece which indicates where the player may interact with the game.

A concept that was brought up during a gameplay session was to let the player actually act these events out themselves in the virtual environment by stepping onto the board as their representative game piece. VR would allow the player to do this differently than a regular computer version of a board game, since the immersion of actually being on the board would



be greater. The hypothesis is that this would augment the experience by allowing the player to be more engaged in the game.

The first way of attempting to achieve this was to shrink the player onto the game board. This was achieved by changing the world-to-meter scale of the player's in game avatar, which changes the scale of the world as perceived by the player. It also causes the player to appear as smaller or bigger from the point of view of other players. When using this method, the board on which game pieces are placed and the world into which the player is shrunk is the same. This way of acting as a game piece was the only version where both the player acting as the piece and the players looking at the board could all see each other. The shrunk player was able to see the other players as giants and the normal sized players could see the small player on the game board, rather than a game piece representing that player.

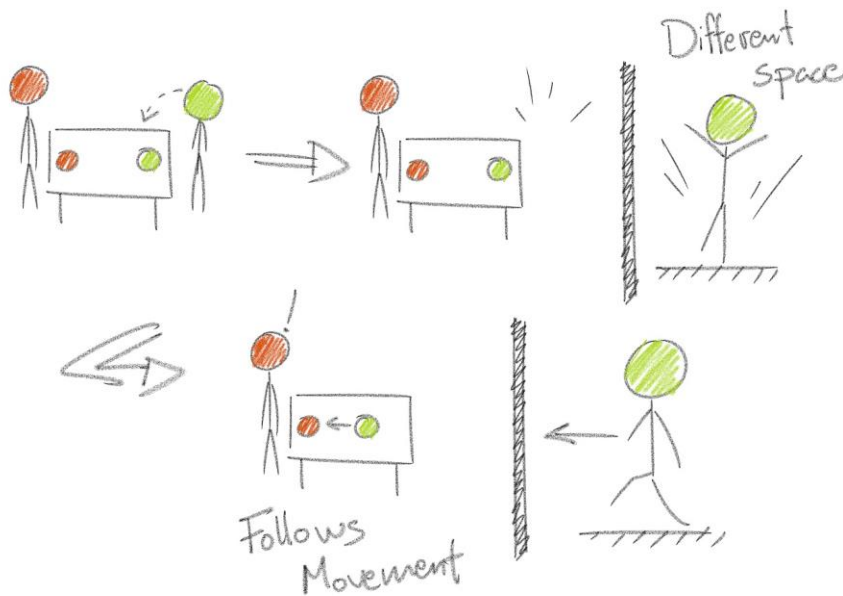


**Figure 5:** Early concept sketch of the first iteration of acting as a game piece.

This method, however, led to drawbacks. As the players were of different size they perceived the physics of the world differently. If the player were originally sized to stand next to the game board and shrunk onto it everything affected by physics, such as gravity, would appear to move faster than normal. A dropped object falls to the ground at a fraction of the time one would expect it to take. If instead it was reversed, with the board size being the original, players who were large would perceive physics as moving in slow motion.

The second version of letting players act as game pieces which was developed consisted of two boards. A normal sized board with regular game pieces and another representation of the same board scaled to the player's size. In this version, each player had a game piece on the normal sized board, when one wished to play as the piece, rather than take its place, they were teleported to the same place on the large representation of the board. The game piece on the original board then followed the motions of that person. This version allowed for flexibility of the appearance of the separate boards. Since the two boards were not the same they could have different level of detail. They still needed to be scaled relative to each other though. This caused problems as the game board needed to be small enough for players to reach everywhere on it and the large representation needed to be big enough for players to play comfortably on.





**Figure 6:** Early concept sketch of the second iteration of acting as a game piece.

About halfway into the project yet another version was created which was a modification of the later version. The aspect which was changed was that rather than having a game piece which followed the player on the regular sized board, the piece only represented which room the player was currently in. This allowed having two game boards that were not identical in scale to each other. As an example: a ballroom on the regular sized board could be just slightly bigger than a normal room, while in the large version it could be gigantic. There had been a problem with balancing how many and how big areas the board could have while still having all parts of the board reachable, which this version solved.

#### 4.3.2 Multiplayer

Board games can be played with a varied number of players but most of them require there to be at least more than one person. One of the greatest elements of traditional board games is the social aspect of several people playing together, usually gathered around the same table. The presence of this company is somewhat lost when transitioning to digital board games played on the computer, where you can usually only communicate through chat windows or by talking using a VoIP service. VR on the other hand could provide players with the possibility to be in the same virtual room as each other and to see everyone's movement and interaction with the game board, while potentially being in different parts of the world.

The process of investigating multiplayer in VR has consisted of gaining an understanding of ways it has been implemented in already existing VR games and to implement multiplayer in BoardNight.

There are many different ways in which multiplayer VR has been realised, both in pure digital form and as different hybrids between digital and physical games. Tabletop Simulator

VR [8] puts players in a virtual world, providing them with avatars and the means to manipulate the virtual environment using motion controllers. This approach is an approximation of a more traditional board game setting with players gathering around a game board and interacting with it using their hands, while at the same time augmenting the experience by allowing remote players to play together.

Games like VR The Diner Duo [56] and Home Improvisation: Furniture Sandbox [57] allow for crossover play between VR and non-VR users. This allows early adopters of VR to be able to play VR games together with friends and other people who does not have VR equipment.

Since different VR hardware have varying constraints and users have different sized play areas, a problem in creating a multi-user experience for VR is how to factor in these differences into the design. One approach is to design with only the most restricted setup in consideration, leaving out possibilities present in less restricted setups. Star Trek Bridge Crew is designed so that player avatars are always seated and immobile. In doing so, players with room-scale VR setups do not get to utilize their bigger play area, but everyone gets the same conditions for playing.

A second approach is to let players utilize their setups as they are, but provide in-game ways of smoothing out any differences. In Tabletop Simulator non-seated players can move around physically within their tracking space and move accordingly in-game. To allow for greater movement capabilities over a bigger in-game area, it is possible to teleport the avatar in the game world. This mechanic allows seated players the same in-game freedom to move as non-seated players, while at the same time not invalidating the strengths or weaknesses with one or the other.

A third approach is to use the asymmetries and design the gameplay around them, using them as a feature rather than a constraint. Mishra Sra et al. [58] presents a game design that utilizes asymmetries by having a role-based design. In their game, players can be either stationary shooters or mobile targets. Shooters shoot virtual snowballs at the targets and need not be mobile. The targets avoid being shot by ducking and moving around and thus need to be mobile. Such novel designs are interesting in many regards since there are also other asymmetric factors besides play area.

### 4.3.3 Interaction Between Players

Many VR games that support multiplayer uses avatars to give the players a presence in the virtual world. These avatars can look and behave very differently. In Oculus Social Trivia [59] the players are represented by orientation-tracked floating heads and there is no visible manipulation of the virtual world. Instead input is given through a menu individual to each player. Pool Nation VR [60] uses more elaborate avatars with motion-tracked heads and hands to allow for more open interaction with both other players and the game world, approximating face-to-face interaction. In BoardNight it has been of importance to

investigate the representation of the player avatars. This investigation has been based in related VR games and studies rather than user tests of BoardNight as such tests were not prioritised and could not be carried out until after the game supported a stable multiplayer.

