

# How to design virtual reality music instruments in Unity using the SenseGlove virtual reality gloves

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*Graduation report*



# How to design virtual reality music instruments in Unity using the Sense Glove virtual reality gloves

## Graduation report

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## Summary

I did my graduation as part of an Immersive Media project set up by Saxion, The Virtual Dutch Men and Sense Glove to build a VR application with Unity where users can play music instruments using Sense Glove's VR gloves. Another goal the project was to create a demonstration video where musicians can be seen playing music using the application. I worked at Saxion together with two other on this project. We received older glove prototypes to work with at first, missing out on sideways finger tracking and haptic and force feedback. We would only have development time with the newer prototypes at the end of the project after the timeframe of this report.

My research was about the designing of virtual reality music instruments making use of them with the Sense Gloves, researching VR glove features, virtual reality music instruments and 3D audio spatialization.

The project was set up to work iteratively with sprints. At a certain point in the project at the end of those sprints a musician onboard with the project would come by to test the prototype and afterwards fill in a questionnaire I developed with the design principles I found when researching virtual reality music instruments.

After crude versions of a piano, a drum and a xylophone we set out to build a synthesizer keyboard. It features a sample preset system, a sustain function and the keys have velocity response to change the volume of samples being triggered according to how hard the keys are hit. The keys don't make use of regular physics solutions as they are problematic with VR gloves but make use of collider areas beneath the keys and use a script to animate the visual key object accordingly to how far the fingers are down. The user doesn't interact with the visual key objects themselves.

The testing went a bit problematic as after the gloves were sent back to Sense Glove for repairs the finger and wrist tracking were still bad and the gloves showed other faults. The audiovisual response of the instrument is good and there were no complaints about cyber sickness. The instrument being closely modeled after real world counterparts is assured with natural mechanisms although it lacks magic mechanisms that extend the instrument past real world limitations. The instrument also lacks the ability to give the sense of giving a performance.

## Preface

I want to thank The Virtual Dutch Men, Sense Glove and Saxion for this project and the opportunity to my graduation as a part of it. I want to also thank Luca Frösler and Mattia Lorenzetti the students I worked with during this project, Cas ter Horst and Sven Ordelman the students that helped me with testing and Max Lammers of Sense Glove for helping out and coming over all the way from Delft.

Furthermore I would like to thank the teachers Rob Maas for his feedback and help with the project, Kasper Kamperman for his guidance with my graduation, Hans Wichman for helping out with coding problems and Alejandro Moreno for coaching the project.

And lastly I want to thank my family for their support during my graduation and my friend Gerwin Steen for proofreading this report.

## Abbreviations

Abbreviation	Explanation
AR	Augmented Reality
CAD	Computer Aided Design
HMD	Head Mounted Device
HRTF	Head Related Transfer Function
IMU	Inertial Measurement Unit
MR	Mixed Reality
SDK	Software Development Kit
VR	Virtual Reality
VRE	Virtual Reality Environment
VRMI	Virtual Reality Music Instrument

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## 1. Introduction

### 1.1. Reason

#### 1.1.1. Graduation assignment

I'm doing my graduation within the Immersive Media project Orchestra VR, spanning two quartiles working together with a group of students on a solution. In this case the product to be build is a VR (Virtual Reality) application prototype where users can play instruments in VR. For the bigger part the project is about the gloves from Sense Glove, these aren't available to the public yet. The gloves track finger movement and eventually we should get to use the prototypes that feature have force and haptic feedback. We also have a motion tracking system available to us that works with individual trackers by Enliven 3D.

#### 1.1.2. Client company outline

The Virtual Dutch Men is the main client for the project. The Virtual Dutch Men was first launched as a subsidiary of Archivision and was founded in 2014 to house the VR projects the company started pursuing. This happened around the time Oculus Rift and other VR technologies started to pop up, the Virtual Dutch Men being one of the first companies to seek contact with the companies building the VR systems. In 2017 the two companies have merged to continue as The Virtual Dutch Men.

### 1.2. Objectives

#### 1.2.1. Question of the client

Build a prototype where the user can play music instruments with the Sense Glove virtual reality gloves optionally combined with the Enliven 3D motion capture system. There should be at least one instrument, but when possible rather multiple, captured as close as possible to how the real instrument would play. Optionally it would be nice if the environment would react (visually) to the music played.

#### 1.2.2. Products or services that are needed

At its base the project is set up to research and test the capabilities of the gloves (and the Enliven 3D motion sensor system) and to see what can be done with it interaction wise.

#### 1.2.3. Parties concerned

The main stakeholder is The Virtual Dutch Men, we can contact them for support with programming or the gloves/motion capturing system. Furthermore Sense Glove and Enliven 3D are also involved with their technology and support. Next to that Saxion together with the students are also stakeholders.

#### 1.2.4. Team and our plan

I work on this project together with the students Luca Frösler and Mattia Lorenzetti. Luca will do programming and other tasks and Mattia will be handling nearly all of the visual aspects with all the modeling, texturing and the writing of shaders. I myself am chosen as leader so next to the programming I will do the managing, organizing and planning of the main project next to my own graduation. The idea is to work iteratively in two week long sprints during the project, starting with very crude versions of instruments.



