Master Thesis

Czech Technical University in Prague

F3

Faculty of Electrical Engineering
Department of Mathematics

# Food and Beverage industry in VR and how it can enhance the user experience

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Field of study: Open Informatics
Subfield: Human-Computer Interaction
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# Acknowledgements

I would like to thank my supervisor Ing. David Sedláček, Ph.D. for all the suggestions and support during the development process and writing of this thesis. I shall sing praises about his patience and benevolence when it comes to me keeping deadlines.

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Last but not least, big thank you to all anonymous contributors on the Unity forum sites and Internet geeks in general for sharing their wisdom.


# Declaration

I hereby declare that the presented thesis is my own work and that I have cited all sources of information in accordance with the Guideline for adhering to ethical principles when elaborating an academic final thesis.

In Prague, 10. August 2020

# Abstract

The main goal of this thesis is to look into culinary and drinking experiences in *Virtual reality* (VR). How we can achieve them and what impact it will have on us. Examination of the two main approaches, fictional flavours simulated during the VR experience and real food enhanced with VR features, was conducted and a review of current market solutions was performed.

Because eventually my goal is to prototype a multiplayer experience that can work on its own but is enriched with drinking, a simple examination of games and game mechanics was conducted too. As a results of the previous analysis and an example of their practical usage, a VR game was designed and its prototype implemented in Unity[1] game engine. Then it was successfully installed onto the desktop PCs with Oculus Rift S[2] headsets and evaluated by usability tests.

**Keywords:** Virtual reality, Food, Drinks, Board games, Unity, Oculus Rift S

**Supervisor:** Ing. David Sedláček, Ph.D.

# Abstrakt

Hlavním cílem této práce je podívat se zblízka na jídlo a nápoje ve spojení s *Virtuální realitou* (VR). Jak dosáhnout tohoto propojení a jak to ovlivní náš celkový zážitek. Byl proveden rozbor dvou hlavních přístupů, fiktivní jídlo a príchutě simulované počas VR zážitku a skutečné jídlo a pití přikrášleno o virtuální prvky. Spolu s tím jsem prozkoumala současná řešení na trhu.

Vzhledem k tomu, že mým cílem je udělat prototyp zážitku pro vícero hráčů, který může fungovat i samostatně, byl také vykonán stručný rozbor her a herních mechanik. Jako důkaz výsledků z předchozích analýz a příklad jejich praktického využití, design hry ve VR byl navržen a její prototyp realizován v herním enginu Unity[1]. Poté byl prototyp úspěšně instalován na stolní počítače s Oculus Rift S[2] headsety a otestován uživatelskými testy.

**Klíčová slova:** Virtuální realita, Jídlo, Nápoje, Společenké hry, Unity, Oculus Rift S

**Překlad názvu:** Jídlo a pití ve virtuální realitě a jak může obohatit uživatelův zážitek

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# MASTER'S THESIS ASSIGNMENT

## I. Personal and study details

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Department / Institute: **Department of Computer Graphics and Interaction**

Study program: **Open Informatics**

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## II. Master's thesis details

Master's thesis title in English:

**Food and Beverage industry in VR and how it can enhance the user experience**

Master's thesis title in Czech:

**Jídlo a pití ve virtuální realitě a jak může obohatit uživatelův zážitek**

Guidelines:

Perform a review of experiences in the Food and Beverage industry which take advantage of VR or AR technology. Describe mainly the way how they achieve the tracking. Summarize a list of hardware and software solutions and their alternatives that can most likely support these existing experiences.
Design a system, hardware and software-wise, that would allow multiple users interacting in VR to share a drink or meal while playing. Implement a prototype of the designed system focusing only on beverages that would let players select, order and consume drinks while participating in the rest of the multiplayer experience which serves as the main attraction.
Test the prototype on the target groups of clients in the location-based entertainment.

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Practical Augmented Reality: Steve Aukstakalnis, 2017, Addison Wesley


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Date of master's thesis assignment: **10.02.2020** Deadline for master's thesis submission: __________

Assignment valid until: **30.09.2021**

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## III. Assignment receipt

The student acknowledges that the master's thesis is an individual work. The student must produce her thesis without the assistance of others, with the exception of provided consultations. Within the master's thesis, the author must state the names of consultants and include a list of references.

Date of assignment receipt

Student's signature

# Introduction

Humans came a long way. Things that were not even Sci-Fi but pure Fantasy not that long ago are becoming reality today. Well, not real-reality we are not the gods yet, only a very dedicated bunch of scientist, engineers and businessmen.
However, real, virtual, augmented, mixed,... For us it's all just the same, another channel through which we can communicate, create, explore, exploit, learn, teach and entertain ourselves. VR already found its utilization in all the major industries including real estate, automotive industry, entertainment, healthcare, education, sports, art, marketing, military and my personal favourite tourism. Why personal favourite you ask? Aside from all the obvious reasons, tourism is right now in a nice stage where catering VR experiences of foreign places only baits the customer to go there in person if they are able to. Beautiful example of that is Thomas Cook's *Try Before You Fly*[3] campaign where customers get a 5 minute preview of various destinations around the world and based on that they can arrange for a holiday to their liking. They observed as high as a 190% uplift in New York excursion bookings. Now, what will happen if the difference between being there and just experiencing it remotely is redundant? Only time will show but it will definitely require some ingenuity from the tourism industry to stay relevant.
Looking closely at what makes VR so attractive to use in anyone's business, according to Finance Online's statistics[4] these are the top workforce development benefits of VR:

- facilitate training and mirroring real-life experiences
- provide information in real time
- enhance creativity in product design and development

- enable remote workforce to collaborate in real time
- allow users to live out someone else's life experiences
- capture novel user data like behaviour, eye and gesture tracking

Be that as it may, obstacles to owning VR technology are still there. Survey from 2017 by YouGov[5] noted that *"55% of US adults think VR products are too expensive. Other top concerns include apprehension about VR leading to isolation, a lack of quality games, and fear of health issues, such as motion sickness, fatigue, and nausea."* These are all valid concerns but VR technology stands for many different things and general public's familiarity with all its sides is not very strong. Depending on respondent's understanding and experience with VR technology the answers can differ quite a bit just like in this survey from 2018 (picture 1) by Perkins Coie[6] where it seems that respondents already had at least some contact with VR technology and thus negative user experience overruled even the price and next concern became the lack of quality and quantity of content offerings.

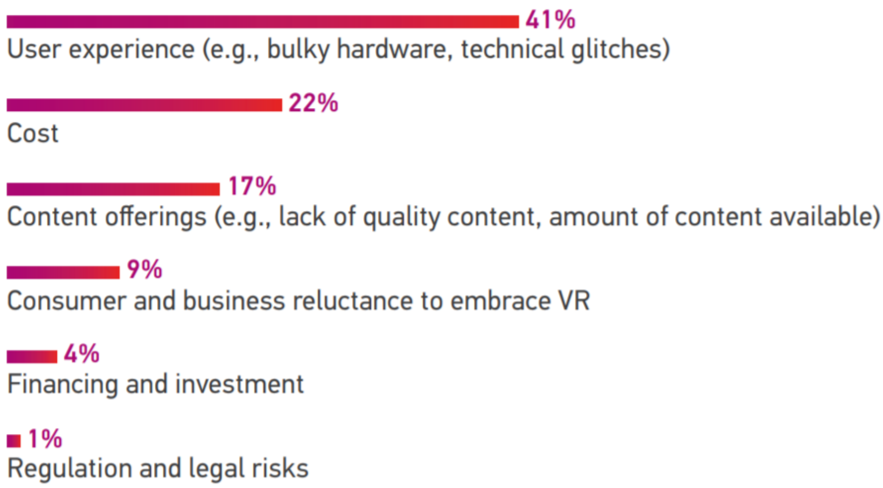



**Figure 1:** What is the biggest obstacle to mass adoption of VR technology?

However, let's not be pessimistic, these surveys are at least 2 or 3 years old and since then we saw a lot of improvements and news in VR sphere that are promising a bright future. I'm 100% sure that whoever saw Steven Spielberg's movie *Ready Player One*[6] won't be surprised when they see a VR headset, a haptic vest or even an omnidirectional treadmill.

The ultimate game changer at least for the VR entertainment industry came in May 2019 when Oculus announced its new all-in-one headset. With final name being Quest, easy setup, no wires, pleasing design and affordable price, it took the VR market by storm. That same year it outsold the PlayStation VR which held the top-selling place from 2017[8]. Let's put this into a perspective, the PlayStation brand had many established users for more than two decades, it had massive repertoire of titles while Oculus was basically a newbie in being a global gaming brand with only a number of titles available for Quest. And still even with a higher price tag it caught up with PlayStation VR and is going head to head with it since (picture 2).

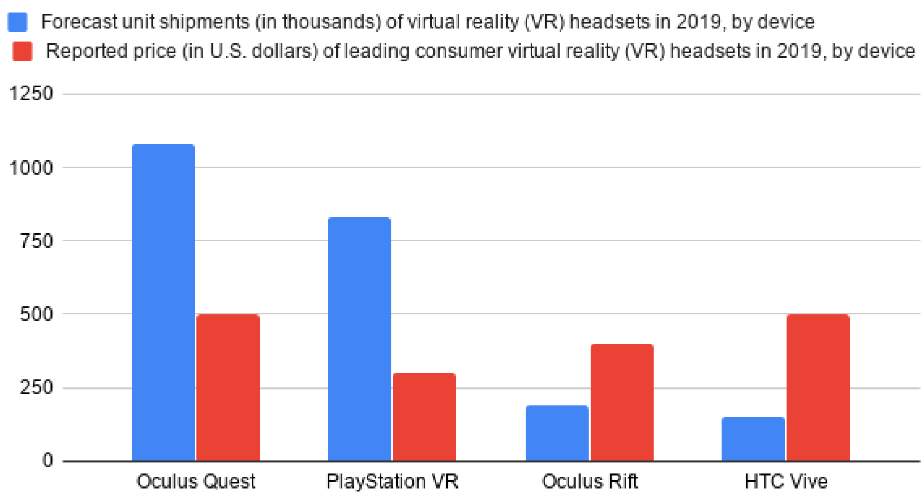



**Figure 2:** Combined statistics of reported price[9] and unit shipments[10] of popular 6 DoF VR headsets by Statista

With the recent situation of COVID-19 (second trimester of 2020), many industries struggled and although demand for in-home entertainment rose, the disrupted supply chains turned out to be quite a hurdle and so even the VR entertainment industry experienced a little setback[8]. On the other hand, for many developers it became a catalyst to dive into the depths of VR and create applications and services that help people deal with this unique situation. Interesting solution is e.g. *Spaces*[11] which serves as a bridge between a VR world and Zoom, Skype, Hangouts and more. Also, game titles that were released during the initial stages of the pandemic experienced a big profit because customers that already owned a headset or newly purchased it were happy to play with it during their newly acquired free time. In April 2020, the launch of *Half-Life: Alyx* saw nearly 1 million additional monthly-connected VR headsets to Steam platform over the prior month (picture 3)[12].

You might notice that I am plainly ignoring VR headsets and applications that don't have 6 DoF (Degrees of Freedom). These 3 DoF devices can be standalone such as *Oculus Go* or work in a combination with your smartphone such as *Google Daydream*. It's not because I disdain these headsets I believe they still have their place in the industry. I just got spoiled by repeated exposure to Oculus and HTC 6 DoF headsets and

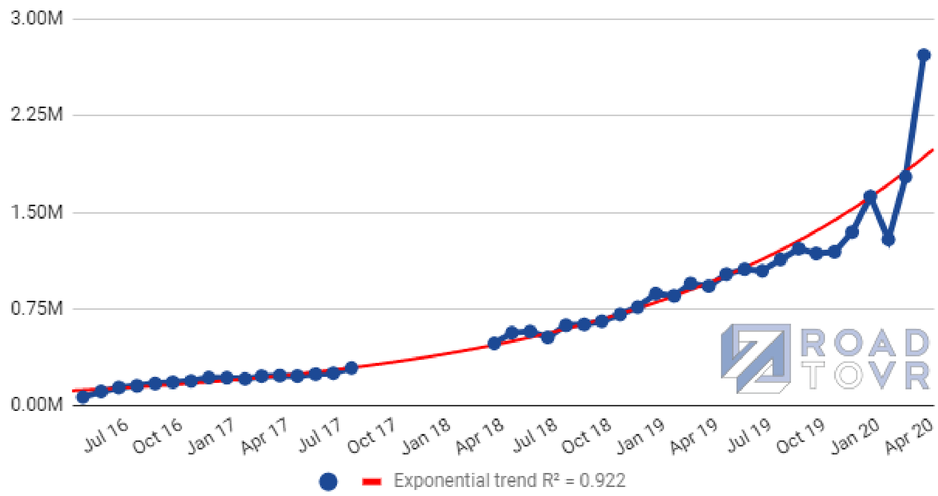



**Figure 3:** Monthly connected number of VR headsets on Steam (by number of headsets) - based on data courtesy Valve

can't go back even if I wanted to. So going forward you can safely assume that when I am talking about VR headsets it's 6 DoF headsets. Having said that, VR setups can consist not only of headsets and controllers but also of a collection of other gadgets such as aforementioned haptic vests or suits, omnidirectional treadmills, racing simulators, flying simulators and many more (picture 4).

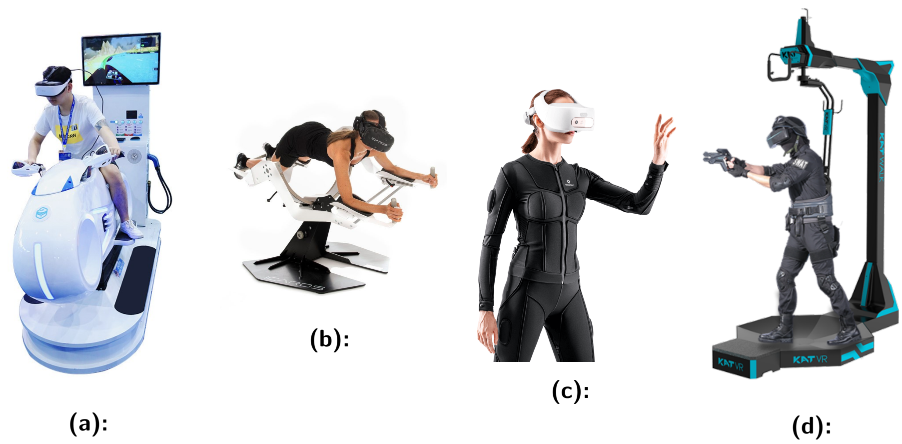



**Figure 4:** Few selected VR gadgets on the market: (a) Funinvr's VR Racing Moto[13], (b) ICAROS Health[14], (c) Teslasuit[15], (d) KAT Walk[16]

Clearly price of these gadgets isn't something that a regular consumer can afford (thinking that it will be used once a week at most), neither would he or she be able to service it so the only place where we can try them out right now is at a location-based entertainment(LBE) centers. Some of them organically adapted VR into their standing attraction lists (amusement parks) and some were strictly dedicated to VR since their establishment (VR arcades).

One thing to keep in mind is that a lot of these centers stage an elaborate environment full of decorations and things that add to the operational cost and a significant portion of LBE centers in the world rely on additional revenues to remain profitable[17]. For example, food and beverage sales, rentals, accommodation, souvenirs, grants, donations and others. The atmosphere and ambiance of the LBE spaces makes it worth it to the customer to come and pay some more because it creates a complete experience not just service. Otherwise they can just stay home and entertain themselves with something else (or even the same) on the Internet for far less or free. That's a typical problem of our age, you are competing not only locally or within your industry but with everything on the Internet too. The money becomes consumable and a dollar spend somewhere else is a dollar not spend at your place[19].