Star Trek Bridge Crew [61] represents players with full body avatars while still only tracking the VR-headset and motion controllers of the player. This can result in a stronger immersion since the abstraction of a human player to a floating head and hands, while presenting the presence of a human, is still an abstraction. On the other hand there are some problems with representing parts of a player that is not physically tracked, as acknowledged by David Votypka of Red Storm [62], creators of Star Trek Bridge Crew. Since only a player's head and hands are tracked, other body parts have to be approximated to fit the tracked motions. This can result in some unnatural poses of the avatar.

To further increase the sense of presence among players in a virtual environment there are several different observations to be made. In a 2016 VRDC presentation held by Rob Jagnow of Google Daydream team [63], he stated some observations that he and his team had made during their time making VR-prototypes. According to Jagnow, players intuitively want to be able to touch each other when put in a multi-user VR environment. The use of haptics in motion controllers can give a tangible sense of physical interaction when two players clap their hands together or bump their fists. Another observation was that players seem to enjoy avatars having eyes that blink and looks around at points of interest, which also helps to increase the sense of presence and immersion.

Another source of information about interaction between players have been a study carried out by Sutcliffe and Alrayes at the University of Manchester [64]. This study separates interaction into three categories:

- Face-to-face interaction (FTF): individuals are able to interact with each other while also being able to see each other's faces and read body language.
- Symbolic interaction (BB): individuals interact only through acts and symbols such as in chatrooms or by e-mail.
- Represented-digital-interaction (SL): individuals interact by speech or written language while also being represented by an avatar in a shared digital space such as in the multiplayer game World of Warcraft [65].

While Sutcliffe and Alrayes investigates how well groups cooperates while using these different types of interaction they also measured experienced quality measures, environmental satisfaction and motivation. These measurements show that participants using FTF communication had a better experience regarding every measured aspect in comparison to those using the other methods of communication. This indicates that FTF communication, or something close to it, is something to strive for if one wants to improve the multiplayer experience for the user.

VR offers a fourth kind of interaction. Just as in SL the user is represented by an avatar in a digital space while the difference of also being in VR is that the avatar reflects the user's body

movements and in turn also their body language. This brings VR interaction closer to the preferred FTF. This would in turn augment the digital board game experience in comparison to games using BB and SL type of interaction.

#### 4.3.4 Asymmetric Information

In board games players usually have access to the majority of the same information. That is, most information about the game is shown on the board. Information that is separate between players is designed so that players can hide it from each other. The information that differ between players is called asymmetric. Asymmetric information was initially proposed as an interesting element by the project supervisor in the projects work description. Members of the project agreed that asymmetric information is indeed an element of interest to VR board games and as such it has been investigated from the very start of the project. By giving each player access to their own information players would need to communicate and cooperate to reach the goal. This means asymmetric information could be used as a means to promote teamwork. In VR, as all players are wearing different headsets with different screens and no easy way to look at what another person is seeing, one could easily design a game where players have access to individual information.

The kind of asymmetric information that was discussed was fog of war [66]. In the first version of fog of war that was planned, players inside buildings were meant to see only what happened in the tile directly next to them while players being outside could see two tiles away from their position. As a first step of implementation the fog of war was not built to take player position into account, instead all players were able see two tiles away regardless if they were outside or not. This version was meant to be updated but the work was not prioritised and as such no further iteration of the element have been made.

During initial planning of the fog of war there were also ideas about items that could affect the fog of war in different ways. An example of such an item is a flashlight, which would increase the player's line of sight, revealing tiles further away. Development of the flashlight was started; a model was imported and the necessary functionality were implemented but it did not work properly in a multiplayer setting. Other elements were prioritized and the flashlight was eventually cut due to time restraints.

#### 4.3.5 Interaction With the Environment

Because of how VR is constructed, a shared limitation for VR applications is restricted movement. The user has a set area to operate in, limited by the sensors' tracking space, which have different extent depending on what system is used and how much space is available for the user. This hindrance affects both how the user moves and interacts with the world in a negative way. During early development, there was an issue as users of the Oculus system were unable to pick up objects that had fallen to the ground, since they were not within the Oculus systems tracking space. Robo Recall [67] is specifically designed for the Oculus Rift and as such suffer the same issue with objects on the ground being out of the players reach. The developers of Robo Recall have solved the problem by letting the player grab any object

from afar. This does not only solve the matter of being unable to pick up objects on the ground but also provides a convenient tool for players who have a restricted play area. The idea was adapted from Robo Recall and was implemented into BoardNight as a solution to the problem.

Another way of interacting with the environment which was created was the laser-pointer. At first it was only supposed to help with interaction between players as a means to precisely point at objects in the environment. After the implementation of the ability to grab items from afar, it was realized that it was easier for players to control what to pick up by only letting them pick up items which they were pointing at with the laser. Therefore, the grab and the laser were combined in such a way that the player is only able to grab things far away by pointing the laser at it first. The laser is also used to interact with any button present in the game.

#### 4.3.6 Visualization of Information

It became clear early in the project that information cannot be visualized in VR the same way as it is in a regular digital environment or real life. This was mainly concluded as members of the project had their first experience of VR during the project's start. It was also validated continuously throughout the project as more already existing VR applications and games were used. No studies about this subject has been found, all data regarding the visualization of information were based on used VR applications and personal experiences related to the project.

There is not any generally established way of visualizing information in VR yet, instead most new VR applications have their own way of solving the matter. An example of this is HordeZ [68], a VR game which takes benefit from VR's ability to fuse physical and digital interaction by displaying weapons available to the player in spheres around the hand-controllers which are then chosen by physically moving your hand into one of the spheres. The amount of ammunition left in each weapon is visualised on the weapons model. Robo Recall instead chooses to adapt the conventional heads up display, HUD [69], from digital games by visualizing information directly on the player's screen.

After a few initial tries of visualizing information in BoardNight on the user's HUD, in a server browser and upon winning the game, this approach was quickly discarded due to the discomfort it caused the users. It seemed more reasonable to mediate information in a way similar to the real world, by having a lot of information displayed on objects such as cards or dices. Two problems with this proposal were soon revealed: The first problem was that objects in VR are not handled as easily as they are in real life. The second problem is the resolution of the headsets, which is not good enough for the user to be able to fast and easily read small texts. In order to give the user a comfortable experience, any text that is to be visualised in VR needs to be displayed not too close to the user and instead larger than it would have been in real life.

Information that needed to be visualized in VR but not in the original game was found during internal game testing. The main information that was missing were the ability to know whose turn it was and how many actions that person had left. When playing the regular board game, this information was easily told from player to player. In the VR environment, it became harder for players to keep track of the turn order and whose turn it was.

As a first step of implementation, when the basics of gameplay were created, a lot of information from Zombicide had been chosen to be left out. The information that was visualized in the first version of BoardNight was critical to gameplay. This information was: Player identification, turn indication, remaining actions, noise generated, and viable moves. Player identification is visualized by giving each player an individual colour and by colouring objects related to that player in that same colour. This is a widespread method of player identification used in both board and digital games. Turn, actions and noise information are all being displayed by floating text, placed relative to certain objects in the world. The importance of the text at this stage of the implementation is that it is accessible and readable. At first, tiles which the player could move to was displayed to the player by highlighting them in different colours. This was later removed as more elements were implemented and the game world became cluttered. Removing the highlights improved this issue. The second reason was that this information had also been embedded in the asymmetric information.

## 4.4 Implementation & Design

The implementation of BoardNight was the primary way of discovering and further exploring elements of interest. This section presents the process of creating the implementation as well as design choices that were made.

### 4.4.1 Unreal Engine

The implementation was created using Unreal Engine version 4.15. The decision to use this engine was made directly in connection with the projects start. There were two reasons for this decision with the first being that the engine was available to the project and it was presented by the project supervisor. The second reason was how the engine is designed which is explained in chapter 3.1.

As no member of the project had previous experience of developing in UE4 a lot of time has been used to learn how to use and to get familiar with the engine. It is a process which continued throughout the project as the engine is complex. One may know the basics to use and develop with it but there is still much expert knowledge to be learned. Methods used for this is described in chapter 4.1.1.

### 4.4.2 Movement

Player movement in VR is restricted by the used systems tracking area. This requires other methods of movement to be available in VR in addition to the users moving themselves. There are several solutions on how to move in VR which have been researched in this

project. The default teleportation present in UE4 is shown in *Figure 7*, which was used unaltered in the board view. Teleporting in this case refers to the ability to point at a place in the VR environment, and by pressing a button, be moved there instantaneously. When acting as game piece, in the action view, the player may teleport to other tiles, using up an action, as well as inside their current tile without spending actions. When it is not their turn they can move in the board view and in their current tile only. This way of moving causes the least amount of VR sickness but it also has negative aspects. Moving short distances and rotating is hard to manoeuvre; what players tend to do is teleport back and forth to get to their desired position.



*Figure 7: Unreal Engine 4's provided teleportation system.*

Another way to implement movement in VR is using joysticks on a controller, but this has a high risk of inducing motion sickness. In the final way of moving which was investigated the user move the controllers in a back and forth motion which in turn makes the the player move in VR. This method was tested at a VR-meetup. At the meetup, the user did not experience VR-sickness when moving forward but immediately felt sickness when turning.

A recurring problem which was encountered was that players of BoardNight were able to physically walk and look through walls which in turn enabled them to break the rules of the game. This often occurred when a player teleported close to a wall and could use the remaining tracking area to move into the wall. This is a problem since the headset does not have direct collision. A suggested solution was to stop the movement of a player's avatar for as long as that players were in an inaccessible area. This solution was reworked after a discussion with developers from Stenkross Studios [70]. Their input was to not lock a player's avatar in place as this could cause disorientation, but rather prevent that player from seeing and taking any action while in a restricted area. The suggestion was accepted but due to prioritizing elements within the project scope it was only partly implemented.

### 4.4.3 Artificial Intelligence

Zombicide, the game which BoardNight is based on, is a cooperative game where up to four players work together to complete an objective. If all players in a game are cooperating to achieve a common goal there needs to be another element in the game which serves as an obstacle and creates a challenge when trying to complete the objective. The obstacle in BoardNight is an AI in the form of zombies, with the following abilities:

- When all players have completed their respective turns, move one tile forward towards the tile with the highest noise, which is generated by players and weapons.
- If a player is in line of sight, ignore the noise and instead move one tile towards the sighted player.
- If in the same tile as a player, attack, causing the player to lose one health point.

At first the idea was to use the AI provided by UE4 and slightly modify it to fit with the rest of the implementation. However, the UE4 AI was realised to be more complex than needed for use in BoardNight and it was also difficult to learn. Instead of spending time learning to use the AI of UE4, an AI specifically made for the zombies in BoardNight was created from scratch.

The way the tiles are set up is that each tile has a number of connected tiles, which then have their own connected tiles and so on, resulting in an unweighted graph that could be used in a shortest path algorithm. The algorithm implemented does an exhaustive search, finding all possible paths without cycles and picking one of the shortest. Exhaustive search algorithms are simple to implement but as the number of objects computed increase the run time increase exponentially. This does not become an issue during this project since the level which has been created is small with few zombies and tiles.

### 4.4.4 Assests

In order for BoardNight to better give the experience of an actual game rather than only being a platform for testing augmentation possibilities it needs to have elements that improves the setting and atmosphere. Such elements include models, sounds and visual effects. To create such elements was not within the scope of the project, instead various materials included in the UE4 standard assets and materials licensed by creative commons [71] have been used. To find this material the web pages BlendSwap [72] and Freesound [73] were used.

In order to use a model downloaded from BlendSwap in an Unreal Engine project the model first has to be converted to the file format FBX [74]. After minor adjustments to the internal hierarchy of the elements within the model have been made the conversion can be done in Blender [75]. A full list of licenses to all materials used under creative commons license can be found in the project files.

Although it is beneficial for the project to increase the impression of the game as an actual finished game there is also a risk in doing so too much. Since the game is still under



development and is primarily used as a testing platform there is a possibility that a too well polished exterior would draw the attention of both developers and testers from augmentation possibilities to how the setting is made and how the atmosphere of the game feels [76]. To counter this, various elements of polish have been left out, such as a realistic texture on most of the models.

#### 4.4.5 Multiplayer

Initially it was intended for BoardNight to support online multiplayer sessions through Steam. Steam in combination with UE4 provided a quick way to implement wide area networking multiplayer, WAN. During development, WAN through Steam resulted in problems with connectivity which motivated the change of networking to be LAN only. These connectivity issues were probably the cause of insufficient understanding of Steam's multiplayer services and not the service itself. The use of LAN still allowed for testing and trying out most things that were, intended for the project. Session management was also initially intended to be more advanced, with the possibility to join available sessions from a server list. Due to limited time, it was chosen to limit this to only being able to join a local server under the assumption that there is never more than one session active in the LAN.

The development of an avatar capable of the intended multiplayer behaviour started early. The goal has been for avatars in BoardNight to feel both responsive and to be synchronized between all clients. Initially there were some problems with the avatars, with hands appearing duplicated in the game world and clients controlling each other's avatars hands, among other problems. This was eventually solved, but as all game elements had to be altered in order to work in a multiplayer setting the wait for a stable multiplayer avatar set back most other implementation for a while early on in the project. The avatars work by letting the movement of an avatar's in-game hands and VR-headset be updated locally at the controlling client. The movement data is sent to the server which multicasts it to all other clients, thus ensuring a synchronized state.

Since all features needed to be multiplayer compatible, a lot of effort went into redesigning and bug fixing every feature once it had been implemented and worked in single player. This slowed down the iteration cycles severely. Coming up with, designing and implementing a feature to a working state without multiplayer support almost always went smoothly and quickly, while redesigning it took considerably longer. When all project members were comfortable with developing features on their own and more work was made in parallel, which was the intended model, the limited availability of testing hardware and the fact that at least two people are needed to test multiplayer functionality properly became a major bottleneck.

## 5. Results

The project has two separate results, the game that was created to investigate the elements of interest and the evaluation of each element. The first result is the game's major mechanics and how elements are described without any association to the project's scope. Secondly it is presented how each element listed as being part of the scope is implemented in the game along with an evaluation of the elements ability to augment the board game experience using VR.

### 5.1 Implementation

The final game can be played by 1 to 4 players cooperatively over a local network. One player hosts a game from the menu and the rest of the players join to get connected to the same session. Once connected, players are spawned inside a room with nothing but the game board and the other players as shown in *Figure 8*. Players are represented by two hands and a VR-headset, in a colour unique to each player.