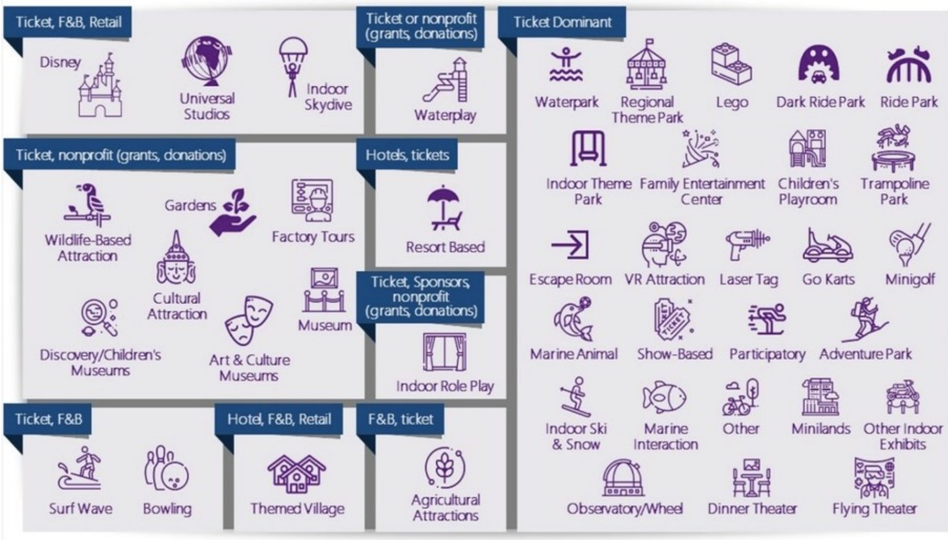



**Figure 5:** Attraction business models and their dominant revenue sources by The Park Database[17]

Here comes my motivation for this thesis. In summer 2018 I was walking in the town square in Bratislava (Slovakia) and saw a banner saying *"Virtual Reality Bar - VRBA"*[18] (vrba means willow tree in slovak language). To my big disappointment it wasn't a bar with people wearing headsets the whole time but a VR arcade that was offering hourly rent of VR headsets to share in a group of people and additionally you could buy drinks at the bar as a spectator. Despite my initial disappointment I quickly realized that those drinks were already an added value to a normal VR arcade (at least here in Slovakia and Czech Republic) or VR LBE in general especially if you want to organize a corporate team-building, game tournament or a plain old birthday party. I quickly forgot about this arcade but the idea of VR bar didn't let go of me and I started to concoct a plan on how to make it into a reality.

After reading up on it on the Internet and asking around I understood why no one attempted it yet. What I strove for was a free roaming multiplayer experience in a shared space with unpredictable occlusions and unguaranteed lighting conditions. The technology just isn't there yet or you would have to price it so high that it wouldn't be profitable anymore and quite honestly I am not skilled enough to pull it off. This meant I had to downscale my dreams and decided to "just" incorporate drinking and food into a game played by a small group of people around a table or in the comfort of their home.

This combination immediately reminded me of tabletop board and card games which are ideal for that. Another thing about board and card games is that they are enjoyed by young or old, male or female and sober or drunk. Which is the customer base of any LBE in a nutshell and although that doesn't seem like a big thing, I'm telling you, it is. Just as in any other industry, in video games business *what sells - that is being produced* and majority of digital games (over 70%) that are being sold fall into one of these categories: action, shooter, sport, fighting or racing[20]. However a lot of demographic groups enjoy a completely different types of games, it's just that these demographics are not usually seen playing video games.

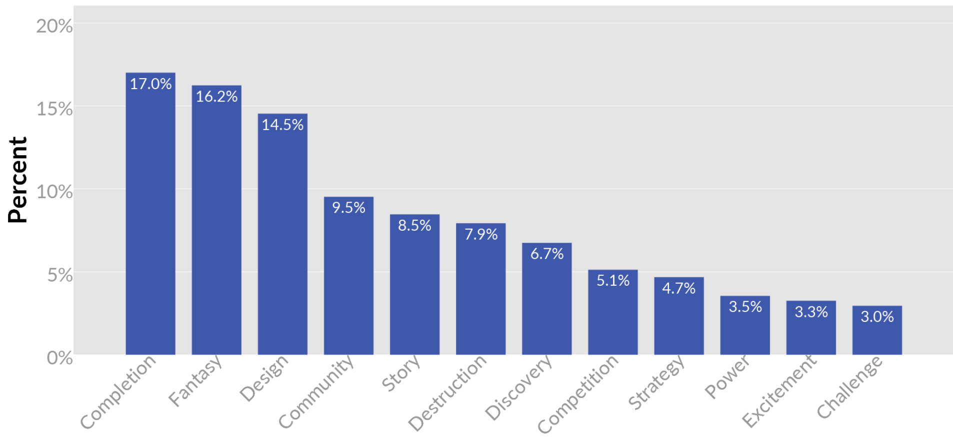



**Figure 6:** Primary motivation in games for females

In picture 6 we can see just one of many demographic groups, *gaming females in active age*, and their motivation to play. I, personally completely identify with this and I couldn't find any reasonable statistics or surveys on games that demographic groups hate but I think that is equally important. It's not that I would readily pay to play a shooter game if there isn't an adventure game. I simply wouldn't play at all and if you have a family of 4 going out, picking a group activity, it is very likely that one of them would behave just the same. Essentially, unless all want to play that particular game at least a little bit, no one will play.

And so my goal is to create a multiplayer VR board game where all these demographics can play together, chat and have a non-alcoholic or alcohol drink together.

# Chapter 1

# About VR

One of the factors that is adding to the misconception of VR is that a lot of product marketing campaigns bend, misinterpret and butcher terms such as mixed reality (MR), 360° interactive VR video or create a whole new catchphrases like *merged reality* even though there is already a perfectly good word for it.
In this chapter I will try to demystify VR, AR, MR, XR and some other terminology directly or indirectly connected to VR. You might be already familiar with them but this field is constantly evolving so try to stay on your toes. Afterwards I will list various methods on how to track physical objects in real world including the head-mounted display (HMD) itself and we will look at some interaction patterns to complete the picture.

## 1.1 Extended Reality (XR)

In the recent years, there is a frequently used term *Extended Reality*, which got popular quite quickly in the developers community also thanks to the game engine *Unity* and its XR plug-in framework[22] that aims to unite inputs from all devices and create a standardized communication between hardware (HW) and software (SW).
XR is an umbrella category that covers the entire spectrum from *the completely real* to *the completely virtual* in the concept of reality–virtuality continuum introduced by Paul Milgram(picture 1.1)[23], it also includes all human-machine interactions generated by computer technology and wearables. The 'X' in XR is simply a variable that can stand for any letter[24].

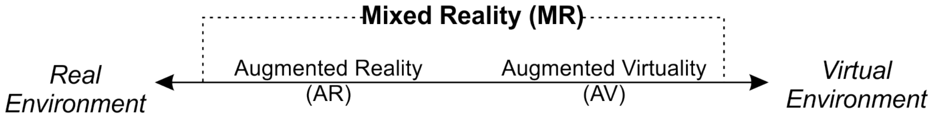
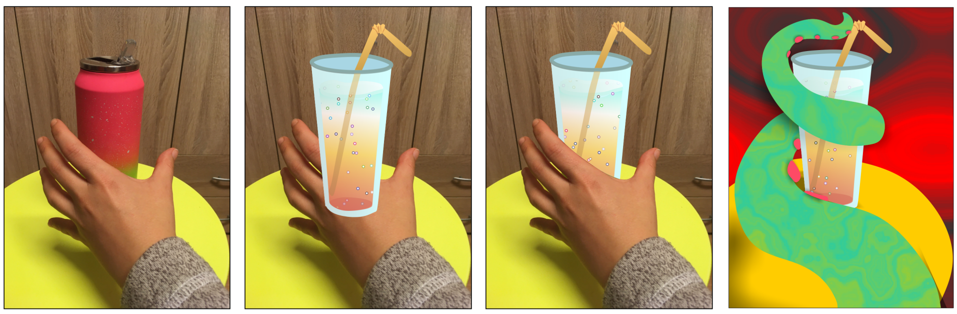



**Figure 1.1:** Reality–Virtuality Continuum *(author)*

The reality-virtuality continuum is an abstract concept which got adapted into the industry in these 3 distinct categories:

- **AR** is an overlay of computer generated (CG) content onto the real world (or a real-time stream of it). Crucial part is that AR objects are not aware of relations among the real-world objects and so the CG content is not able to respond to it. For example it can't detect visual occlusion between augmented content and real-world content.
- **MR** is an overlay of CG content onto the real world (or a real-time stream of it). In comparison to AR, augmented content can interact with objects in the real world. The most apparent interaction being the visual occlusion, the CG objects are visibly obscured by objects in the physical environment.
- **VR** is a purely CG content. It encompasses all immersive experiences starting from real-world content such as (interactive 360° Video), complete CG scenes or hybrids of both.



**(a) :** Reality **(b) :** AR **(c) :** MR **(d) :** VR

**Figure 1.2:** Reality and visual representatives of XR *(author)*

In conclusion, AR and MR are not the same, MR experience can be called AR but not the other way around.
There is a reason why majority of XR experiences is targeting visual augmentation. Not only is it the easiest one to enhance with the current technology and knowledge but vision is also our most dominant sense. According to Rosenblum's *See What I'm Saying*[25] we perceive approximately 83% of all impressions by means of our sight, followed by hearing (roughly 11%), smell, touch and the last one is taste.

## 1.2 Tracking and mapping for VR

Since VR without an interacting observer is nothing but a simulation, we need to insert a reference for the user's headset (camera view) and peripherals (usually controllers) into the space and track their positions. For this feat we can use various types of sensors and technology, depending on which physical law and phenomenon we want to take advantage of. Sensors record the signal when the real-world object moves or is moved and transmit the received information to the computing unit (middle device or computer). There we can use methods such as *Time of Flight* (ToF), *Time Difference of Arrival* (TDoA), *Angle of Arrival* (AoA) or even a simple *triangulation* to assess the position of the real-world object[26].
Here is a list of successful (not necessarily on the market) concepts:

- **Magnetic** tracking relies on measuring the intensity of the magnetic field in various directions. Let's demonstrate it in the 2D space based on the schema in the picture 1.3.

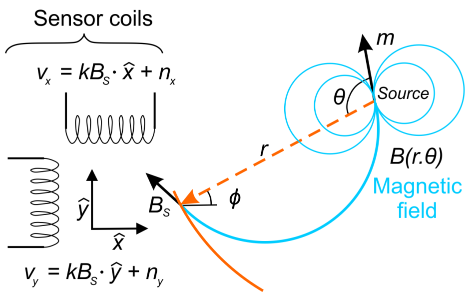


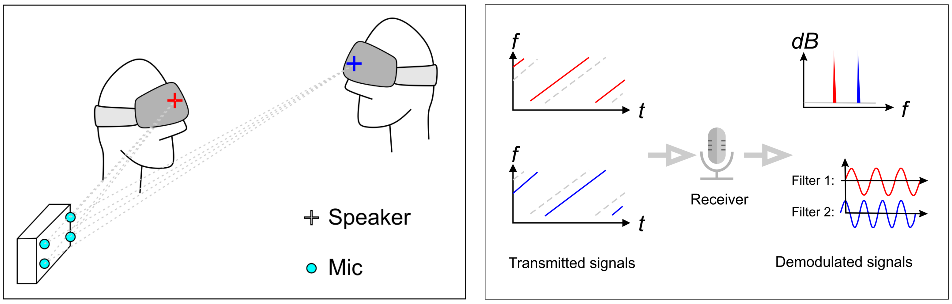

**Figure 1.3:** A 2D simplified EMTS (*author, based on the original in [27]*)

*"According to Faraday's Law, when a receiver sensor moves in the space inside an alternating (AC) magnetic field B(T), a voltage, proportional to the vectorial or cross product of the cross sectional winding area and the intensity of the magnetic field, is induced in every winding this producing N times the total voltage across the coils (being N the number of turns of the winding). This induced voltage immediately gives the measurement of rotation (θ) vs the reference emitter coils and the position (as the modulus of the resulting vector) in relation with the modulus of the emitting vector (r)."*[27]
An electromagnetic tracking system (EMTS) like this can accurately calculate position and orientation in 2D system but we can also construct one with base station generating direct current (DC) or pulsed DC excitation. Magnetic tracking has been implemented in several VR peripheral devices, such as the Razer Hydra[29].
EMTS's accuracy is very high especially in a controlled environments,

for example Hydra's specs are 1 mm positional accuracy and 1 degree rotational accuracy. However users have to be aware of the risk of interference from[30]:

- conductive materials near emitter or sensor
- magnetic fields generated by other electronic devices
- ferromagnetic materials in the tracking volume

- **Acoustic** or ultrasonic tracking measures the TDoA it takes a known signal to reach the known receivers. You either distribute multiple transmitters in the environment or vice-versa like it is done in MilliSonic tracking[32] in picture 1.4. The fundamental principle is that the system




**(a) :** single microphone array  **(b) :** TDoA at each VR headset

**Figure 1.4:** Concurrently tracking multiple devices with a single microphone array at a high per-device frame rate (*author, based on the original in [32]*)

has to be calibrated so that transmitters and receivers are aware of each other. When multiple transmitters or receivers are positioned on one rigid object, we can determine its orientation relative to the transmitters. Successful implementation of an acoustic tracking system was done for example by InterSense. Limitations of acoustic systems are[31]:

- susceptible to measurement error as a result of ambient noise, temperature, atmospheric pressure, and humidity
- often not very high update rates
- requires a direct line of sight between emitters and receivers

- **Inertial** tracking is commonly composed of these three orientation sensors:

  - **accelerometer** detects linear acceleration, it is also known as g-force acceleration. Calculation works based on these two laws: 1. the derivative of position with respect to time is velocity 2. the derivative of velocity is acceleration.
    So we first integrate the output to find velocity and then integrate again to find the position relative to some initial point. They are very cheap, but rather inaccurate.

- **magnetometer** doesn't really fall into this category but because it is closely interlinked with the other two sensors especially in mobile devices I've put it here. Magnetometer detects the earth's magnetic field. Usually it is used as a compass. Just like in magnetic tracking, it can be influenced by magnetic sources in close proximity.
- **gyroscope** in comparison to the accelerometer is more accurate at the beginning but its precision decreases with time. The angular velocity is derived from the Coriolis Effect. This multi-axis micro-electromechanical system (MEMS) uses vibrating mechanism but has the same operating principle as the mechanical gyro.

Depending on the quality of the manufactured sensors (they can be very cheap) we can expect smaller or bigger side effects of noise, drift or inaccuracy in the measured data. To somewhat counter errors in calculation from one another, a sensor fusion has to be used. In the picture 1.5 you can see Paul Lawitzki's algorithm [28] which is one of many ways how the outputs from these sensors can be merged.

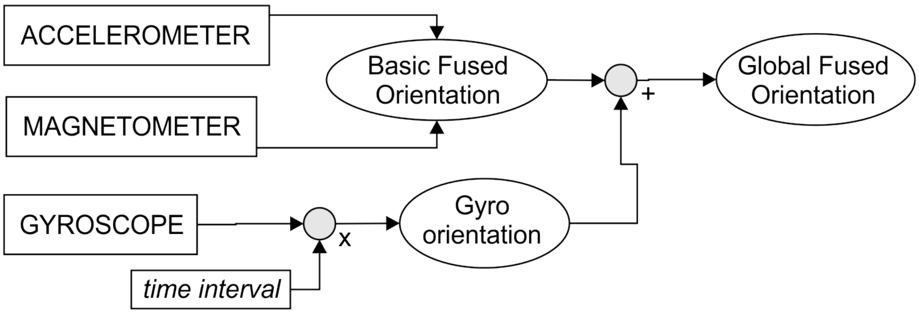



**Figure 1.5:** Paul Lawitzki's algorithm for sensor fusion (*author, based on the original in [28]*)

- **Wireless** tracking is sometimes called indoor GPS because it shares the same concept. Wireless tracking uses a set of Access points (AP) that are placed around the perimeter of the tracking space and a transmitter which triangulates its position based on the APs. In WiCapture[33] the headset transmits standard WiFi packets which are received by standard WiFi AP (picture 1.6). In each packet there is a metadata called Channel State Information (CSI) which encodes the transformation the environment has induced upon the transmitted WiFi signals. The CSI metadata is then processed to recover the position of the headset.
- **Optical** tracking has several methods of obtaining 6DoF of an object. We can make the process of tracking more efficient by introducing markers either on the tracked object or in the environment. Markers (picture 1.7) are typically high in contrast to themselves or to the environment and they can even contain additional data.

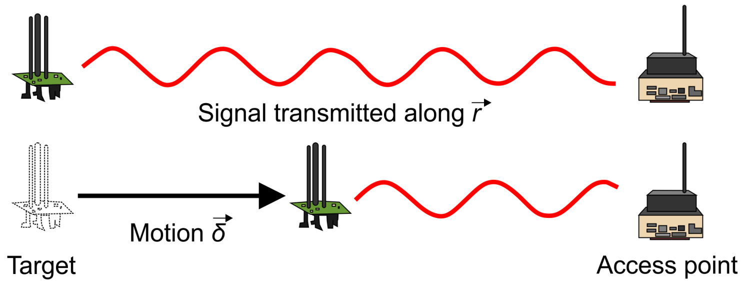
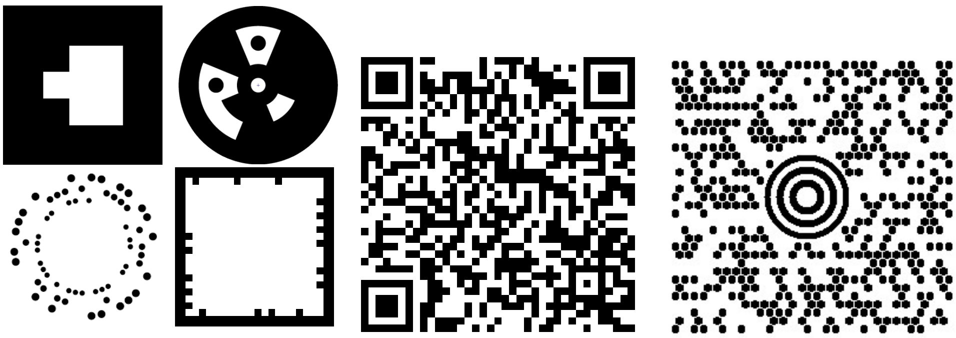



**Figure 1.6:** The change in the phase of CSI can be modeled in terms of the displacement of the target. WiFi waves in 5 GHz spectrum have 6 cm wavelength. So, even millimeter-level motion creates measurable phase shift. (*author, based on the original in [33]*)



**(a) :** Frame (fiducial) markers can vary depending on the SDK, here it is (left to right, top to bottom): ARToolKit, InterSense, RUNE-tag-129 and Vuforia (ID 0)

**(b) :** 2D-Barcode markers QR (Quick Response Code) and Maxicode (US Postal Service) used in industrial systems to carry data, these two say *"Master thesis: Food and Beverage industry in VR and how it can enhance the user experience,2020"*

**Figure 1.7:** Various markers (*author*)

*Marker-based tracking* or *markerless tracking*, they are both using different cameras and setups to obtain positional information but the main pipeline behind it (picture 1.8) is the same. It starts with acquiring image data (image frame) (A) and running it through numerous algorithms (B) like edge, corner or blob detection, Harris or Laplacian detector, Difference of Gaussians,... to determine dominant features in the received image. After extracting the features, they can be compared with features acquired in the previous run (frame-to-frame tracking) and object's established features (C and D). The rest of the process is about pose estimation and its refinement (E, F and G) until it is forwarded to the underlying system (H) and the whole pipeline will restart with the next image frame[35].
Another method to achieve optical tracking is with a depth map camera. A depth map camera, like the Microsoft's Kinect uses various technologies (structured light, ToF) to create a real-time map of the distances of

the object from the camera[30].
Optical tracking in general is quite robust, but it takes a lot of processing power. The potential complications are:

- low illumination and occlusion
- not stable and strong enough features or too many identical features

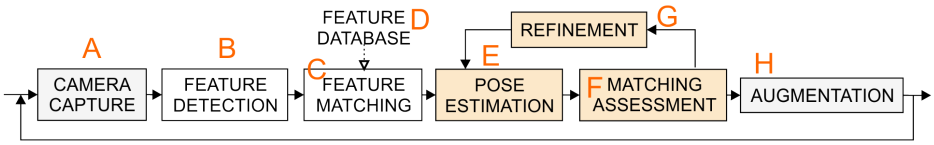
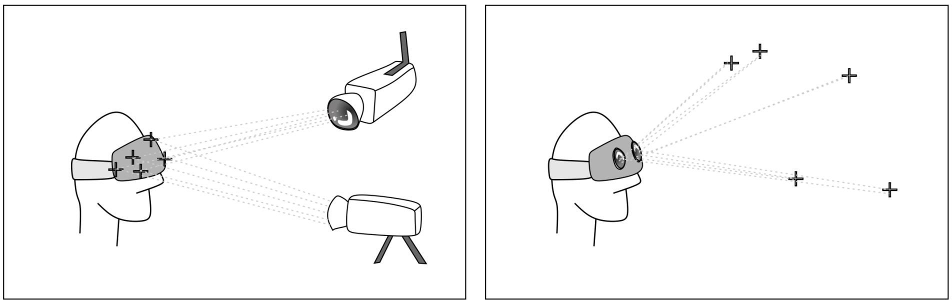



**Figure 1.8:** Optical tracking pipeline for markerless NFT (*author*)

There are two opposite approaches *Outside-In* and *Inside-Out* on how to setup and arrange the optical sensors.
Outside-in VR tracking uses cameras or other sensors placed in a stationary location around a designated area. Tracked object (e.g. a headset) moves freely in this area which is defined by the intersecting visual ranges of the cameras. The system usually needs room calibration after the cameras (or sensors) are put in place.
In the inside-out tracking, the camera or sensors are located on the device that is being tracked (e.g. HMD) and in a few occasions it needs special broadcasting devices placed in a stationary locations around it (also called base stations, lighthouses etc.).
Here are some VR HMD on the market categorized based on which optical tracking setup they use:

- **Outside-In marker-based:** Oculus Rift, PlayStation VR
- **Outside-In markerless:** (Xbox Kinect has some community solutions on how it can be used for VR)
- **Inside-Out lighthouse-based:** HTC Vive, Valve Index
- **Inside-Out markerless:** Oculus Rift S, Oculus Quest, HP Reverb G1 & G2, Microsoft HoloLens

In practice if we want to get a stable 6DoF tracking, we will typically use fusion of two or more technologies. The most prevailing combination so far is inertial with optical tracking.
Additionally we can improve the stability with *Predictive* tracking that takes the processed data and based on a set of algorithms estimates the next position and orientation in case of delay or incomplete data in the next loop of tracking[34]. Here are 3 regularly used predictive tracking algorithms:



**(a) :** Outside-In tracking **(b) :** Inside-Out tracking

**Figure 1.9:** Optical tracking, categorization based on setup *(author)*

- **Alpha-Beta-Gamma predictor** estimates both acceleration and velocity to use them appropriately in its prediction. It sacrifices noise reduction for exemplifying responsiveness.
- **Dead Reckoning** uses both the position and velocity at any given time to predict the next position. Assuming that both the last known position and velocity are correct and that the velocity remains the same we get a correct result.
- **Kalman predictor** is used to help reduce the sensor noise in systems where a mathematical model for the system currently exists.

## 1.3 Interaction patterns in VR

To create a pleasant experience whether in real life, on the desktop screen or in VR, we need to be able to easily and efficiently interact with the others, objects and the system itself. After playing some of the most popular games in VR, you will quickly realize that natural interaction and easy adaptation to the techniques is crucial for players to enjoy the game. This doesn't necessarily mean that the interaction has to be as in real life or that the player should have unlimited options, the chosen technique should fit with the problem player is facing in such a way that after repeated encounter the player will readily use the same technique with ease and won't even think about other ways to solve it.
When it comes to interactions there are usually multiple ways how to approach the same problem. I am sure you yourself can think of multiple ways how to e.g. open a normal real-world door and you probably actually used some of them too. You can be a normal sane person and use your hands, you can be a bit creative and use your feet if you are flexible enough, you can shout at your friend or family member to open the door for you, you can probably take the door apart and enter that way. In short if you don't have

any limitations there is literally unlimited amount of ways how to solve this. Now as a designer of your VR experience it is in your power to decide which ones will actually work because unlike in real life, if someone tries to blow the door up, the door's collider might just completely ignore the whole explosion (don't try this at home I swear your door has a functioning collider).
There are people who've spend a fair amount of time on this and managed to accumulate and categorize various interaction techniques into groups called interaction patterns. The similar traits of these techniques are considered from the user's point of view (e.g. using hand or feet is the same, it's still my body that has to interact with the handle but if I call a friend it will be someone else's limb and I just shouted however for the developer it would be the same because the door just has to react to someone's hand).
In these two sources [36][37](one is a university course the other is a book it was based on) it is proposed that these patterns should be further grouped into 5 overarching patterns: *Selection, Manipulation, Viewpoint control, Indirect control and Compound.*
In other words *Selection* as an *overarching interaction pattern* is a very generalized high-level interaction concept that doesn't reveal anything about how it will be implemented. Then we can decide that the objects that the player needs to select from will be out of his reach and so he should be e.g. *Pointing* when making his decision but that can be also done by different means so this is also an *interaction pattern.* Now, if we were to enable the player to point with his hand then that's already an *interaction technique* because we can clearly see how the interaction will be done (and probably even implemented). Here are all the overarching patterns, their branching-out patterns and even some examples of their techniques for illustration:

- **Selection patterns**
  - ⋆ **Hand selection** - Realistic hands, Non-realistic hands, Go-go technique, Clutching
  - ⋆ **Pointing** - Hand pointing, Head pointing, Eye-gaze selection, Object snapping, Precision mode pointing, Two-handed pointing
  - ⋆ **Image-plane selection** - Head crusher, Sticky finger, Lifting palm, Framing hands
  - ⋆ **Volume-based** - Cone-casting flashlight, Two-handed box (snap, nudge), Direct volume selection
- **Manipulation patterns**
  - ⋆ **Direct hand manipulation** - Direct application, Non-isomorphic rotations, go-go technique
  - ⋆ **proxy** - Virtual proxy, Tracked physical props
  - ⋆ **3D tool pattern** - Hand-held tools, Object attached tools, Jigs
- **Viewpoint control patterns**

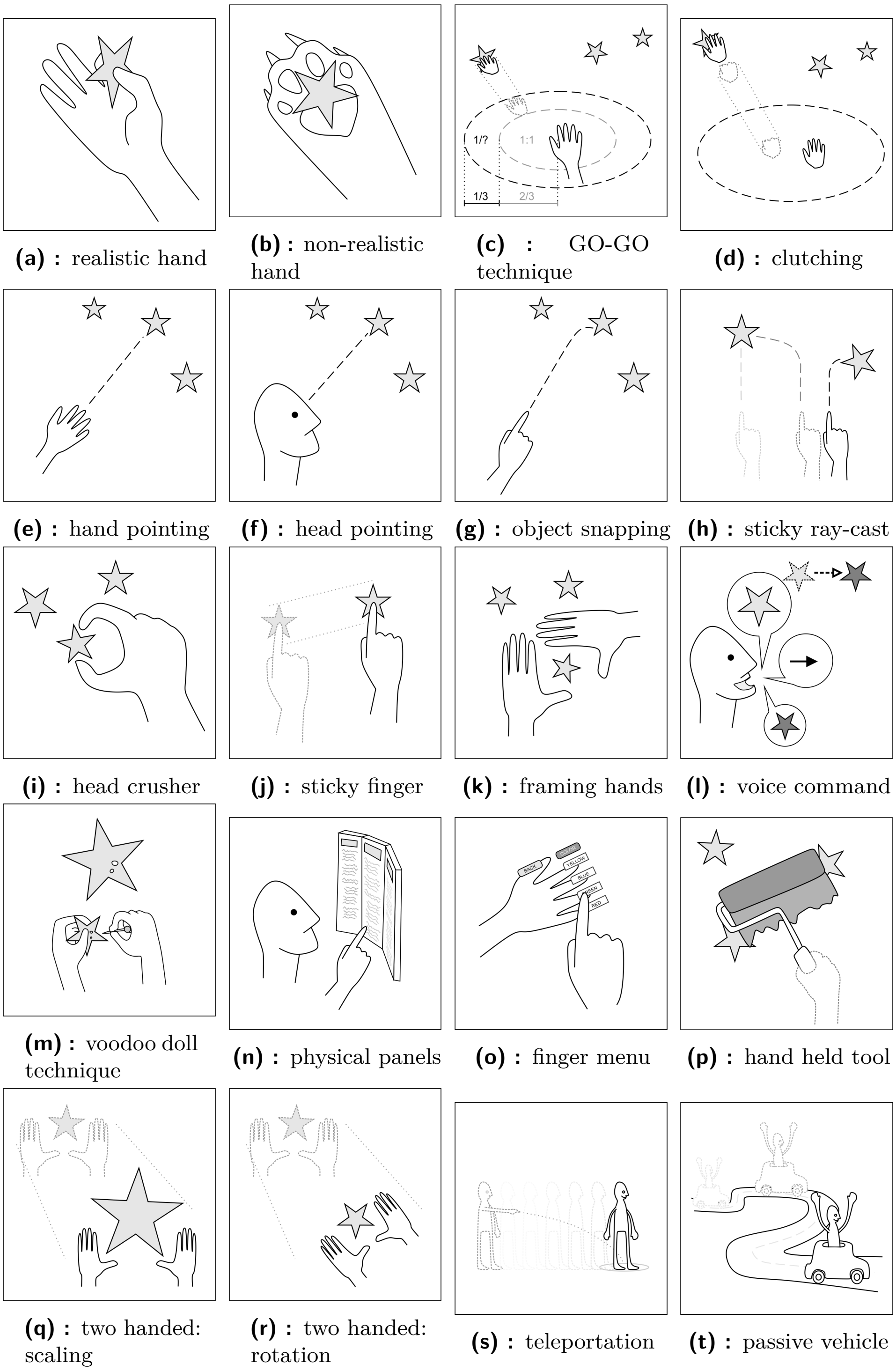
- ⋆ **Walking** - Real walking, Redirected walking, Walking in place, The human joystick, Treadmil walking and running, Hand walking
- ⋆ **Steering** - Navigation by leaning, Gaze-directed steering, Torso-directed steering, One-handed flying, Two-handed flying, Dual analog stick steering, World-grounded steering devices, Virtual steering devices
- ⋆ **3D Multi-touch** - Digital ArtForms' Two-Handed interface, The spindle
- ⋆ **Automated pattern** - Reducing motion sickness, Passive vehicles, Target-based travel and route planning, Teleportation

- **Indirect control patterns**
  - ⋆ **Widgets and Panels** - 2D desktop integration, Ring menus, Pie menus, Color cube, Finger menus, Above-the-head widgets and panels, Virtual hand-held panel, Physical panels
  - ⋆ **Non-spatial Control pattern** - Voice menu hierarchies, Gestures

- **Compound patterns**
  - ⋆ **Pointing hand** - HOMER, Extender grab, Scaled world grab
  - ⋆ **World-in-miniature** - Voodoo doll technique, Moving into one's own avatar, Viewbox
  - ⋆ **Multimodal pattern** - Immersive "put-that-there", automatic mode switching

Judging by the nature of the game I am designing, I should probably look into all the branching-out Selection patterns. However Viewpoint control patterns are very likely useless for me except for Automated patterns because my players will be very likely just sitting behind the table the whole time and moving only as a group.
There are also techniques such as Eye-gaze selection which is simply impossible for me because of the hardware's technical specs.
Also complex techniques where real hand is in a different position in comparison to the virtual hand should be considered very carefully because of the multiplayer aspect of the game. Just imagine players sitting behind the table, quite close to each other and when you reach out you suddenly touch someone's hand even though nothing should be there.