*Figure 8: The game board and two players interacting with each other.*

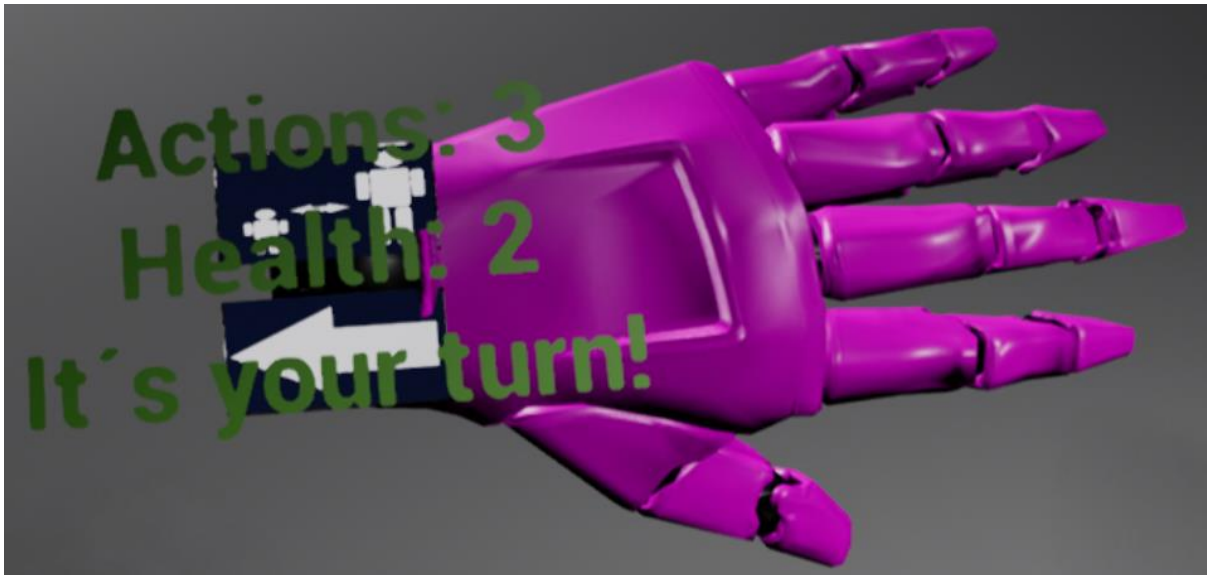
Players move around in the VR environment by using the default teleportation provided by UE4, which is further explained in chapter 4.4.2. Movement is restricted based on the game rules in such a way that players can only move between tiles on the game board during their own turn if enough actions are available. Moving between tiles costs one action, the cost increases by one for each Zombie present in the player's tile. Players can only move between directly adjacent tiles, one tile at a time.

When a player first changes perspective to the action view, a pawn representing that player will appear on the game board in that player's current tile. The pawn is a cube in the same colour as the player, as shown in *Figure 9*. If the player chooses to change tile the pawn will also move to that tile. The player can also choose to go back to the initial perspective, the board view, pick up the cube and place it on a tile which the player wishes to move to. Moving in this way follows the same restrictions as the players moving by themselves.



*Figure 9: The game board with three player pawns and a zombie pawn.*

By looking at the top of their left hand, players see an interface as shown in *Figure 10*, which displays how many actions the players have left for their turn, whose turn it is, and how many health points the player has left. There are also two buttons; one for ending the turn and one for changing between the board and action view. The buttons are interacted with by pointing the laser at it with the right hand and pressing the trigger.



*Figure 10: The UI on the player's left hand displaying actions, health and turn. Behind the text are the buttons for switching perspective and switching turn.*

There are several drawers and cabinets placed around the map which can be searched by the player for the cost of one action. When a container is searched, there is chance to find a melee weapon, ranged weapon or spawn a zombie. The melee weapon can be used to hit zombies in the same tile for a chance to kill it and the ranged weapon is used to shoot at zombie one tile away. Both hitting a zombie with a melee weapon and shooting at it costs one action.



*Figure 11: Two players in the action view while wielding melee weapons, surrounded by searchable containers.*



When on a tile that is inside a building, the player can only see zombies one tile away, this range is increased to two while on a tile outside. Which tiles are in line of sight is represented by ceiling lights or lamp posts lighting them up. Each tile also displays how many actions it costs to leave that tile and how much noise is currently generated in it. The default noise of a tile is zero, it is then increased by one for each player inside that tile and for every time someone uses a loud weapon. Noise is reset when the zombies have made their turn.



*Figure 12: A scene from the game board as seen while acting as a pawn.*

When every player has ended their turn, all zombies will do their actions simultaneously and then switch back to the first player's turn. During its turn, a zombie will first check if there is a player in the same tile as itself. If so the zombie will attack the player, causing the player to lose one health. Players start with two health, when a player's health reaches zero their current and all future turns will be skipped. They can still watch their friends play, but cannot do so themselves. If there is no player in the same tile as the zombie it will look for players within its line of sight, following the same rules as the player which means that if a player can see a zombie, the zombie can also see the player. If there is a player within sight the zombie goes one step towards that player, otherwise it takes one step towards the tile with the highest generated noise for the turn. There are spawn points at specific locations of the map that spawns between zero and three zombies at the end of each turn.

To win the game the players must complete the objective. The objective is to find a special container and loot the item within it, which must then be brought back to the tile where the players started.

## 5.2 Elements of interest

How each element of interest is utilised in the current version of the implementation will be presented individually along with opinions and, if found, related work on the element's ability to augment the board game experience.

### 5.2.1 To Act as a Game Piece

The way the player is able to act as a game piece is by teleporting to a large-scale representation of the board. The two views, one where users play by interacting with game pieces and the other where they do actions themselves, are separated in such a way that while being in one view the player cannot see or interact with the other. This creates active gameplay as players are constantly switching views while also interacting with the environment, objects and each other. This way of acting as a game piece does not mediate the feeling of being a game piece to the player. Instead the game board is interpreted as a representation of the large-scale view, much like a minimap [77] is used in other games, with the larger view being interpreted as the main game world.

### 5.2.2 Multiplayer and Interaction Between Players

Players are able to inhabit a shared virtual space as well as see each other's avatars and interact with the same world elements. A clear difference has been found between traditional avatars, which are represented by animations and control inputs, and avatars that is controlled by motion tracking. The sense of human presence is larger to the user as a new dimension of digital communication is achieved in the form of body language. During interactions in BoardNight players have been found using a lot of exaggerated body language to express themselves. As seen in Sutcliffe and Alrayes paper [64] users prefer face-to-face, FTF, interaction over communication through a traditional game avatar. As the multiplayer in VR is more similar to FTF interaction than normal game avatars the VR interaction has potential to augment not only digital board games but all digital communication.

Players can interact with each other by controlling their avatar, picking up objects, pointing an individual laser and taking actions in the game. The possibilities of the motion tracked avatar have already been covered. The ability to pick up the same objects as other players (as well as taking those objects out of other player's hands) creates a sense of players inhabiting the same world. It is therefore valuable as a complement to the multiplayer experience. The laser enables players to point at objects and locations. This type of interaction is of importance and it is also believed to augment the communicative experience. This is based on the frustration players expressed while not being able to point with the same precision as outside of VR, as a way of communicating in early versions of BoardNight.

### 5.2.3 Asymmetric Information

Asymmetric information is implemented in the form of fog of war [66]. Players are only able to see enemies in that player's immediate vicinity. The implementation of asymmetric information in a cooperative game is believed to encourage communication between players.

Whether or not to include asymmetric information in a game is argued to be a matter of game design rather than augmentation, but it did result in players communicating more when trying to figure out where enemies were. It is also argued that it is easier to implement this form of design in a VR board game, as it can be done in several more ways when created in a digital environment.