Because of everything above and also for easier game designing later on, I created an interaction alphabet (picture 1.10) for myself that consists out of interaction techniques that I considered useful for my game. There is a high chance that I will add onto it or remove some during the designing phase but for now it should cover all 5 overarching patterns except for Compound patterns.




**(a) :** realistic hand
**(b) :** non-realistic hand
**(c) :** GO-GO technique
**(d) :** clutching
**(e) :** hand pointing
**(f) :** head pointing
**(g) :** object snapping
**(h) :** sticky ray-cast
**(i) :** head crusher
**(j) :** sticky finger
**(k) :** framing hands
**(l) :** voice command
**(m) :** voodoo doll technique
**(n) :** physical panels
**(o) :** finger menu
**(p) :** hand held tool
**(q) :** two handed: scaling
**(r) :** two handed: rotation
**(s) :** teleportation
**(t) :** passive vehicle

**Figure 1.10:** Few selected techniques creating an interaction alphabet *(author)*

# Chapter 2

# XR in Food & Beverage industry

Believe it or not, XR technologies've already grazed the F&B industry. Although it's mostly just early-adopters, in high-end restaurants or academic papers, people try to take advantage of its potential.
Currently the biggest trends in F&B industry are mobile food orders, digital ordering kiosks and E-commerce in general. Having the digital menu in your pocket at all times and an option to pay for it through immediate online payment brings us closer (and faster!) to our meals. Now imagine that you can not only see the picture on the screen but also look at its virtual version 1:1 just like in this AR app *Before "I Do," See Your Wedding Cake* by Kabaq[38]? You could avoid so much disappointment over small portions or even better, you can see how to correctly eat this new foreign food that you've never heard of before and just had to try.

Most businesses are already painfully aware that unless you are *"on the Internet"* the customers won't find you. When trying out a new restaurant, it already became a standard to check its rating before even considering going in. However how can a restaurant get a good rating if their food is not good, it takes too long for them to serve you or the place doesn't look clean? To tackle all these problems and more the restaurant *honeygrow* in Philadelphia decided to create a VR training series with practical tests composed of VR games and 360° videos recorded in their location[39]. If you've ever worked at least a part-time job in the kitchen or some kind of fast food joint, you know that no matter how perfect your mentor is, he or she will accidentally miss something or even worse the place is so shorthanded and busy that your training got skipped and it's swim or sink time for you right from the start. There are many studies on how the job satisfaction rises with a proper training[40] and the trainees can practice on unlimited amount of virtual

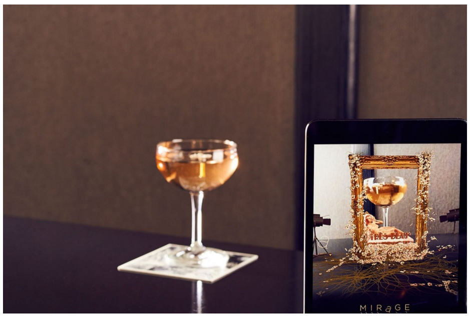
resources unlike in real life.
Apparently people have better and faster understanding of the process when they can try it first hand in VR in comparison to watching videos[41]. But it's not only about getting the right answers, sometimes it's more important to get exposed to all the various situations with a virtual AI-driven customer[42], come up with your own answers and see the consequences before you try it on a real customer.

Moving on from the backstage of F&B industry, in the following sections I will dive into XR experiences in research papers and experiences that the customers of bars, restaurants and other dinning places can experience either with real food, augmented or fully virtual.

## 2.1 Real F&B

Let's start with the easy stuff. Real food and drinks in XR experiences.
Imagine you own a small tasting winery. You can't very well compete with a well known or bigger wineries but you got a great idea, what if you incorporate into your tastings a 360° videos of the places where the grapes were grown and so the people who come to taste the wine will not only try a new taste but also better understand its unique origin. So exactly that, did the *Old Irish* beer brewery in their campaign *100% Real Virtual Reality*[43] but they took it to another level by hiring actual actors and surprising the viewer with the surroundings of an irish pub right after he takes off the HMD.
Similar experience is from *Immersion & Gunn*[46] where users can watch immersive video clips of the Scottish landscape while drinking two types of lager. These are not outliers, there is quite a big number of places that do this kind of complementary VR experience for their food or drinks. Another example is Michael Fawthrop's conjunction with Macallan[44], the world-renown Scottish distillery. The VR exploration of oak forests before landing at the Macallan distillery is part of a meal course and helps to paint the image of the Scottish nature and their distillery.
A more elaborate (and expensive) meal can food lovers experience at Japanese restaurant *Tree by Naked*[45]. This multi-sensory experience is divided into six chapters and one of them is in VR. Another VR dining experiences is *Aerobanquets RMX*'s culinary show which pushes the boundaries of interaction with the VR world even further by using hand-tracking and additional trackers for food "plates" (picture 2.1a)[47] which is almost the same as Royal Caribbean's special VR dining that has a similar setup but without additional trackers[48].
In case that this is still not enough you can spend a small fortune and invite your friends or family to a dinner at *Sublimotion*[49] where a chef with two

**(a) :** Aerobanquets RMX's culinary VR experience in 7 bites



**(b) :** City Social's Mirage AR app with interactive art pieces

**Figure 2.1:** Experiencing real food or drinks with XR technologies

Michellin stars will create a custom meal course for you with a technically challenging theatre show to pair it of (AR or VR you take your pick).

So far I was talking mostly about VR but AR is actually more common especially because of its ease of adaptation on mobile devices. Artistically pleasing one is City Social's *Mirage* AR app with menu of 12 unique cocktail drinks (picture 2.1b)[50] or Jose Cuervo's innovative campaign to show their history in your own bottle of tequila[50].

## 2.2 Augmented F&B

As I've mentioned at the end of the talk about XR (section 1.1), taste is our literally least impressive sense. Not because we don't use it everyday but because it never works alone. Our layman definition of taste is that it's what we experience when we eat but that is actually an orchestra of signals from various different senses. Taste in its full glory is not just sweet, salty, sour, bitter and umami flavours but a multi-modal sensation made up of chemical substances and involves the senses of smell, hearing, touch and sight which can all in turn influence the final taste. Research has shown that stimulating certain senses can lead to perception changes in others and this bi-directional relation was proven for taste with smell[51][52], vision[53], touch[54][55] and hearing[56][57] multiple times.

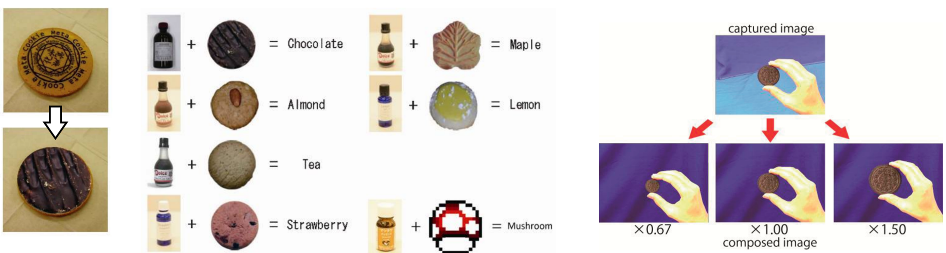
As usual everything has its limit and so each sense has its own constraints when it comes to digitization as we can see in the table 2.1[58]. Takuji Narumi from The University of Tokyo in cooperation with other researchers from Japan conducted a series of experiments that tested just how much vision and smell can influence the taste and our intake of food in general[59][60][61]. In one of his first experiments called *MetaCookie+*, he created an AR HMD with

| Sense | Limitations |
|---|---|
| Smell | Generation, storage and diffusion of scents<br>Synchronization access to olfactory displays<br>Scent alteration |
| Hearing | Lacks Integration of other senses<br>Foods without distinct sounds<br>Configuration |
| Taste | Small range of sensations<br>Lacks research with different viscosities, elasticities, adhesiveness, pH values, temperature, mixture of solids an liquids |
| Vision | Overwhelming perceived food proportions<br>Eating methods<br>Environment restrictions |
| Touch | Hardness range<br>Vibration locations<br>Display shapes<br>Lacks integration of other senses<br>Precise control of electrical stimulation<br>Lacks tongue and lips studies |

**Table 2.1:** Limitations of research involving the human senses

an olfactory display (basically a smell dispenser not a display in traditional sense) that could augment smell and the streamed picture of a cookie with additional visual toppings and seasoning (picture 2.2b) which tricked the user into thinking that the cookie is sweeter than it actually was or flavoured with a specific ingredient. The following year he published a research on how visual size of the food can influence our satiety (picture 2.2c). He says that 50% bigger size leads roughly to 10% less food intake and 30% smaller size than the original means 15% bigger intake.

Last year to elaborate on their previous findings with the MetaCookie+,




**(a) :** Original cookie

**(b) :** Combination of food flavours and appearances

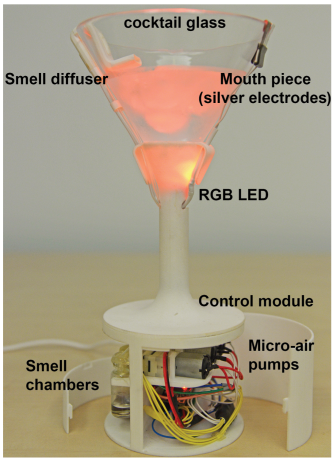
**(c) :** The result of scaling an appearance of a cookie

**Figure 2.2:** Tricking brain with smells and visuals

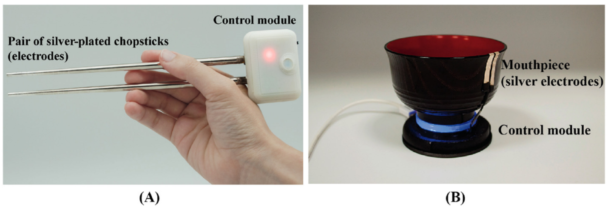
they created an AR HMD with interface using generative adversarial network (GAN)-based real-time image-to-image translation. This in a bit more words means that the image of the food that user perceived through the HMD looked different based on what they told the interface to show and it wasn't just a static picture overlay but it adapted real-time to the real world deformation of the food. This time without using any olfactory augmentation they successfully tricked the brain into perceiving a different taste than it should. The effectiveness seems to depend on the original and target types of food (broccoli into steak is a no-no) as well as the history of each individual with the particular food.
They are not the only ones who tried to alter the taste with XR visuals. In 2018 there was a research on tasting the same food in different visual contexts[62]. It appears that we consume food in environments that can *"spill over"* into our perceptions of the food. For humans some food is *unsuitable* for certain settings but when the food and surrounding settings match we enjoy the taste more by perceiving it stronger or more full.

Brilliant, now we know how to influence the taste by altering other senses but what about altering the taste itself can't we somehow trick the taste receptors? Hiromi Nakamura got inspired while exploring the ways how we could use our tongue to control a computer and created the *salt-flavored electric fork*[63]. When the person wants to get a taste of salt, all they have to do is press a button on the fork. This action will release an electrical current, which stimulates the person's tongue. As she herself stated, a traditional Japanese cuisine doesn't make you fat but because of the high saltiness it brings a risk of high blood pressure so this is not only a perfect solution but also prevention.
Another way how to augment the taste is by modifying the temperature of the surface of the tongue within a short period of time (from 25°C to 40°C while heating, and from 25°C to 10°C while cooling) and that is exactly what *Thermal Taste Machine*[64] does. When tested on people, they described the experience of 20 different known (taste and non-taste) sensations including sweetness, fatty/oiliness and warmness when rapidly heated and similarly for cooling, a mint, pleasantness and coldness.

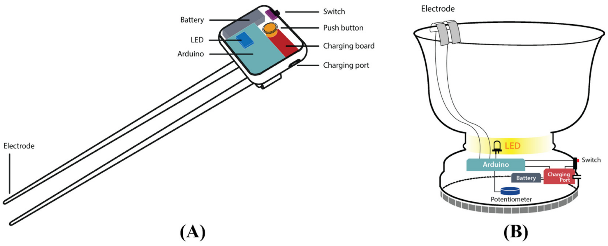
Last researcher on the forefront of augmented taste is Nimesha Ranasinghe and his team from the National University of Singapore who made a big contribution to this field. Starting with the *Spoon+ and Bottle+*[65] and also *Digital Lollipop*[66] from 2016 to *Virtual Lemonade*[67] in 2017 which had an added RGB light to change the color of the water based on the original lemonade, then continuing on with the *Vocktail* (picture 2.3a)[68] from the same year that had not only the taste and color augmenters but also an olfactory unit and finishing it off with two electric taste utensils: a pair of chopsticks and a soup bowl (picture 2.3b and 2.3c)[69]. In all their taste augmenters they use a similar system to Nakamura's electric fork




**(a) :** Vocktail (taste, smell, color) [68]




**(b) :** A pair of utensils: chopsticks and soup bowl [69]




**(c) :** The same utensils: architecture and technology[69]

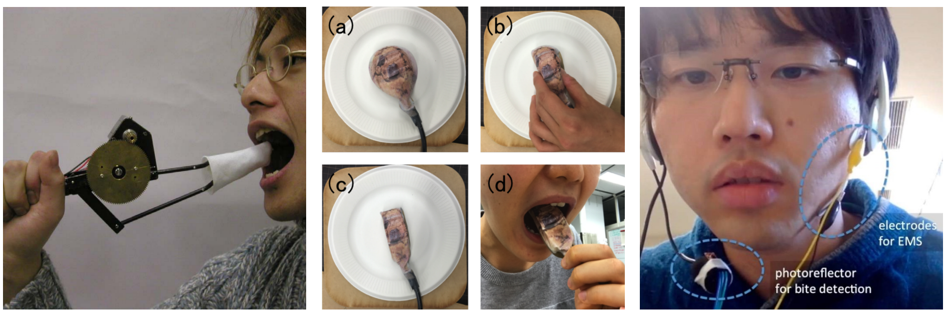
**Figure 2.3:** The two last projects from the National University of Singapore Vocktail and a pair of utensils

where a silver electrode recreates a flavour by stimulating the drinker's taste buds with a pulse of electricity. Their aim is not only allowing consumers with restricted dietary requirements to maintain flavour experiences without ingesting excessive amounts for them dangerous ingredients (e.g. products with high sodium content) but also being able to share that experience with others. This concept of digitally capturing, sending and reproducing flavour characteristics of foods and beverages can be achieved e.g. for a lemonade with as little as a PH sensor and an RGB colour sensor to capture the acidity and colour respectively. This opens up a whole spectrum of virtual multi-sensory dining scenarios.

I said that the last researcher was Ranasinghe and his team which is true but they are not the last group that is using science to modify the taste of food. A true last participant is *Project Nourished*[70] by Kokiri Labs, an XR enhancement for ingestibles which allows participants to experience eating and drinking in a transformative way by altering not only visual, gustatory and olfactory senses but also hearing and touch. There was more than 50 professionals in their respective fields cooperating on this, trying to solve problems such as reverse engineering what we hear in our head when we chew a certain food or how to imitate a texture of the food. Their solution to this is to use a flavour-neutral edible material like agar, a low-calorie thickening agent made from seaweed that is 3D-printed into the texture or shape of the food they want. Throughout the years they changed their motto from *"eat whatever and however much you want without consequences"* to *"eat what you could normally not"* to get attention of groups that actually need this. Currently the project is not running as of yet but they are promising more updates soon.

## 2.3 Virtual F&B

This category is a bit hard to fill if we want to create a truly virtual food. Not only we have to deceit all of our senses that what we are chewing is really what we think it is but... wait, *"what"* is already a problem. There are few ways how to avoid *"what"*.
First option is to use something like *Food Simulator*[71] to force feedback on user's teeth which directly changes the perception of texture. Second option is similar in a sense that we put something in our mouth that pretends to be food and this one is based on a pneumatic jamming system. By using jamming, a physical process by which particles become rigid when the density is increased we can emulate various food textures[72]. Our third currently known option is to use electrical muscle stimulation (EMS) to the masseter muscle[73]. Firstly we have to detect the biting motion and then send an impulse through electrodes to the muscles on our face to give sensations of hardness or chewiness as a user bites down. Beauty of this is that there really is nothing in the mouth but users feel as if they are chewing some food due to haptic feedback by EMS.
Now that that's solved, we are at our initial problem where we devised a treacherous plot, we convinced ourselves that we are chewing something and that something is what we think it is but there is nothing to swallow. So I guess that's one more problem on top of all the other ones to solve for the future scientists *"how to persuade someone that he had something in his mouth and that he already swallowed it although nothing of that sort happened"*. That's of course only if we want to fake an act of eating and not only tasting the food. Maybe the brain chips or hypnotism will be easier...




**(a) :** Biting with Food Simulator [71]

**(b) :** Pneumatic jamming system [72]

**(c) :** Electrical muscle stimulation [73]

**Figure 2.4:** Food texture through haptic technology

## 2.4 Summary of hardware and software solutions

Instead of just randomly listing hardware (HW) and software (SW) solutions, I will go through a list of possible use case scenarios and based on the existing or theorised technology in this chapter I will give my recommendation on HW and SW solutions.

- **XR campaign of a product that aims for masses**:
  - mobile AR app and AR marker on the product itself, it's cheaper because customers can use their own devices and directly share it on social media, there is a lot of out-of-the-box solutions when it comes to marker-based AR frameworks such as Vuforia[74]
  - VR 360° video of how and where it was made or another related script, requires specialized HW and SW to take and edit 360° video but it's memorable and wondrous thus good for any brand
- **complementary XR experience to eating or drinking**:
  - same as in previous category but I would advice to consider whether it's really necessary to use it because it can not only enrich the dining experience but also break it unless it's done flawlessly and also it is very likely that the price of the experience will rapidly increase
- **a whole culinary or drinking experience in XR**:
  - for interaction with food or drinks I would definitely recommend you to use hand-tracking (no one wants to hold the clunky controllers for that) e.g. Leap Motion[75] or the headset integrated hand-tracking (like the one on Oculus Quest) however to track the F&B there are 3 option that I know of:
    - ⋆ HW trackers on plates or beverage containers
    - ⋆ SW (probably an AI e.g. neural networks) recognizing more complex hand gestures (grab handle/grab food/release food/...) and guessing the position of the food and drinks based on that
    - ⋆ additional optical tracking setup for food and drinks most likely with markers or AI-driven SW for recognizing food itself e.g. machine learning (convolutional neural network)
- **magical XR science fair project with food or drinks**:
  - *salt-flavored electric fork*[63]
  - for more advanced *MetaCookie+*[59] with simpler olfactory unit

# Chapter 3

# Games

Before diving into our own project it's always a good idea to see what's already out there and because my task is to design not only a setup to eat and drink in VR but also play a game, that is what I should also look into. In the following sections, I would like to summarize what types of games are popular in both traditional medium and in immersive VR environment and list their strong points. For the traditional medium I've used a filter to select only those games that are similar to the game I want to design in the following chapter, especially in length, number of players, minimum recommended age etc. To have a nice variety I've picked 10 unique games and described them in greater detail. On the other hand VR domain is not yet diverse enough for that kind of filter so the common greatest denominator of the experiences I've picked is that they are all designed for the 6DoF HMDs.

## 3.1 Traditional board and card games

There is a surplus of great board and card games but to not get lost in them I've set up a few requirements or limitations if you will. First I've use 2 criteria:

- Number of players is 2 to 4 but preferably can reach up to 6 per game [↓/↑]
- Time to finish is less than 30 minutes (can reach 45 min on occasion) [T]

After going through almost 50 games (appendix B) suggested by my friends or family, coworkers, mentors and even children from my old high school (I have to stay up to date with the trends), I decided that I will need more constraints. Some of them were clear from the beginning but other ones emerged during the process of describing each game. Unfortunately, a lot of popular titles got disqualified even with the first 2 criteria because of the time it takes to finish them (e.g. Bang![76] or Carcassonne[77] see more of them in the table B.1). Here are the additional criteria:

- Minimum recommended age is at most 10 years old [A]
- All players finish together [F]
- The gameplay is scored and we can determine one ultimate winner (number of winners and losers) [W and L]

My top 10 choices are flagships of their genre or have a unique gameplay (table 3.1). This time a lot of titles got disqualified because players get eliminated during the game or they win but the others are still playing (e.g. UNO[78]).

| **Name** | **A** | $\downarrow$ | $\uparrow$ | **T** | **F** | **W** | **L** |
|---|---|---|---|---|---|---|---|
| Sets[79] | 10 | 2 | 8 | 30 | T | 1 | n-1 |
| Sushi Go![80] | 8 | 2 | 5 | 20 | T | 1 | n-1 |
| Colt Express[81] | 10 | 2 | 6 | 30 | T | 1 | n-1 |
| Kingdomino[82] | 8 | 2 | 4 | 20 | T | 1 | n-1 |
| Snakes and ladders[83] | 4 | 2 | 4 | 30 | T | 1 | n-1 |
| Dominion[84] | 10 | 2 | 4 | 30 | T | 1 | n-1 |
| Pexeso[85] | 5 | 2 | 6 | 15 | T | 1 | n-1 |
| Timeline inventions[86] | 8 | 2 | 8 | 15 | T | 1 | n-1 |
| Lotos[87] | 8 | 2 | 4 | 30 | T | 1 | n-1 |
| Between Two Cities[88] | 8 | 2 | 7 | 20 | T | 1 | n-1 |

**Table 3.1:** Final 10 selected games (basic criteria)

Naturally, there are other categories to consider, such as:

- Is the order in which players take turns permanent, progressive, no order etc.? This is an important attribute of the game especially when I plan to implement it later on. [O]
    - **Permanent (PO)** - the order is decided at the beginning of the game and stays the same for the whole duration, a special case is when all players play at the same time which is the **Simultaneous turn (ST)**

  - **Progressive (PR)** - the order is decided at the beginning of the game but after a specified time or event in the game the first player becomes the last player and the game continues until the next event when the new first player becomes the last player again and so on
  - **Claim action (CA)** - the order is decided based on the state of the game at the beginning of each turn
  - **No order (NO)** - players can take turns whenever they want

- What are the features and actions that represent randomness and strategy? Those two are the core parts of any game and if either one of them is missing the game might not feel so exciting for some people. For example game *Snakes and ladders* doesn't have any strategy and relies purely on luck while throwing a dice. [Random/Strategy]

- Does it require substantial flexibility/reflexes/precision (Dexterity column)? Keeping in mind that I want to implement it using a computer vision based hand tracking technology, there is a real chance that some gestures/movements won't be suitable or possible. [D]

- Is each turn the same? Usually if turns can be different, this means that the rules of the game are also more complicated which is not really something I want. [Each Turn]

- What are the keywords that best describe this game? [Category]

In the following table (3.2), I've highlighted a few cells that have unique content. It's possible that you will know some of the games under a different name in your country/region because there are different versions of it but I decided to keep the titles in the wording that I am most familiar with.
To summarize the actions that are being performed by players during the game, we can generalize them into the following:

- Drawing a card/tile
- Rolling a dice
- Selecting a card/tile from a grid/row
- Putting cards/tiles in an order
- Placing card/tile in one of the available places
- Selecting card/tile to play next

These actions will be closely intertwined with interaction patterns from the section 1.3.

| Name | O | Random/Strategy | D | Each Turn | Category |
|---|---|---|---|---|---|
| Sets | **NO** | drawing set cards /finding sets | **T** | T | **competitive; reflexes; collecting sets of cards** |
| Sushi Go! | **ST** | drawing cards /selecting cards | F | **select game /chopsticks action** | cards; accumulating and collecting sets of cards |
| Colt Express | **PR** | drawing round cards /programming actions | F | **program actions /...** | **programming game; robbing treasure; character cards** |
| Kingdomino | **CA** | drawing tiles /selecting tiles | F | T | domino tiles; building |
| Snakes and ladders | PO | **rolling dice /no** | F | T | roll dice; ups and downs |
| Dominion | PO | drawing hand /using action cards | F | **play card /defend after attack** | upgrading your deck of action cards; collecting WP |
| Pexeso | PO | flipping cards /memorizing | F | T | **flipping cards; memory** |
| Timeline inventions | PO | drawing cards /placing them onto the timeline | F | T | **knowledge; guessing** |
| Lotos | PO | drawing cards /card placing | F | T | dominance strenght; power ups; unique placing of the cards |
| Between Two Cities | PR | drawing tiles /placing tiles | F | diffent tiles and tiles selection | competetive+cooperative; building tiled cities |

**Table 3.2:** Final 10 selected games (additional criteria)

*Few words on randomness in these games:* Big problem is rolling of a dice. It seems like a simple action but it's very hard to make it natural and believable. That's why I've decided that when implementing action "Rolling a dice", it will not be rolled by the player but by the system and the player can only watch the dice being thrown into the air.
I would say that general rule of thumb is that if it's an action that requires game engine's physics in combination with player's hands then the developer should find another interaction pattern to substitute for it.
My experience after working in a VR LBE for a year (we use Leap motion technology) is that people are complaining that the technology is at fault and they actually did everything right. To be fair they are sometimes right but majority of the time it's just their clumsiness, not enough coordination or they didn't pay attention when they were taught the interaction gestures. Not surprisingly, I would like to avoid these types of complaints as much as possible.
On the other hand when I've asked people about a randomness which is decided by the system such as shuffling cards in the deck when playing Solitaire[89] on their PC, everybody was surprised why I would even doubt it. So my conclusion is that it's acceptable to let the system take care of the randomness and let the player work only on the strategy and quick reflexes.

### 3.1.1 Each game from final 10 in greater detail

*Game setup, used actions* and *goals* are extracted from the official rules that can be found online or attached to the game box. *Concerns* are my notes on what I would find harder to properly balance out or implement in the VR (or in any other media).

#### SETS

- **Game setup:** field of 3x4 displayed cards (replenished from the deck during the game) and shuffled deck of remaining cards (all cards in the game should add up to 81 cards)
- **Used Actions:** 1. (simultaneously all players) find and select 3 cards that form a set based on the specified rules
- **Goal:** discover the biggest number of sets
- **Concerns:** how to determine whether a set exists in the displayed cards if not swap displayed cards, how to make sure that fast hand movements get still registered correctly

#### SUSHI GO!

- **Game setup:** each player receives a specific number of cards (2 players => 10 cards, 3=>9, 4=>8)
- **Used Actions:** 1. (simultaneously all players) select 1 card from the deck and pass the remaining cards onto the next player 1B. use chopsticks action to select a different card 2. place flipped card onto one of your sets or create a new one
- **Goal:** collect the biggest number of points
- **Concerns:** how to quickly and simply explain all the rules about making sets for each type of card

#### COLT EXPRESS

- **Game setup:** each player gets a player figurine, deck of action cards, deck of blank cards and character sheet, additionally there is a deck of round cards

- **Used Actions:** (0. reveil round card) 1. select an action card for gameplay programming (1.2. reveil the last action card) 2A. move your figure up/down/left/right 2B. take one loot from the carriage that you are in 2C. punch another player in the same carriage left or right and get one of his loots if he dropped any 2D. shoot a player in the adjacent carriage and give them a blank card into their deck 2E. move the marshall left or right and appropriate action follows (player moved to the roof)
- **Goal:** collect the biggest amount of money
- **Concerns:** how to select a direction for movement or player to apply action to, rules will be mostly enforced by allowing player to do only specific actions in his turn (e.g. you are not allowed to punch another player if there isn't another player in your carriage with you)

### KINGDOMINO

- **Game setup:** shuffle the domino tiles
- **Used Actions:** 1. take your tile and move your figure onto the next one 2. place the tile next to your castle
- **Goal:** earn the biggest number of points based on the terrain size and number of crowns on that terrain
- **Concerns:** how to limit the placing field which is 5x5 tiles

### SNAKES AND LADDERS

- **Game setup:** display a board with all the snakes and ladders
- **Used Actions:** 1. roll a dice and move
- **Goal:** be the first to reach the top
- **Concerns:** no strategy that can be employed everything depends on luck

### DOMINION

- **Game setup:** each player gets a deck of shuffled cards consisting of 3x1 victory point cards (VP) and 7x1 coin cards (C), decide which card decks will be in the game

- **Used Actions:** 1. draw the top 5 cards from your deck 2A. buy an additional card into your deck (C/action card (A)/VP) 2B. use A to play an action
- **Goal:** earn the biggest number of victory points through VP
- **Concerns:** designing the rules for action on A

### PEXESO

- **Game setup:** field of 8x8 hidden cards/tiles
- **Used Actions:** 1. flip first card 2. flip second card 3*. if previous two cards were a pair repeat
- **Goal:** discover the biggest number of pairs
- **Concerns:** how to easily select a card from the field

### TIMELINE INVENTIONS

- **Game setup:** shuffle the deck and distribute 4 cards to each player, also place one card on the timeline with time displayed
- **Used Actions:** 1. pick a card from your hand 2. place the card on the timeline if it's incorrect draw another card
- **Goal:** get rid of all your cards
- **Concerns:** how to select the events in history to make it fair for everyone

### LOTOS

- **Game setup:** shuffle the neutral gray cards deck and display first 4 of them, each player gets their own deck of card, 3 tokens, 2 guardians
- **Used Actions:** (0. draw 4 cards) 1A. play up to 2 cards on a single flower 1B. exchange up to 2 petal cards 1C. place/move a guardian 2. second action repeats first action choices 3. replenish your hand either from your deck or from the neutral deck 4*. if a flower is completed and you are the dominant one on it you get to unlock one of your tokens or get to earn five points

- **Goal:** earn the biggest number of points
- **Concerns:** how to properly convey all the rules

### BETWEEN TWO CITIES

- **Game setup:** each player gets a figurine and another one is placed onto the scoreboard, they also draw 7 cards and place them on the table to their right hand
- **Used Actions:** 1. Player takes a pile of cards that is placed to their right hand, picks 2 of them and places the rest to their left hand 2. All players simultaneously try to place one card into the city on their right and one on their left. 3. Repeat these steps with different tiles always until there is only 1 left, then discard this last card and draw more
- **Goal:** build both cities (left and right) equally valuable so that the lower one is still worth enough for you to win, if there is a tie between two players, they should compare their other cities
- **Concerns:** How to transition the rules into the game for only 2 players and how to explain the complex rules

## 3.2 VR games

We will be looking mainly into mechanics that would be nearly impossible or simply impossible to do in traditional board games. There is a good number of games that incorporate both, traditional and digital, for example narrative detective games based on voice (phrase or word) recognition which serve to substitute the need for a game master (a person that is creating the story or answering the questions). Another good idea is to use music tracks to indicate running time instead of flipping and repetitively checking the good old hourglass. Based on the following table of VR games and experiences (3.3) I've listed just the first few basic mechanics that I was able to recognize (there is still many more among them for sure) and separated them semantically like this:

- Sound effects, beat/music analysis and procedural generation
- Responsive environment, transform dimensions (3D to 2D)

- Mirror, screenshot/picture
- Haptics, natural movement (walking, jumping,...), physically extreme actions, change scale
- Environmental scanner, map position/location, labelling of objects in the scene, tutorial
- Gaze control, controllers, joystick
- Rewind time, cut scenes, companion, high-score, immortality
- Avatar transformation (animal, mechanical, deprecated, simplified,...)

A lot of these mechanics have to somehow be prompted by the player. I have mentioned before that because I plan to have players interact with food and drinks, I will need to use a technology that can track hands as they are. For that I will use optical tracking which means that there will be some HW limitations and in theory each person has two standard functional hands with 5 fingers on each but in practice that is very seldom the case. There are skin variations (either by birth, age, health or choice), fashion / cultural / religious accessories, shape deviation and scale variations.
The angle of the hand when doing the gestures is also important. If the camera from its position can't determine the gesture or even which hand it is (left/right) then it is a bad idea to include that particular gesture and it shouldn't be used. Alternatively we can combine hand tracking with another technique like voice recognition or keyboard input but we should always make sure that the user understands which technique is used for what type of interaction and we shouldn't mix them.