#### 5.2.4 Interaction With the Environment

The player is able to interact with the game world by picking up objects and taking actions. The player is given the ability to pick up items from afar. To give the players this ability makes them less limited by their VR systems' tracking area. It is also perceived as generally convenient. Therefore, this feature is an augmentation to VR games in general. It is also an augmentation of the board game experience as players are able to grab game pieces otherwise out of reach. Additional support for this conclusion is found in the VR game RoboRecall [67], from which the element originates. RoboRecall also uses long range interaction as a way to make up for the VR systems limited movement.

#### 5.2.5 Visualization of Information

Information is currently visualized by player colour and text. Player colour helps separating players from each other and it also provides a means to keep track of elements belonging to different players. As the player colour is represented both on avatars and board pieces, situations where there are confusion over which game piece belong to which player is avoided. This is a minor augmentation to the board game. Informative text in VR board games can be made more convenient than in physical ones. Examples include text only shown to specific players or text updating statistics in real time. These and other ways of visualizing text are augmenting the board game. The issue of text size is still present. Text in VR generally needs to be larger than in the physical world and therefore it can be hard to give detailed information in the form of text.

## 6. Discussion

In this chapter, the project will be discussed and evaluated with different viewpoints in focus. These viewpoints are firstly the results, how these were perceived and what conclusions could be drawn from them. Then the methodology, discussing if the right methods were used. Also, the validity of the project, how the project may be used for future works, and lastly if there are any ethical dilemmas with it.

### 6.1 Result

In BoardNight, we managed to implement the features that were needed for the purpose of this project, with which we are satisfied. The greatest achievement of the implementation is the multiplayer. A functioning multiplayer has been essential to be able to test game elements in a credible way, while being one of the most important aspects of the game and also by far the hardest to implement and maintain. All other game elements have been forced to revolve around the multiplayer and several additional work hours has been put into every mechanic to make sure it works when the game is played by several people at once. Looking at the implementation not as a means of exploring certain aspects, but as a full game there are plenty of improvements and extra features that would need to be added in the future. While BoardNight is playable in the way that was intended at the start of the project it is far from a finished game.

In BoardNight there is little reason for the player to leave the action view. This is because all actions can be made in this view and none are exclusive to the board view. The purpose of the board view is currently only to give players an overview of the board state and to provide a place to group up in the event that the players are spread across the map. This makes the game perceived not as a VR board game but as a VR game with board game elements. The line which defines how much a game may be augmented while still being perceived as a board game is vague. As a major part of this project has consisted of creating a platform for testing board game augmenting elements it is relevant to, as part of future work, make sure that this platform is also a board game. This can be done by switching the players focus back to the board view from the action view.

Interaction between players has been successfully tested in the implementation however there are parts of the element left out which have been discussed within the project but never made it to testing and implementation. This is mainly the representation of the VR avatar. There are still many questions left unanswered regarding how the avatar should be represented.

Visualization of information in VR is not covered to its full extent in the project and the projects result is lacking in this area. This is partly a consequence of how the implementation was built. There has been greater focus on producing a working prototype and testing platform than to make sure this platform provides a good user experience. As the way of creating good user experiences is different in VR than previously known systems there were no quick way of establishing a good basic user experience. A lot of focus was therefore put



on how VR was constraining the usual way of creating a user experience. It is believed that if a throughout study was to be made about user experience in VR it would be found not that it is restrictive but enabling in the way that entirely new ways of interacting can be made possible by the designer. An example was discussed in connection with the presence of a HUD in VR. While a HUD may feel unnatural in VR, hence restricting the usual way of visualizing information, it could potentially enhance the game immersion if it was presented as part of an interface on the visor of a helmet the player was wearing, as in the game *Metroid Prime* [78].

## 6.2 Methodology

The methods and tools that were utilized to realise the project worked well most of the time. They allowed the project to achieve most of what was set to accomplish. The working model with short iterative development cycles allowed us to always have something to work on, most of the time many things in parallel, while at same time allowing us the flexibility of trying out different ideas and solutions as they presented themselves. This model thus seems generally well suited for an exploratory project such as this. However, sometimes we had problems where our workflow broke down due to inconsistent availability to VR-gear. Of our two sessions with VR access per week, we did not always have access to more than two VR setups. When 5 people have different features that needs testing and two VR-setups are needed for each test, this becomes a severe bottleneck.

The iterative workflow and development was greatly facilitated by the use of Git [39]. Git allowed for parallel work to be coordinated and newly implemented or changed functionality could quickly be distributed to multiple computers for testing. This proved immensely valuable since testing needed to be done regularly and often in a multi-user setting.

The use of Google Docs [38] for writing and storing project documentation, such as reports, logs, time logs and compilations of resources have worked very well, allowing full transparency throughout the project for all participants.

Our method for examining and trying out other relevant games was perhaps not structured enough and a more thought through method for identifying and thoroughly testing games should probably have been thought out. Ideally, a list of games that seemed interesting in relation to our elements of interest should have been compiled early in the project. This could have resulted in a more efficient and rewarding process. We did propose the purchase of *Tabletop Simulator* [8] to our supervisor, but the time it took for us to receive it was well over two months which did not motivate further purchases. Instead we relied on watching playthroughs and other video material of games that seemed relevant, and most of the hands-on testing was with games that happened to be available to us.

UE4 turned out to be a great tool for the project and in building the game prototype a good deal of knowledge about VR, game design and software development was garnered. The fast learning curve of UE4 meant that the development of the game prototype could begin almost instantaneously and learning to use the engine happened in parallel with the project's progression. However, this rapid and less structured progression makes it harder to pick up on and utilize best practices and proper design structures. In the case of the game prototype developed for the project, many aspects would definitely have benefitted from a more complete early overview of the prototype constituents. Due to a lack of understanding and

misconceptions in regard to how certain things work in UE4 some implementation decisions came around and presented new problems later in the project. As an example, important gameplay functionality was split over both server and client instances in attempts to facilitate a fast iteration speed, as allowing clients to take care of much functionality by themselves is often faster to implement. Even though early testing of such implementations might seem successful, many times this presented further problems in later stages, with problems having to be solved in roundabout ways. In some instances, refactoring the problematic functionality when new knowledge arose could more definitively solve the problems. However, in some of the more fundamental underlying parts of the code, a rewriting was not viable due to the project's time constraints. Thus, the code base should, if it were to be expanded upon, be reworked with greater compliance to the different best practices that are suggested in for example the UE4 documentation [46]. The implementation of the game prototype could have been done using other tools than UE4. For example, the in many ways equated game engine Unity3D [79] could have been used. Unity3D provides much of the same or similar functionality as UE4 and is also free for non-commercial use. The choice was arbitrary and UE4 was suggested in the early stages and thus chosen.

### 6.3 Validity

As the project is exploratory in its nature the results of the project have low validity. There are no empirical data validating the statements that are made. Instead the results which are presented are based on project members' personal perception of the analysed data. If the project would be repeated and performed in a similar way by a different group the results would probably differ from those presented in this report.

To increase the validity of the project user tests would have to be carried out. The project has laid the foundation for such tests by providing a set of elements which could prove valuable to test. To develop and execute such tests is extensive, both work intensive and time consuming, thus being outside the project's scope.

Even though the results of the project are uncertain they could prove to be of use in more areas than those which are focused on in this project. To general board game design the exploration of asymmetrical information and the ability to carry out actions as a board piece could be of interest. Variations of these aspects already exist in games, examples include Stratego [80], which withhold information about a player's pieces to its opponent, and Flick 'em Up! [81], which is a board game where players executes actions themselves. Digital game design could benefit from the investigation of interaction between players. Face to face interaction is currently lacking in digital games and improving on this area could give a developer an advantage compared to its competitors. Finally, all VR applications are able to benefit from further exploration of what makes a pleasurable VR experience regardless of what game type that exploration is based on. Thus, any VR developer could benefit from presented views and opinions and also from achieving knowledge of which areas could prove valuable to test and explore further.

## 6.4 Future Work

Because of time constraints BoardNight was not fully realized in the timeframe of the project, neither was the investigation of potential elements of interest. Much more could be done in both aspects. Here some of the possible future developments for the project are presented, both in regard to BoardNight and the investigative effort.

### 6.4.1 Implementation

If BoardNight is to be presented as a complete game there are several aspects that need additional work. The current ruleset in BoardNight is rudimentary and only allow for crude gameplay. The absence of more intricate rules takes away some of the strategic considerations that make Zombicide a cooperative experience, such as trading of items and having characters with different abilities, which is a major part of the original game. Also, experimenting with original gameplay design ideas and custom rules would allow for creating a game that is more tailored towards utilizing the possibilities of the VR-augmented game design space.

Since BoardNight is very rough around the edges as it is now, it is not really approachable for new players unfamiliar to the ruleset and the gameplay mechanics. Only minimal hinting of valid moves and possible actions are provided and there is no tutorial or other kind of help. This unfriendliness is due to usability not being part of the original project scope, but future work would definitely demand an effort in streamlining the gameplay experience. In the same vein, proper session management through a lobby and server browser needs to be implemented to allow for online multiplayer to be managed in such a way that players can find and be able to play with their friends.

Visually and aesthetically there is much left to do to make the game feel intriguing and coherent with custom assets that removes the current stock-asset look and feel. Also, to facilitate the creation of more game levels, maybe even allowing players to assemble their own scenarios as well as allowing for house rules [82], developing some kind of level editor would be useful.

### 6.4.2 Elements of Interest

The investigation of different games and the resulting elements of interest could be made more thorough, allowing the identification of additional elements of interest. One way to approach this would be to test and examine a wider selection of games from different design spaces, possibly using a more structured method.

The points brought up in chapter 6.3 surrounding the validity of the project and its results should also be addressed. User testing of various aspects of the elements of interest would provide a better ground for evaluating the effects the different elements have on a gameplay experience, and possibly helping in finding new not previously considered elements.

## 6.5 Ethical

Not many ethical concerns regarding augmenting board games using VR were found since board games in general do not have many known ethical problems. However, there are some concerns with VR and thus with developing for VR.

The fact that it is so expensive for the average person could lead to problems in and of itself. If it rises in popularity and more developers turn to creating games and applications for VR, it could become one of the new mainstream platforms to develop for. However, due to how expensive it currently is, only a certain amount of people will actually be able to buy it. This in turns means that the user base would be quite small, and therefore require even more expensive games. This could lead to a divide between those people who can afford a system and its games, and those who cannot. It is problematic because VR would become exclusive to the richer population.

This could also be a problem that would solve itself before it even begun. As VR grows in popularity, more companies would create their own platforms and spend money on researching and developing cheaper and faster ways to produce VR-technology. This would lead to competition and innovation and cause the price of producing these systems to drop. So, by becoming more popular, it could also become more available to the average person.

Another problem that could occur, yet cannot easily be tested, is whether or not increased use of VR could become addictive. There have not really been studies done on large quantities of people regarding if frequent use of VR could result in some kind of addiction. There have been many stories created in which the concept of having complete control over an artificially created world leads to addiction and other mental illnesses, such as the concept of Holo-Addiction, introduced in the episode “Hollow Pursuits” of the TV-series “Star Trek: The Next Generation” [83], where the person prefers the Holodeck, a virtual holographically created world, over the real world. As of right now, this is most likely not a very probable issue to occur, since VR-sickness is such a common affliction, especially if a game is played for a longer period. It may be something to consider in the future though, if methods of preventing VR-sickness is invented.

So, while there is a longstanding fear of VR-addiction, this is all speculation and fiction since there has not been any tests done to see how common this would possibly be. There could possibly be a problem, which this project would then aggravate, but as of right now it is nearly impossible to tell for sure how big this problem would be.

## 7. Conclusion

We have arrived at six elements which we consider to be of interest when designing not only augmented board game experiences, but experiences in many different genres for VR. These elements are:

- *To act as a game piece*, the possibility of playing from the perspective of a game piece.
- *Multiplayer*, different ways of realizing multi-user gameplay.
- *Interaction between players*, possible ways of interaction with other players.
- *Asymmetric information*, giving players access to individual information to promote teamwork.
- *Interaction with the environment*, the ways a player can interact with a game world.
- *Visualization of information*, how to display different kinds of information in VR.

There are probably many other elements that could be of great interest to study in order to explore how they affect, or could be made to affect, gameplay in VR game designs. The elements we have investigated is by no means objectively more important than any others. Limited time had us choosing only a few.

If time had allowed, undertaking user studies and proper testing of different elements could have yielded more objective, and thus arguably more interesting and useful, results. However, this was not the case and as such the results are not to be taken as absolute truths, but instead as suggestions.

It is also not the case that the elements which have been discussed are necessarily to be considered as enhancements to game designs. As stated in the introduction, that which has been investigated are possible augmentations to board games using VR, in the sense that these elements could potentially provide new ways of implementing already existing functionality, such as online multiplayer instead of the demand of physical attendance.

## References

- [1] P. A. Piccone, "In Search of the Meaning of Senet," *Archaeology*, pp. 55-58, Aug 1980. [Online]. Available: <http://www.gamesmuseum.uwaterloo.ca/Archives/Piccone/index.html> [Accessed 25 Apr 2017].
- [2] O. Duffy, "Board games are back," *The Guardian*, 25 Nov 2014. [Online]. Available: <https://www.theguardian.com/technology/2014/nov/25/board-games-internet-playstation-xbox> [Accessed 25 Apr 2017].
- [3] Oculus VR LLC, 2017. [Online]. Available: <https://www.oculus.com/experiences/gear-vr/>. [Accessed 25 Apr 2017].
- [4] J. Matulef, "Valve is making three "full" VR games," *Eurogamer*, 10 Feb 2017. [Online]. Available: <http://www.eurogamer.net/articles/2017-02-10-valve-is-making-three-fully-fledged-vr-games> [Accessed 25 Apr 2017].
- [5] T. Howard, Interviewee, *Q&A: 'Skyrim' creator Todd Howard talks switch, VR and why we'll have to wait for another 'Elder Scrolls'*. [Interview]. 21 Nov 2016. [Online]. Available: <http://www.glixel.com/interviews/skyrim-creator-todd-howard-talks-switch-vr-and-elder-scrolls-wait-w451761> [Accessed 25 Apr 2017].
- [6] J. Petiz, D. Eriksson and S. Björk, "Augmented board games - Enhancing board games with electronics," Interactive Institute, Gothenburg, 2005. [Online]. Available: <http://www.digra.org/digital-library/publications/augmented-board-games-enhancing-board-games-with-electronics/> [Accessed 25 Apr 2017].
- [7] Å. Wikberg, Å. Ericson and P. Törlind, in *Design, process och metod*, Lund, Studentlitteratur, 2015, p. 125.
- [8] Berserk Games, "berserker-games.com," 2017. [Online]. Available: <http://berserker-games.com/tabletop-simulator/>. [Accessed 10 Feb 2017].
- [9] HTC Vive, "vive.com," 2017. [Online]. Available: <https://www.vive.com/eu/>. [Accessed 1 May 2017].
- [10] J. Barret, "Side Effects of Virtual Environments: A Review in Litterature," DSTO Information Science Laboratory, Edinburgh South Australia, 2004. [Online]. Available: <http://dspace.dsto.defence.gov.au/dspace/bitstream/1947/4079/1/DSTO-TR-1419%20PR.pdf> [Accessed 25 Apr 2017].
- [11] Epic Games LLC, "epicgames," 2017. [Online]. Available: <https://epicgames.com>. [Accessed 28 Apr 2017].
- [12] Epic Games LLC, "unreal engine documentation," 2017. [Online]. Available: <https://docs.unrealengine.com/latest/INT/Platforms/VR/ContentSetup/index.html#vrandsimulationsickness>. [Accessed 11 May 2017].
- [13] S. Laitinen, "Do usability expert evaluation and test provide novel and useful data for game development?," *Journal of usability studies*, vol. 1, no. 2, pp. 64-75, 2017.
- [14] P. Shotwell, "The Game of Go: Speculations on its Origins and Symbolism in Ancient Chine," 194. [Online]. Available: [http://www.usgo.org/files/bh\\_library/originsofgo.pdf](http://www.usgo.org/files/bh_library/originsofgo.pdf) [Accessed 25 Apr 2017].