So instead of assigning a gesture to each mechanic that I want to use in the game, based on the games I've tried so far, I think that the steepest learning curve (when it comes to hand interactions) is when specific actions are linked to certain objects in the scene. This means that to do an action A, player has to interact with object A but he/she can interact with it the same way he/she interacted with object B while doing action B. This will at the same time enforce player's believe that he/she is actually using his/her hands. Much bigger focus should be instead on the side effects, like transitions, animations and sound effects. System always has to give a feedback after receiving a command to ensure the player that he/she is doing the right action (or doing the action at all).

| Name | Number of players | Seated/Standing | Dexterity | Category |
|---|---|---|---|---|
| Beat Saber | 1 | standing | T | Casual; Music; Sports |
| Stormland | 1 | both (better standing) | T | Explore; Survival; Adventure; Action |
| Half + Half | 1...n | standing | T (simple) | Arcade; Exploration; Social |
| Arca's Path VR | 1 | both (better sitting) | T (only for head) | Arcade; Casual; Puzzle |
| Sparc | 1...2/n | standing | T | Action; Social; Sports |
| RUSH | 1..n | both | T (only for head or other modes) | Action; Adventure; Racing |
| Snow Fortress | 1..2 | standing | T | Action; Arcade; Casual |
| Keep Talking and Nobody Explodes | 1 (VR) + 1 (R) | both | F | Puzzle |
| SUPERHOT VR | 1 | standing | T | Action; Puzzle; Shooter |
| PokerStarts VR | n | sitting | F | Casual; Social; Strategy |
| Space Pirate Trainer | 1 | standing | T | Action; Arcade; Shooter |
| Robo Recall | 1 | standing | T | Action; Arcade; Shooter |
| VRChat | n | both | F | Art/Creativity; Casual; Social |
| Tilt Brush | 1 | both | F | Art/Creativity; Casual; Productivity |
| Dead and Buried | 1...n | standing | T | Action; Arcade; Shooter; Social |
| NVIDIA VR Funhouse | 1 | standing | F | Arcade; Casual |
| Dance Central | 1...n | standing | T | Music; Social; Sports |
| Creed: Rise to Glory | 1...n | standing | T | Action; Fighting; Sports |
| I Expect You To Die | 1 | sitting | F | Exploration; Puzzle; Simulation |
| Acron: Attack of the Squirrels! | 1 + n on mobile device | both | T | Action; Arcade; Social |
| BOXVR | 1..n | both (better standing) | T | Action; Casual; Sports |
| Bogo | 1 | standing | F | Casual; Narrative; Simulation |
| Journey of the Gods | 1 | both | T | Action; Puzzle; RPG |
| Job Simulator | 1 | standing | F | Casual; Food; Simulation |

**Table 3.3:** Selected VR games

# Chapter 4

# Design my own multiplayer VR experience with F&B

For the purpose of this thesis I decided to design a system that would allow multiple users interacting in VR to share a drink or meal while playing. It needs to let the players select, order and consume food and drinks while participating in the rest of the multiplayer experience which serves as the main attraction.
Ideally this solution will be suitable not only for the VR LBE but also for the home entertainment.

## 4.1 System requirements

Even without story and context of the graphical content there are Functional and Non-Functional requirements that arise for this VR multiplayer game. There are also requirements covering expected features of a more complex game (e.g. data persistence, customization). Requirements caused by story and context of graphical content are in this case simply categorized in Functional requirements under *Minigame selection*, *Minigame gameplay mechanics* and *Player as an observer of the Minigame*.

### 4.1.1 Functional requirements

Functional requirements define specific behavior or functions not in any particular order. They are marked *compulsory* or *optional*, depending on whether they are required by the thesis assignment and also they are marked *implemented* or *not implemented*, depending on whether they were implemented in the prototype or not. If they are not implemented, prototype's system design is prepared for their future implementation without any radical changes.

**RF1** **compulsory, implemented**
Correct readjustment of the HMD for each player

**RF2** **optional, implemented**
Log in under different accounts

**RF3** **optional, implemented**
Log in authorization

**RF4** **compulsory, implemented**
Active hand tracked interaction with 3D objects

**RF5** **compulsory, implemented**
Minigame selection

**RF6** **compulsory, implemented**
Order a drink

**RF7** **optional, not implemented**
Order food

**RF8** **optional, implemented**
Full-body avatar

**RF9** **optional, implemented**
Mirror for avatar

**RF10** **optional, implemented**
Data persistence for continuous playing

**RF11** **optional, not implemented**
Dynamic language selection

**RF12** **optional, not implemented**
Voice chat in case of players in two different rooms

**RF13** **compulsory, one implemented**
Minigame gameplay mechanics

**RF14** **optional, not implemented**
Player as an observer of the Minigame

**RF15** **optional, implemented**
Select difficulty of the Minigame

### 4.1.2 Non-Functional requirements

Non-Functional requirements specify criteria that can be used to judge the operation of a system, rather than specific behaviors. They address e.g. usability, performance, supportability, etc. In this case most of them are specified by VR HMD of our choice which is Oculus Rift S and Leap Motion.

**RNF1** Portable to Oculus Rift S with Leap Motion

**RNF2** Play area has at least one table and enough space for 2 players to sit there

**RNF3** Play area has a good visibility and lighting conditions

**RNF4** Stable Internet connection for networking

**RNF5** Networking for 2-4 players

**RNF6** Online database and backend to POST and GET information about players, seats availability and ordered drinks (or food)

**RNF7** Sustain at least standard minimum frame rate for comfort in playing VR

**RNF8** Response time kept at minimum

**RNF9** Enough internal memory space for installation

**RNF10** Enough internal memory space for local data persistence

## 4.2 Use cases

Use cases are made up of a set of possible sequences of interactions between the system and a user. They are related to a particular goal and they should cover in their scenarios all Functional requirements.

**UC1 Put on the HMD**

1. take into your hands the physical HMD with the game running in it and put it on your head
2. read through the instructions displayed on the screen
3. based on the instruction readjust the HMD on your head until you see clearly
4. confirm that you are done with the setup

**UC2 Get seated (assuming you weren't seated correctly)**

1. look around and check the seat around the table one of them should be clearly highlighted
2. take a seat

**UC3 Log in (under your own account)**

1. pick an option with your account details
2. confirm your choice
3. select a correct *player validation token*

**UC4 Select a Minigame**

1. tap arrows (left and right) until you find the minigame you want to play
2. wait for your friends to select the same minigame or change your choice by repeating 1. step
3. when an allowed combination of observers and players takes place the game begins

**UC5 Looking at your avatar**

1. select the *mirror action*
2. readjust the mirror position to look at your avatar

**UC6 Order a drink**

1. select the *order a drink action*
2. tap arrows (left and right) until you find the drink you want to order
3. if you are allowed to order the confirmation becomes available so confirm
4. wait for drink to come

**UC7 Order food**

1. select the *order food action*
2. tap arrows (left and right) until you find the food you want to order

3. if you are allowed to order the confirmation becomes available so confirm
4. wait for food to come

**UC8 Leave the minigame**

1. prompt the minigame cancellation
2. confirm your choice

**UC9 Log out**

1. prompt the log out
2. confirm your choice

## 4.3 Game world

Player experiences the game in 3 folds. First one is the **Log in Lobby** scene where he/she is still not logged in under any account and has to follow through all the steps to be able to enter into the next part of the game.

Second scene is **Neutral space**, players around the same table and in the same group can already see each other but they are not playing any game yet. In here, they can also look at their avatar, order a drink interact with each other or the world around especially with the minigame selector and select the minigame they want to play. After they all agree on the game to play they get transported into the selected minigame.

**The Minigame world** differs base on the minigame that got selected but the basic premise is the same, the table and players are still there just the environment changes. Players get instructions on how to play and the minigame starts. Players automatically return to the Neutral space after finishing the minigame.
The minigame mechanics are based on one of the final 10 games from the chapter 3.1.1.

### 4.3.1 Minigame “Knight’s gamble”

Based on the game Sets.
Players find themselves outside of the city walls in the middle of makeshift

knights barracks. Their goal is to collect as much money as possible by searching for matching triple coins. Coins have different shapes, materials, nominations and icons. To find a suitable triple, all 3 coins have to be either identical or completely unique in each feature (they can of course be identical in one and unique in another e.g. material, nominal value and shape is all the same but they have all unique icons).
The added value that you wouldn't normally see in real world sets is that each player can pick their own difficulty level and the coins will be displayed in his or her HMD based on that.

### 4.3.2 Minigame "Pirate's treasure"

Based on the game Pexeso.
Players find themselves on a deserted island with few palms and coconuts and an array of treasure chests. In each treasure chest is one object and their goal is to get as much treasure as possible by matching the pairs of identical objects.
The added value that you wouldn't normally see in real world pexeso is that one special object when found will automatically get you the matching object to the next object you uncover thus getting you a pair without any effort.

## 4.4 Flow of information

In this section, we will define all parts of the systems that will be needed for a successful run of the game. The whole system consists of actors (Admin, Player), Temporary modules (Game operator, In-game Visuals, Interaction) and Persistent modules (Documentation (for now that's this thesis), Player's personal details, Drinks and food orders).

- **Actors**: each person interacts with the system under a specific role as an actor and one person can take on multiple roles if necessary. Also, multiple people can share one role (e.g. Admin) but it should always be clear who is ultimately responsible.
    - **Admin** - A person who either communicates with the player or received all data that the player wishes to customize. This person is also responsible for the correct setup. All necessary information for this role is available in the Admin's documentation (for now this

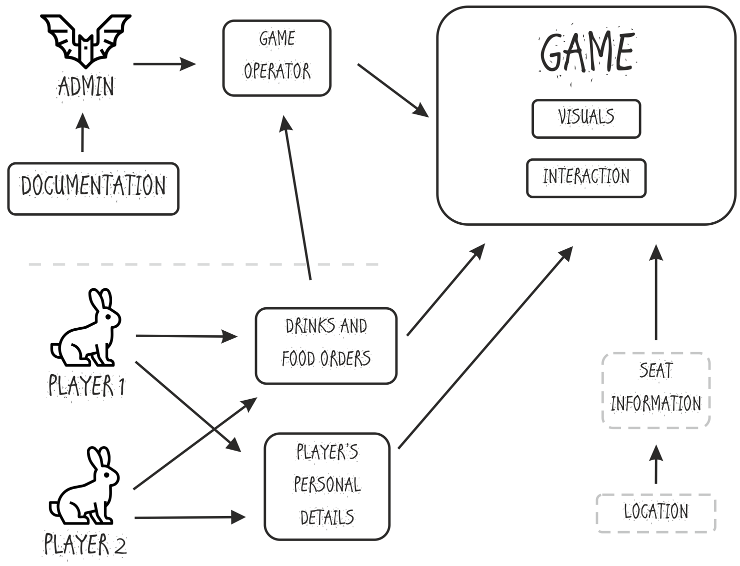



**Figure 4.1:** Flow of information in the designed system

thesis). Admin is also the one that receives drink or food orders and needs to take care of them. At the same time, the Admin should also make sure that players know how to properly use the equipment without destroying it.

- **Player** - A scheduled or random person that wants to play the game. They should pick a nickname for themselves before they play and confirm their log in details.

- **Temporary modules**: these modules are part of the VR game and they are repetitively reset for each run of the game when player logs in.

  - **Visuals** - Everything that is visible in the scene. It is made up of environment, lighting, avatars, NPCs, props, VFXs, texts,... There are a few different types of sources that can influence how something will look like:
    - Permanent game scripted setup
    - Player's specific customization (e.g. nicknames)
    - Current minigame customization
  - **Interaction** - main interaction is via hand tracking and additional possible interactions can be through head position, gaze direction or keyword recognition.
  - **Game operator** - this interface will help the Admin to set up current and upcoming games. Also, it helps the Admin to keep track of the registered players and their data (part of this is currently as a database manipulation and the rest is through windows application and mobile phone application).

- **Persistent modules**: various data sets have to be customized and stored for a specific run of the game furthermore each run of the game will create additional data sets that are of interest to the players and should be available for them (this has more value for the future upgrades).
  - **Documentation** - steps for Admin on how to deal with certain situations.
  - **Player's personal details** - each player will have a nickname in the game (not necessarily displayed above their head) and this nickname will be the base for their unique identification in the system (e.g. nickname is "Ula" and with added suffix "123" it will make a unique id "Ula123").
  - **Drinks and food orders** - each player can order one drink per game and Admin has to be able to check who and what ordered and where they are sitting.

## 4.5 The act of drinking and eating

When I was deciding on which tracking to use for food and drinks (additional sensors, special AI based on hand gestures or additional setup just for drinks, see more in 2.4) I decided to go as low-cost for the user as possible so that this solution can be used even in home settings. Which means that if they already own a VR HMD than it's cheaper for them to get a Leap motion than to buy a new HMD with integrated hand tracking. Also because I want to use Unity game engine it means as long as the hand tracking is dependent on the Leap motion and not the HMD it is easier to port it to other (newer) HMD later on.
By relieving controllers of their primary purpose we got 2 fully compatible trackers that can be used for food and drink tracking. With this method we won't be able to track the liquids and food itself but we can track the containers that all of these are in (cups and plates). The rest (picking up the the food, putting it down,...) can be now approximated easier because we know the general area where the food should be so we can eliminate false positive of gesture recognition when player isn't trying to grab the food.
This is the simplest dining setup however we can always upgrade it by adding additional optical tracking just for food and drinks. This could be achieved e.g. by Kinect with an AI software running in the background facing the table on which the food and drinks are.
That being said the most crucial thing right now is to design the adapter for controllers that would fixate the food and drinks in permanent relative position to them at all times.

# Chapter 5

# Implementation

As mentioned before, implementation will be focusing only on the drinking not eating part of the game (minigames are of course required anyway), nevertheless, tools and technology should be selected based on the whole proposed design so even eating should be taken into consideration while choosing the right set of tools.