- [15] ICv2, "Hobby Games Market Climb to \$880 Million," *The Business of Geek Culture*, p. #88, 20 Jul 2015. [Online]. Available: <https://icv2.com/articles/markets/view/32102/hobby-games-market-climbs-880-million> [Accessed 25 Apr 2017].
- [16] A. Curry, "Monopoly Killer: Perfect German Board Games Redefines Games," *Wired*, 23 Mar 2009. [Online]. Available: <https://www.wired.com/2009/03/mf-settlers/> [Accessed 25 Apr 2017].
- [17] GmbH Catan, "Catan," 28 Apr 2017. [Online]. Available: <http://www.catan.com/about-us/ludography/electronic>. [Accessed 28 Apr 2017].
- [18] Project Playwood, "Wartile," Mar 2017. [Online]. Available: <http://www.wartile.com>. [Accessed 28 Apr 2017].
- [19] O. Duffy, "High-tech Cardboard: The rise of digitally augmented board games," *arstechnica*, 5 Jul 2016. [Online]. Available: <https://arstechnica.com/gaming/2016/05/from-xcom-to-golems-cardboard-games-with-digital-brains/> [Accessed 25 Apr 2017].
- [20] BoardGameGeek, "BoardGameGeek - SpaceAlert," 28 Apr 2017. [Online]. Available: <https://boardgamegeek.com/boardgame/38453/space-alert>. [Accessed 28 Apr 2017].
- [21] BoardGameGeek, "BoardGameGeek - XCOM," 28 Apr 2017. [Online]. Available: <https://boardgamegeek.com/boardgame/163602/xcom-board-game>. [Accessed 28 Apr 2017].
- [22] M. Hill, "The Sega VR headset that never was," *gizmodo*, 2014. [Online]. Available: <http://www.gizmodo.co.uk/2014/11/the-sega-vr-headset-that-never-was/> [Accessed 25 Apr 2017].
- [23] W. Seibert, "Virtual Reality then: A look back at the nintendo virtual boy," *techspot*, 2015. [Online]. Available: <http://www.techspot.com/article/1085-nintendo-virtual-boy/> [Accessed 25 Apr 2017].
- [24] D. Heaven, "Virtual reality rises again," *New scientist*, 22 Jun 2013. [Online]. Available: <http://www.sciencedirect.com.proxy.lib.chalmers.se/science/article/pii/S0262407913615407?np=y&npKey=4e95ca9588a377e3ee40e5dcfb3233bd5aaa57070772ed6b0a6acdfd0613dbe3> [Accessed 25 Apr 2017].
- [25] Samsung, "samsung - gearvr," 2017. [Online]. Available: <http://www.samsung.com/global/galaxy/gear-vr/>. [Accessed 28 Apr 2017].
- [26] Google, "google - cardboard," 2017. [Online]. Available: <https://vr.google.com/cardboard/>. [Accessed 28 Apr 2017].
- [27] Sony, "playstation vr," 2017. [Online]. Available: <https://www.playstation.com/sv-se/explore/playstation-vr/>. [Accessed 28 Apr 2017].
- [28] Sony, "playstation 4," 2017. [Online]. Available: <https://www.playstation.com/sv-se/explore/ps4/>. [Accessed 28 Apr 2017].
- [29] Technopedia Inc, "technopedia," 2017. [Online]. Available: <https://www.techopedia.com/definition/3952/sandbox-gaming>. [Accessed 11 May 2017].
- [30] BoardgameGeek, "boardgamegeek - Mask Anubis," 2017. [Online]. Available: <https://boardgamegeek.com/boardgame/194723/mask-anubis>. [Accessed 11 May 2017].
- [31] Steel Crate Games, "keeptalkinggame," 2017. [Online]. Available: <http://www.keeptalkinggame.com/>. [Accessed 11 May 2017].
- [32] Epic Games LLC, "unreal engine documentation networking," 2017. [Online]. Available: <https://docs.unrealengine.com/latest/INT/Gameplay/Networking/>. [Accessed 11 May 2017].

- [33] Valve, “steam store,” 2017. [Online]. Available: <http://store.steampowered.com/>. [Accessed 11 May 2017].
- [34] Microsoft, “xboxlive,” 2017. [Online]. Available: <http://www.xbox.com/>. [Accessed 11 May 2017].
- [35] Helios Interactive, “heliosinteractive,” 2017. [Online]. Available: <http://heliosinteractive.com/project-artemis-ue4-multiplayer-vr/>. [Accessed 11 May 2017].
- [36] Epic Games LLC, “unreal engine documentation behavior trees,” 2017. [Online]. Available: <https://docs.unrealengine.com/latest/INT/Engine/AI/BehaviorTrees/index.html>. [Accessed 11 May 2017].
- [37] A. Davis, “what-could-possibly-go-wrong,” 14 Feb 2016. [Online]. Available: <http://www.what-could-possibly-go-wrong.com/fluent-behavior-trees-for-ai-and-game-logic/#conclusion>. [Accessed 11 May 2017].
- [38] Google, “google Drive,” 2017. [Online]. Available: <https://www.google.com/drive/>. [Accessed 11 May 2017].
- [39] GitHub Inc, “github,” 2017. [Online]. Available: <https://github.com/>. [Accessed 11 May 2017].
- [40] Google, “google scholar,” 2017. [Online]. Available: <https://scholar.google.se>. [Accessed 11 May 2017].
- [41] Chalmers Library, “chalmers library,” 2017. [Online]. Available: <http://www.lib.chalmers.se/>. [Accessed 11 May 2017].
- [42] Allen institute for artificial intelligence, “semantic scholar,” 2017. [Online]. Available: <https://www.semanticscholar.org/>. [Accessed 11 May 2017].
- [43] Institute of Electrical and Electronics Engineers, “ieeexplore,” 2017. [Online]. Available: <http://ieeexplore.ieee.org/>. [Accessed 11 May 2017].
- [44] Digital Games Research Association, “digra,” 2017. [Online]. Available: <http://www.digra.org/>. [Accessed 11 May 2017].
- [45] Association for Computing Machinery, “dl.acm,” 2017. [Online]. Available: <http://dl.acm.org/>. [Accessed 11 May 2017].
- [46] Epic Games LLC, “unreal engine documentation,” 2017. [Online]. Available: <https://docs.unrealengine.com/latest/INT/>. [Accessed 29 Apr 2017].
- [47] Twitch Interactive Inc, “twitch.tv,” 2017. [Online]. Available: <https://www.twitch.tv/unrealengine>. [Accessed 29 Apr 2017].
- [48] YouTube LLC, “youtube.com,” 2017. [Online]. Available: <https://www.youtube.com/>. [Accessed 29 Apr 2017].
- [49] Epic Games LLC, “unreal engine forum,” 2017. [Online]. Available: <https://forums.unrealengine.com>. [Accessed 29 Apr 2017].
- [50] BoardgameGeek, “boardgamegeek - concept,” 2017. [Online]. Available: <https://boardgamegeek.com/boardgame/147151/concept>. [Accessed 11 May 2017].
- [51] BoardgameGeek, “boardgamegeek - ascending empires,” 2017. [Online]. Available: <https://boardgamegeek.com/boardgame/37919/ascending-empires>. [Accessed 11 May 2017].
- [52] Guillotine Games, “zombicide.com,” 2017. [Online]. Available: <https://zombicide.com/en/>. [Accessed 11 May 2017].