## 5.1 Development

I've started a little bit from the side because I needed to make sure that this game fits into my previously designed complex database system for an LBE (picture 5.3). Except for database, first thing that got finished was a helper application with name *ManageEntities*. It can correctly fill up the database with a setup of the play area, set the computer to be a specific seat in the location (around the table: North, East, South, West) and many more. This was especially helpfully during the development and testing because I could quickly and dynamically change settings without accessing the database directly.
To sum it up we have database, helper application for the operator of the game, app for customers to create accounts, game itself and backend to support it all. Main idea behind the design is that players will get separated into groups when they arrive and computers (seats) get assigned to the groups. This is to guarantee that players can rearrange themselves up to the group dynamics (picture 5.1). For this to work as efficiently as possible, ideally each potential player fills up their own player data in some kind of device that can

communicate with the database. I've create a mobile app for customers that can take many more (and in this case unnecessary information)(picture 5.2b) and one part of *ManageEntities* which is desktop app that can be use by an operator for quick setup because it omits all the unnecessary information (picture 5.2d). All, backend, mobile app, helper app and unity game, are

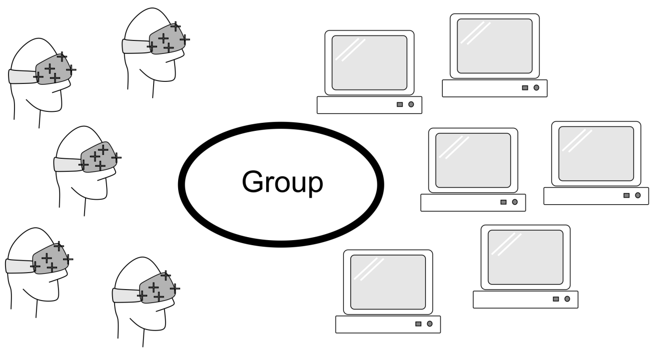
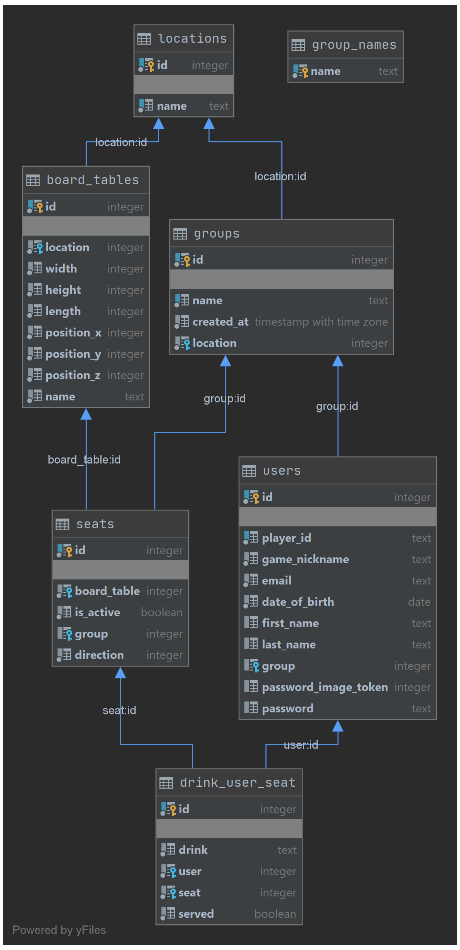


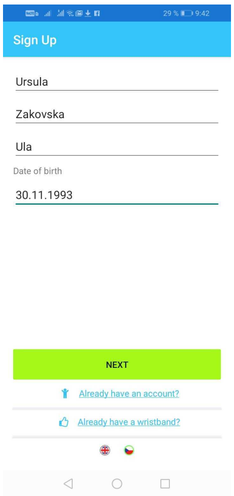

**Figure 5.1:** Many users can be part of the group and many seats can be assigned to this group (doesn't have to be 1:1)

written in *C#* which makes it easier to keep the structure and relations throughout all applications. When it comes to the Unity game, the appendix C has various screenshots from the game demonstrating techniques to select an account, verify it, select game, tutorial and many more. As you can imagine one person can't put multiple headsets on one head so VR development is sometimes a very grotesque activity, nevertheless the application successfully allows players to play the minigame (*Knight's gamble*) and drink at the same time while talking to a friend who is in the real-world relation to the player. The one thing that I blatantly forgot about is service application for people who are preparing drinks. For now, the only way how to tell that player ordered a drink is to check on the table in the database for ordering drinks (Drink-User-Seat table).
When designing the physical solution for the cup, I had to pay attention to the following things:

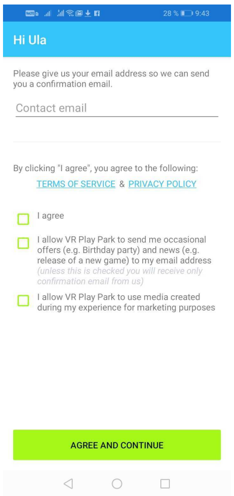
- easily accessible batteries
- slip-in/slip-out mechanism for the cup so that it's quick
- possible to print on 3D printer
- sturdiness and reliability for everyday use
- cost-effective when it comes to material
- safety (broken teeth, spillage, broken nail, stability)
- design that can be adjusted for other controllers



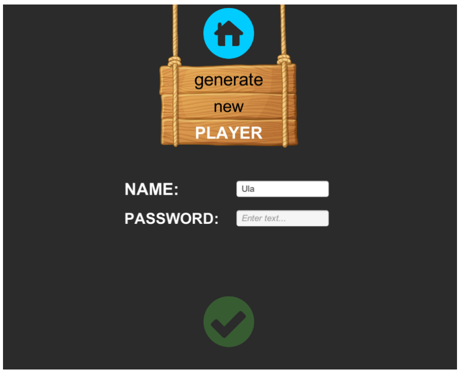

**(a)** : Selected entities used in this game




**(b)** : Mobile app, first screen




**(c)** : mobile app, second screen




**(d)** : ManageEntities

**(e)** : Creating new users, 2 screens on the left are equivalent to the screen on the right

The history of my cup design goes very far, I've actually started with HTC Vive controllers that had their own 3D printed cup instead of a slip-on holder on an industry made cup but after much consideration I've realized that the solution needs to be modular if not for anything else then for the hygiene. One thing that was a happy accident with the design of the final holder is that in the way people are holding it, it is still possible to use the trigger button (front big button usually used for teleport) as an interaction button so that drinks can have some animation.

The biggest challenge I would say was the silicon hat for the cup. It is normally sold for small children and not many of them are suitable for VR drinking. After trying few of them (most of them scored very high on cuteness but very low on practicality) I've decided that a version with straw is probably the most natural one.

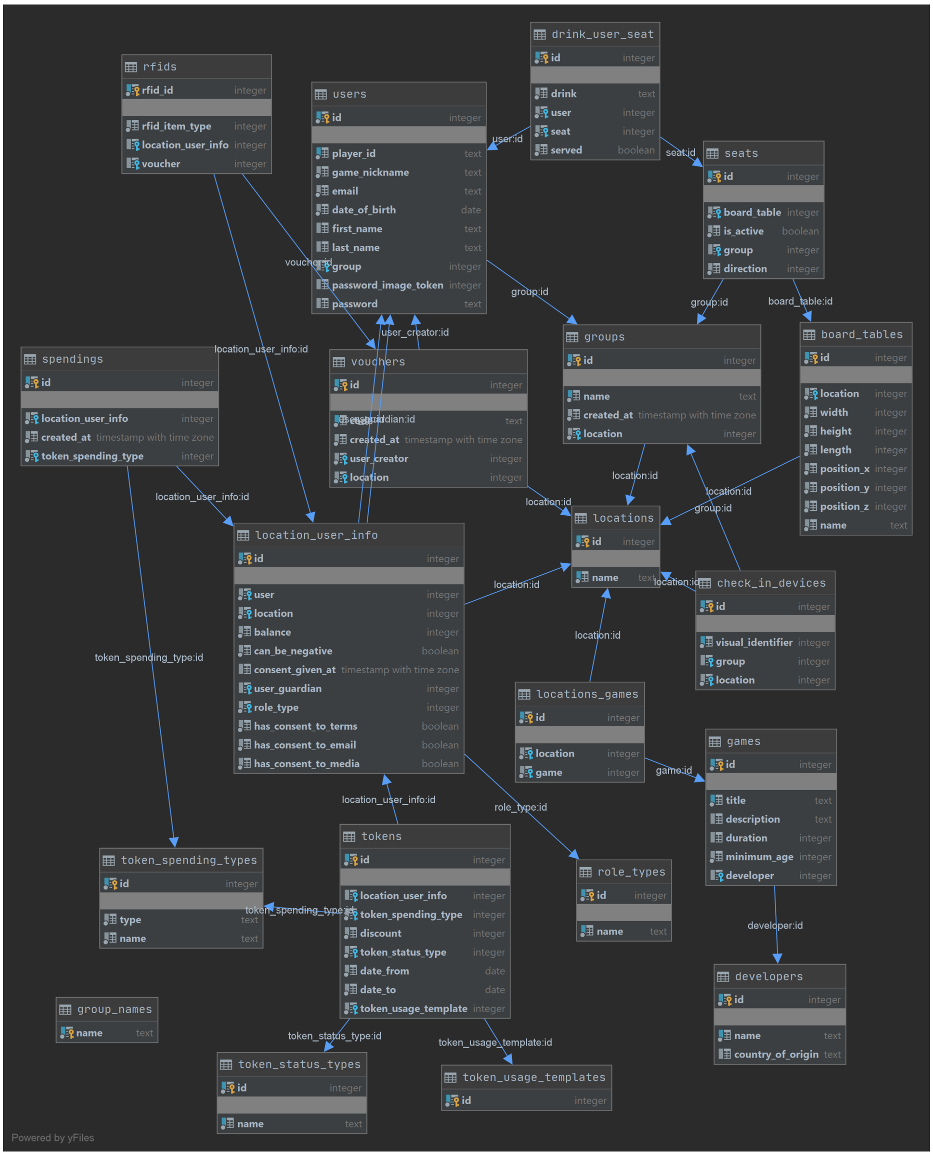
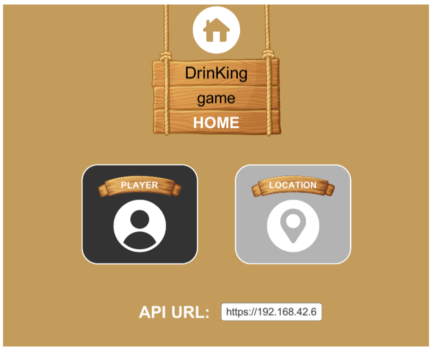
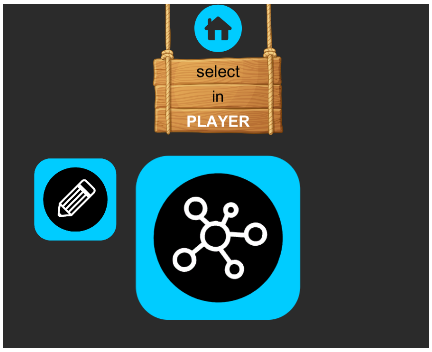


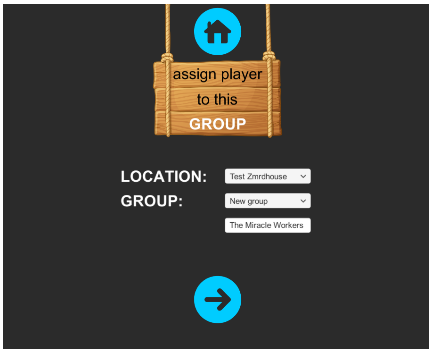

**Figure 5.3:** Database entities in a bigger picture



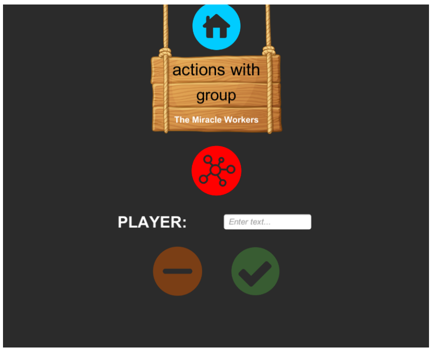

**(a) :** Home screen



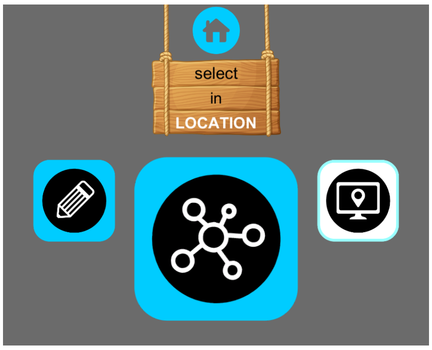

**(b) :** Player options



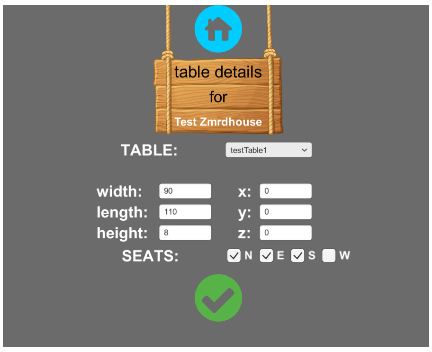

**(c) :** Player to group



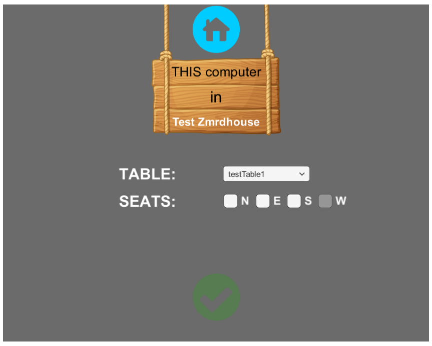

**(d) :** Add, remove player or whole group



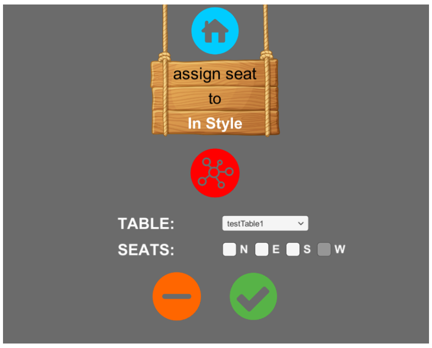

**(e) :** Location options




**(f) :** Location setup




**(g) :** Set this seat




**(h) :** Assign seat to group

**Figure 5.4:** Other screens from manage entities

**Figure 5.5:** Last few 3D model iterations over the cup holder, one of the 3D print previews, final model with cup, controller, straw and rubber tip and 2 in-game verions of the cup

# Chapter 6

# Usability Testing

Understandably so, this being the multiplayer experience, it had to be constantly tested with other people even during the development. These people become the group that is knowledgeable of the system and so the results during the final testing were actually incomparable with the first runs. I am mainly talking about the minigame that can be very easy but also very hard and at the end many testers had to select the hard mode so that they can feel a challenge against newcomers.
Some of the shortcomings that were found out during the testing were already fixed such as:

- design of the cup should allow for spontaneous cheers (the holder clip was moved towards the player)
- even with stabilized straw people still tend to bump their noses and such (actually unstable straw seems better because players are more careful)
- interaction buttons shouldn't be just hung up in the air (some of them are still in the air but have a backdrop or the personal menu was moved to the wrist where it offers a passive feedback
- forcing player to be in a specific area while interacting with the game takes out the inter-human interaction out of the game (removed collider around the seat area that was tracking the presence of the player)

But many more are still in the application and require fixing. This is in no way a functioning experience, it is lacking more content and precision when it comes to relative positions of the object in the space.

# Conclusion

In this thesis I've made a detailed research on Food&Beverage in VR and XR in general. First, I've talked about the recent situation in VR industry, especially in the entertainment and even more in the Location-based entertainment. Then I've looked into various ways how we can track the player and other peripherals, then I've talked about interaction patterns and how we can categorized them and finally I got to the F&B in context of Extended reality (XR). I've analysed and compared each approach that can be taken while making such experience and included real examples from the industry or research. Instead of listing a summary of hardware and software solutions as was planned originally, I decided that it is better to look at it from different side. Rather than talking about what we can do, I gave my suggestions on business situations that we can find ourselves in and how to solve them. Lastly I've browsed through traditional tabletop and VR games that got recommended through various sources and selected a few of them that I've found suitable for VR adaptation in this format.

With knowledge gained from this research I've designed a VR game with features of drinking and eating and implemented its prototype. The result of this thesis is a working VR game for Windows PC with Oculus Rift S Virtual reality headset and Leap Motion unit that fulfills the requirements (allowing player to interact with the VR world, other players and his own drink).

During the implementation despite testing numerous part of the system separately, it proved to be quite tricky to combine them in one project. Especially troublesome were real-world 1:1 tracking and multiplayer. To be honest I've expected to have more than just one minigame in the prototype and I've even prepared the assets for them but after challenging myself with the VR multiplayer experience and successfully finishing it I can only say that I am happy with the results and anything and everything I've learned through this can be definitely used in my future projects.