- [53] Guillotine Games, “zombicide game rules,” 2017. [Online]. Available: <https://zombicide.com/en/game-rules/>. [Accessed 11 May 2017].
- [54] Stroug, Artist, *Composition de la boite*. [Art]. 2016. [Online]. Available: [https://commons.wikimedia.org/wiki/File:Zombicide\\_-\\_Saison\\_1.jpg](https://commons.wikimedia.org/wiki/File:Zombicide_-_Saison_1.jpg) [Accessed 25 Apr 2017].
- [55] BoardgameGeek, “boardgamegeek - snakes and ladders,” 2017. [Online]. Available: <https://boardgamegeek.com/boardgame/5432/snakes-and-ladders>. [Accessed 11 May 2017].
- [56] Whirlybird Games, “vrthedinerduo,” 2017. [Online]. Available: <http://www.vrthedinerduo.com/>. [Accessed 11 May 2017].
- [57] The Stork Burnt Down, “homeimprovisation.com,” 2017. [Online]. Available: <http://www.homeimprovisation.com/>. [Accessed 11 May 2017].
- [58] M. Sra, “Resolving Spatial Variation And Allowing Spectator Participation In Multiplayer VR,” in *UIST '16*, Tokyo, 2016. [Online]. Available: <http://dl.acm.org/citation.cfm?doid=2984751.2984779> [Accessed 25 Apr 2017].
- [59] Oculus LLC, “vrscout.com,” 2017. [Online]. Available: <https://vrscout.com/news/oculus-social-trivia-gear-vr/>. [Accessed 11 May 2017].
- [60] Cherry Pop Games, “poolnationvrgame.com,” 2017. [Online]. Available: <http://www.poolnationvrgame.com/>. [Accessed 11 May 2017].
- [61] Ubisoft, “ubisoft.com,” 2017. [Online]. Available: <https://www.ubisoft.com/en-US/game/star-trek-bridge-crew/>. [Accessed 11 May 2017].
- [62] A. Jem, “Shared Rooms: Designing Multiplayer VR,” *develop online*, 12 Dec 2016. [Online]. Available: <http://www.develop-online.net/opinions/shared-rooms-designing-multiplayer-vr/0227615> [Accessed 25 Apr 2017].
- [63] R. Jagnow, Writer, *Lessons Learned from VR Prototyping*. [Performance]. Google Daydream Lab, 2016. [Online]. Available: <https://www.youtube.com/watch?v=G295PAPzZX8> [Accessed 25 Apr 2017].
- [64] A. Sutcliffe and A. Alrayes, “Comparing User Experience and Performance in Second Life and Blackboard,” University of Manchester, Manchester, 2011. [Online]. Available: <https://pdfs.semanticscholar.org/0c54/f0e2b38220b6b96c4ffcdcaa2ff29aeb653b.pdf> [Accessed 25 Apr 2017].
- [65] Blizzard Entertainment, “worldofwarcraft.com,” 2017. [Online]. Available: <https://worldofwarcraft.com/en-us/>. [Accessed 11 May 2017].
- [66] S. Björk, “gameplaydesignpatterns - fogofwar,” 2017. [Online]. Available: [http://gameplaydesignpatterns.org/Fog\\_of\\_War](http://gameplaydesignpatterns.org/Fog_of_War). [Accessed 11 May 2017].
- [67] Epic Games LLC, “epicgames.com,” 2017. [Online]. Available: <https://www.epicgames.com/roborecall/en-US/home#recall>. [Accessed 11 May 2017].
- [68] Zenz VR, “zenzv.com,” 2017. [Online]. Available: <http://www.zenzvr.com/>. [Accessed 11 May 2017].
- [69] Technopedia Inc, “technopedia,” 2017. [Online]. Available: <https://www.techopedia.com/definition/1917/heads-up-display-hud>. [Accessed 11 May 2017].
- [70] Stenkross Studios, “stenkrossstudios.com,” 2016. [Online]. Available: [stenkrossstudios.com](http://stenkrossstudios.com). [Accessed 11 May 2017].
- [71] Creative Commons, “creativecommons.org,” 2017. [Online]. Available: <https://creativecommons.org/>. [Accessed 11 May 2017].

- [72] POIFOX, “blendswap.com,” 2017. [Online]. Available: <http://www.blendswap.com/>. [Accessed 11 May 2017].
- [73] Music Technology Group, “freesound.org,” 2017. [Online]. Available: <https://www.freesound.org/>. [Accessed 11 May 2017].
- [74] Blender Foundation, “code.blender.com,” 2017. [Online]. Available: <https://code.blender.org/2013/08/fbx-binary-file-format-specification/>. [Accessed 11 May 2017].
- [75] Blender Foundation, “blender.org,” 2017. [Online]. Available: <https://www.blender.org/>. [Accessed 11 May 2017].
- [76] O. Rexfelt, *Lectures from course UsabilityMMT031*, Gothenburg: Chalmers university of Technology, 2017.
- [77] S. Björk, “gameplaydesignpatterns - minimap,” 2017. [Online]. Available: <http://gameplaydesignpatterns.org/mini-maps>. [Accessed 11 May 2017].
- [78] Nintendo, “nintendo.com,” 2017. [Online]. Available: <http://www.nintendo.com/games/detail/metroid-prime-trilogy-wii-u>. [Accessed 11 May 2017].
- [79] Unity Technologies, “unity3d.com,” 2017. [Online]. Available: <https://unity3d.com/>. [Accessed 11 May 2017].
- [80] BoardGameGeek, “boardgamegeek - stratego,” 2017. [Online]. Available: <https://boardgamegeek.com/boardgame/1917/stratego>. [Accessed 29 Apr 2017].
- [81] BoardGameGeek, “boardgamegeek - flick em,” 2017. [Online]. Available: <https://boardgamegeek.com/boardgame/169124/flick-em>. [Accessed 29 Apr 2017].
- [82] J. W. D, “familygamenightideas.com,” 8 Aug 2014. [Online]. Available: <https://familygamenightideas.com/how-house-rules-can-enhance-your-board-games>. [Accessed 11 May 2017].
- [83] S. Caves, *Hollow Pursuits*, C. Boyle, Ed., 1990.