Here I would like to acknowledge the Unity packages from Asset Store (or their own dedicated sites) that I've used in this thesis (available either for purchase or for free):

- Photon PUN 2 - FREE
- POLYGON - Modular Fantasy Hero Characters
- Oculus integration
- Skybox Series Free
- JSON .NET For Unity
- The Fantasy Music Collection (STARTER)
- Magic Spells Sound Effects
- Interface and Item Sounds
- Horse Animset Pro (Riding System)
- Final IK
- Skybox Series Free
- POLYGON - Nature Pack
- POLYGON - Adventure Pack
- POLYGON - Knights Pack
- POLYGON - Vikings Pack
- POLYGON - Western Pack
- Leap motion - Unity modules
- Fantasy and Role-Play Game - Adventure Quest icons by Chanut is Industries
- URP LWRP Mirror Shaders

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# Appendix A

## Acronyms and Glossary

**3DoF** Degrees of Freedom - rotational motion only: pitch, yaw, and roll

**6DoF** Degrees of Freedom - forward/back, up/down, left/right, yaw, pitch, roll

**360° Video**

**AC magnetic field** magnetic field with Alternating Current

**AI** Artificial Intelligence

**AoA** Angle of Arrival

**AP** Access point

**AR** Augmented Reality

**CG** Computer Graphics

**CSI** Channel State Information

**CTU** Czech Technical University

**DC magnetic field** magnetic field with Direct Current

**E-commerce** Electronic Commerce - the activity of electronically buying or selling of products on online services or over the Internet

**EMS** Electrical Muscle Stimulation

**EMTS** ElectroMagnetic Tracking System

**F&B** Food and Beverage (Industry)

**GAN** Generative Adversarial Network

**HMD** Head-Mounted Display

**LBE** Location-Based Entertainment

**MEMS** Micro-ElectroMechanical Systems

**MR** Mixed Reality

**NFT** Natural Feature Tracking

**PC** Personal Computer

**QR** Quick Response (code)

**ToF** Time of Flight

**TDoA** Time Difference of Arrival

**VR** Virtual Reality

**WP** Winning Point

**XR** Extended Reality

# Appendix B

## List of selected traditional board and card games

To fit all the columns onto one page I had to abbreviate the header names:

- **A**: minimum recommended age
- ↓: minimum number of players
- ↑: maximum number of players
- **T**: time to finish
- **O**: order (PO - permanent order, PR - progressive order, ST - simultaneous turn, CHoD - change of direction, CA - claim action, NO - no order)
- **Random/Strategy**: dominant features representing randomness and strategy
- **D**: does it require dexterity (F/(T)why)
- **Each Turn**: is each turn the same (T/(F)why not)
- **F**: do they finish together (T/F)
- **S**: can players be scored and put in order (T/F)
- **W**: number of winners if number of players is n
- **L**: number of losers if number of players is n

| Name | A | ↓ | ↑ | T | O | Random/Strategy | D | Each Turn | F | S | W | L | Category |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Blafuj | 8 | 2 | 6 | 20 | PO | initial card distribution /lying | F | get card /take out card | T | F | n-1 | 1 | cards; lying |
| Černý petr (Old maid) | 5 | 2 | 4 | 15 | PO | initial card distribution /bluffing | F | T | F | T | n-1 | 1 | cards; lying |
| Clovece nezlob se (Ludo) | 5 | 2 | 6 | 30 | PO | throw dice /used figure | F | T | T | F | 1 | n-1 | board |
| Dominion | 10 | 2 | 4 | 30 | PO | drawing hand /using action cards | F | play card /defend after attack | T | T | 1 | n-1 | cards; deck of action cards |
| Hady a rebriky | 4 | 2 | 4 | 30 | PO | rolling dice /no | F | T | T | T | 1 | n-1 | dice; ups and downs |
| Hanabi | 8 | 2 | 5 | 25 | PO | card drawing /hints suggesting | F | T | T | F | n/0 | 0/n | ordering cards; can see everyones cards except for yours |
| Kralovske rosady (Gambit royale) | 8 | 2 | 6 | 30 | PO | drawing cards /card placing | F | normal turn /special card requires to select additional one | T | T | 1 | n-1 | hierarchy cards; special action cards |
| Kvarteto (Go fish) | 5 | 2 | 5 | 20 | PO | drawing cards /asking for cards | F | T | T | T (based on time of completion) | 1 | n-1 | collect; guess other player's cards |
| Labyrint | 7 | 2 | 6 | 30 | PO | drawing goal items /selecting row or column to shuffle | F | T | T | T | 1 | n-1 | collect treasure |
| Majesty | 7 | 2 | 4 | 30 | PO | drawing cards /selecting a card | F | T | T | T | 1 | n-1 | activating effects with special cards; accumulating WP |
| Obesenec | 7 | 1 | n | 10 | PO | picked word /letter selection | F | T | T | T | 1 | n-1 | word game |
| Pexeso | 5 | 2 | 6 | 15 | PO | flipping cards /memorizing | F | T | T | T | 1 | n-1 | flipping cards; memory |

| Name | A | ↓ | ↑ | T | O | Random/Strategy | D | Each Turn | F | S | W | L | Category |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Svabi salat | 5 | 2 | 6 | 10 | PO | drawing cards /attention for words | F | T | T | T | 1 | n-1 | cards; attention for words |
| Timeline vynalezy | 8 | 2 | 8 | 15 | PO | drawing cards /placing them onto the timeline | F | T | T | T | 1 | n-1 | knowledge |
| Ubongo 3D | 8 | 2 | 4 | 30 | NO | gems picking /pieces positioning | speed of placing pieces | T | T | T | 1 | n-1 | spatial vision; 3D positioning and rotation |
| UNO (prsi) | 6 | 2 | 10 | 30 | PR | drawing cards /selecting cards to play | shouting uno | normal turn /shouting uno | T | T | 1 | n-1 | cards; paying attention |
| Vybusne kotatka (Exploding kittens) | 7 | 2 | 5 | 20 | PO | drawing cards /selecting cards to play | F | your turn /Nope card | F | T | 1 | n-1 | cards; special action cards |
| Velbloudi dostihy (Camel Up!) | 8 | 2 | 8 | 30 | PO | dice rooling /betting | F | T | T | T | 1 | n-1 | betting |
| Spirits of the forest | 14 | 1 | 4 | 20 | PO | tokens /tiles selection | F | T | T | T | 1 | n-1 | collecting tiles; collecting point |
| Hej! To je moje ryba! | 8 | 2 | 4 | 20 | PO | no /moving the penguins | F | T | F | T | 1 | n-1 | collecting tiles; dame movement |
| Lotos | 8 | 2 | 4 | 30 | PO | drawing cards /card placing | F | T | T | T | 1 | n-1 | dominance strenght; power ups |
| 7 divu sveta | 10 | 2 | 7 | 30 | PO+ST +CHoD | drawing cards /playing cards | F | T | T | T | 1 | n-1 | 3 stages with their own deck of cards; collecting points |
| Vladce Tokia | 8 | 2 | 6 | 30 | PO | rolling 3x6 dices /dice selection | F | your turn /yield from the city if attacked | T(someone 20 WP) /F(Last monster standing) | T | 1 | n-1 | survival; special powers |
| Splendor | 10 | 2 | 4 | 30 | PO | drawing field cards /gems selection | F | T | T | T | 1 | n-1 | accumulationg strategy; bonus tiles by long-term strategy |
| Zakázaný ostrov | 10 | 2 | 4 | 30 | PO | drawing cards /selecting action and movement on the tiles | F | T | T | T | 0...n | 0...n | character cards; environment tiles; collecting treasures; cooperative |

| Name | A | ↓ | ↑ | T | O | Random/Strategy | D | Each Turn | F | S | W | L | Category |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Coup | 13 | 2 | 6 | 15 | PO | draw character /action used; killing | F | T | F | T | 1 | n-1 | character cards; coins; character actions; bluffing; assasination |
| Sushi Go! | 8 | 2 | 5 | 20 | PO+ST | drawing cards /selecting cards | F | select game /chopstics action | T | T | 1 | n-1 | cards; accumulating and collecting cards |
| Blockus | 5 | 2 | 4 | 20 | PO | no /placing your tiles | F | T | F | T | 1 | n-1 | placing tiles |
| Machi Koro | 7 | 2 | 4 | 30 | PO | drawing cards; rolling dice /using actions | F | your turn /someone activated your landmark | T | T | 1 | n-1 | types of action cards; special legacy cards; 10 legacy games |
| Tsuro | 8 | 2 | 8 | 15 | PO | drawing path tiles /placing tiles | F | T | F | T | 1 | n-1 | path tiles; gradual elimination |
| Guillotine | 12 | 2 | 5 | 30 | PO | drawing cards /playing cards | F | T | T | T | 1 | n-1 | collecting point cards; rearranging order for character cards based on many different rules |
| Coloretto | 7 | 2 | 5 | 30 | PO | drawing cards /selecting and taking cards | F | T | T | T | 1 | n-1 | collecting color cards |
| Zelvi zavody | 5 | 2 | 5 | 20 | PO | drawing cards /playing cards | F | T | T | T | 1...n | 1...n | bluffing; cards; cooperation |
| Colt Express | 10 | 2 | 6 | 30 | PR | drawinground cards /programming actions | F | program actions/... | T | T | 1 | n-1 | programming game;robbing treasure; character cards |
| Fluxx | 8 | 2 | 6 | 15 | PO | drawing cards /playing cards | F | rules always change; e.x. to get rid of the keeper cards | F | T | 1 | n-1 | rules and goals always changing; cards; possible to join in during the game |
| Kingdomino | 8 | 2 | 4 | 20 | CA | drawing tiles /selecting tiles | F | T | T | T | 1 | n-1 | domino tiles; bulding |

| Name | A | $\downarrow$ | $\uparrow$ | T | O | Random/Strategy | D | Each Turn | F | S | W | L | Category |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| The Mysterious Forest | 6 | 2 | 4 | 15 | PO | throwing dice for tokens /token usage | F | forest/battle | T | F | 0/n | 0/n | uncovering tiles; memory; cooperative; tokens |
| Monstrous | 10 | 2 | 8 | 30 | PO | throwing monsters; card drawing/aiming; monster selection | T | T | T | T | 1 | n-1 | monster cards with special powers; throwing cards |
| Celestia | 8 | 2 | 6 | 30 | PR | dice throwing /stay or leave the ship | F | captain /stay or dissembark | T | T | 1 | n-1 | collecting treasure cards |
| Why First? | 7 | 2 | 6 | 20 | NO | drawing cards /placing cards | F | card to others /card to yourself | T | F | 1 | n-1 | competetive short strategies; cards |
| Between Two Cities | 8 | 2 | 7 | 20 | PR | drawing tiles /placing tiles | F | diffent tiles and tiles selection | T | T | 1 | n-1 | competetive+cooperative; building tiled cities |
| Sleeping Queens | 8 | 2 | 5 | 10 | PO | drawing action cards /usage of action | F | your action /other's action | T | F | 1 | n-1 | action cards; collecting queens |
| Sety | 10 | 2 | 8 | 30 | NO | drawing set cards /finding sets | T | T | T | T | 1 | n-1 | competetive; reflexes |
| Escape: Chrámová Kletba | 8 | 1 | 5 | 10 | NO | rolling dices | T | roll dice/lent dice /events action | F | T | 0/1 | n/n-1 | time limit; cooperative |
| Mental blocks | 10 | 2 | 9 | 15 | PO | drawing action cards /usage of action | F | T | T | F | 0/n | n/0 | time limit; cooperative |
| Safari bar (Beasty bar) | 8 | 2 | 4 | 20 | PO | drawing cards /selecting cards | F | T | T | T | 1 | n | cards; hierarchy order; special effects |
| Kryci jmena (Code names) | 12 | 2 | 8 | 15 | PO | drawing cards /selecting hints | F | T | T | F | n/2 | n/2 | imagination; intuition; teamwork |
| Múza | 7 | 2 | 12 | 30 | PO | drawing cards /selecting hint type | F | T | T | F | n/2 | n/2 | imagination; intuition; teamwork or competition |

| Name | A | ↓ | ↑ | T |
|---|---|---|---|---|
| Arkham Horror | 12 | 1 | 8 | 180 |
| Bang! | 8 | 4 | 7 | 45 |
| Carcassonne | 8 | 2 | 5 | 60 |
| Citadela | 10 | 2 | 7 | 60 |
| Dixit | 8 | 3 | 6 | 30 |
| DORN | 10 | 2 | 6 | 90 |
| Kronika panstvi | 12 | 2 | 4 | 60 |
| Monopoly | 8 | 2 | 8 | 180 |
| Moreplavci | 12 | 3 | 5 | 90 |
| Osadnici z Katanu | 10 | 3 | 4 | 90 |
| Proroctvi | 10 | 2 | 5 | 180 |
| Rise snu | 12 | 2 | 5 | 60 |
| Saboter | 8 | 3 | 10 | 30 |
| Soudruhu nezlob se | 10 | 2 | 8 | 45 |
| Temne znameni | 12 | 1 | 8 | 120 |
| Unstable unicorns | 14 | 1 | 8 | 45 |
| Vladci podzemi | 10 | 2 | 4 | 120 |
| Záchranáři: Boj s ohněm | 10 | 1 | 6 | 45 |
| Zlatohrad | 8 | 2 | 4 | 40 |
| Fazole | 10 | 3 | 5 | 45 |
| Dice Forge | 10 | 2 | 4 | 40 |
| Milostný dopis (Love letter) | 8 | 2 | 4 | 15 |
| Azul | 8 | 2 | 4 | 45 |
| Sagrada | 8 | 2 | 4 | 40 |
| Century: Cesta koření (Century: Spice Road) | 8 | 2 | 5 | 50 |
| Ticket to Ride | 8 | 2 | 5 | 45 |
| Villages of Valeria | 13 | 1 | 5 | 45 |
| Honshu | 8 | 2 | 5 | 40 |
| Imhotep | 10 | 2 | 4 | 40 |
| Isle of Skye (Ostrov Skye: Jak se náčelník stal králem) | 8 | 2 | 5 | 60 |
| Lanterns | 8 | 2 | 4 | 40 |
| Karuba | 8 | 2 | 4 | 40 |
| Discoveries: The Journals of Lewis and Clark | 14 | 2 | 4 | 60 |
| Broom Service | 10 | 2 | 5 | 60 |
| Qwirkle | 6 | 2 | 4 | 45 |
| Doba Kamenná (Stone age) | 10 | 2 | 4 | 60 |
| Kryci jmena | 12 | 2 | 8 | 15 |
| Passtally | 8 | 2 | 3 | 40 |
| Photosynthesis | 10 | 2 | 4 | 60 |

**Table B.1:** Rejected popular games not meeting even the first 2 criteria

# Appendix C

# Screenshots and photos

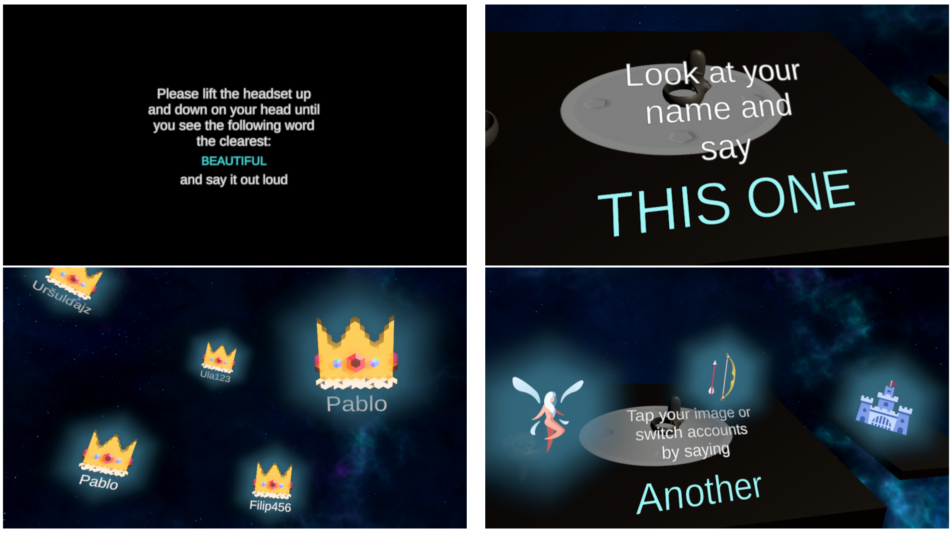


**Figure C.1:** In-game screenshots


**Figure C.2:** In-game screenshots

# Appendix D

## Contents of enclosed CD

```
README.txt ........................ the file with CD contents description
src ............................................ the directory of source codes
  VRDrinKing ...................... directory with parts of the project
    Assets ............ directory with extracted files from the project
      Scripts ............ directory with scripts used in the project
    Backend ....................... directory with backend materials
      DrinKing ................... directory with the right backend
    Builds .................................. directory with builds
      ManageEntities directory with build of the helper application
      VRDrinKing................ directory with the VR application
    CupHolder ................ directory with materials for 3D print
  thesis............ the directory of LaTeX source codes of the thesis
text ........................................ the thesis text directory
  thesis.pdf ......................... the thesis text in PDF format
media ............................................ the media directory
```