### 1.2.5. What does the client want to do with the results?

At the end of the project The Virtual Dutch Men wants a video of a demonstration showcasing actual musicians playing instruments in VR with the Sense Gloves (where we can optionally involve the Enliven 3D motion tracking system).

Because we are working with prototypes, much of this will be new and knowledge gained might be interesting to parties involved.

### 1.2.6. Limiting conditions & project boundaries

We are working with prototypes and have been warned about how the systems might not be user friendly. At the beginning of the project we will be even working with older less advanced prototypes. Due to some hassles (not to be disclosed) the Enliven 3D motion tracking system has gotten less focus.

The Virtual Dutch Men have set the following project criteria:

- The prototype should contain at least one instrument (multiple if possible) captured as close as possible to the real deal.
- Optional: Have the environment reacting to the music played.
- Optional: Play together with others.

Deliverables should be:

- Detailed instrument concept(s) challenging the limits of the technology involved.
- A prototype VR application where the user can play music using the Sense Glove (and Enliven 3D motion tracking system).
- A visual interesting portfolio item for all parties involved (promo video).

The deadline for the project was broadly defined: the end of the Immersive Media project, at the beginning of July when the presentation should be held. For my graduation this moment comes earlier.

## 2. Preliminary problem definition

Creating a VR application to play music instruments is a good use case for testing the capabilities of the gloves. When successful it will be a nice way of showing the possibilities of the gloves, displaying musicians playing instruments in VR comfortably will certainly help support it.

### 3. Theory framework

#### 3.1. VR Gloves

Gloves that track finger movement and communicate the measurements with a computer have been around since the 1980's. These gloves are called data gloves (Holland-Moritz, n.d.).

##### 3.1.1. Data gloves

Before VR systems like the Oculus Rift and HTC Vive started to break through these gloves only got much attention from the industrial sector. With exceptions like Nintendo releasing its 'Power Glove' in 1989 for the NES (Nintendo Entertainment System), recognizing 256 different hand positions, the first data glove concept for video games. NASA was the first to pursue VR with data gloves (Holland-Moritz, n.d.).

An example of today's industrial use of data gloves is in car manufacture. During production it is used to check if workers are holding the right parts or are performing the tasks in line with the process. They are also used to simulate the assembly before it's being built (Holland-Moritz, n.d.).

Data gloves are also used to teach adaptable robot arms by recording human movement, creating robots that support humans in their work (Holland-Moritz, n.d.).

### 3.1.2. The current state of VR gloves

Table 1

#### Competing gloves compared

	CaptoGlove	Dexmo exoskeleton	Gloveone	Hi5 gloves
Applications	AR (Augmented Reality), VR, regular gaming, robotics, healthcare and drone control	AR, VR and MR (Mixed Reality) (with training, medical, educational and gaming) and motion capture	VR	VR
Platform support	Smartphones (Android & iOS), computers (Windows), smart TV's and drones.	Computer, Oculus Rift, HTC Vive PSVR and HoloLens	Computer (Windows)	Computer (Windows)
SDK / Plugins	C++, C#, Unity and Unreal Engine	LibDexmo	C++, C# and Unity	Unity and Unreal Engine
Input latency	-	25ms – 50ms	-	± 5ms
Third party arm tracking required	Yes	Yes	Yes	Yes
Force feedback	No	Yes	No	No
Haptic feedback	No	No	Yes	Yes
Wireless	BTLE 4.0	NRF	BTLE	2.4 GHz RF
Battery	Yes	2000mAh LiPo	800mAh LiPo	Replaceable AA
Battery life	10 hours	6 hours	4 hours	3 hours
Weight	-	320g	-	105g
Washable	Yes	-	-	-
Purchasable	Yes	Yes	No	Yes
Price	\$ 870,-	TBD / \$ 12.000,-	-	\$ 999,-
Source(s)	("Buy CaptoGlove online and get worldwide shipping," n.d.; "Captoglove," n.d.; "Plug & Play, cross platform compatibility and more features - CaptoGlove," n.d.)	("Dexta Robotics," n.d.; "Preorder - Dexta Robotics," n.d.; My digital life, n.d.)	("Gloveone: Feel Virtual Reality," n.d.)	("Home   Hi5 VR Glove," n.d.)

Table 2

*Competing gloves compared continued*

	HaptX	Manus VR gloves	Senso Glove	VRfree glove system
Applications	VR (training, simulation, location-based entertainment and design and manufacturing)	VR (training simulations, arcades) and motion capture	VR and AR	VR
Platform support	Computer	Computer (Windows), HTC Vive, Xsens, PhaseSpace, OptiTrack and Vicon	Computer and Smartphone (Android)	Computer
SDK / Plugins	HaptX SDK, Unity and Unreal Engine	Unity, Unreal Engine and Motion Builder	C++, Android, Unity and Unreal Engine	Unity and Unreal Engine
Input latency	-	5ms	10ms	<30ms
Third party arm tracking required	Yes	Yes	No	No
Force feedback	Yes	No	No	No
Haptic feedback	Yes	Yes	Yes	No
Wireless	No	2.4 GHz	Yes	Yes
Battery	No	Varta power cells	Yes	700mAh
Battery life	-	3-6 hours	10 hours	'Long'
Weight	-	68.5g	-	-
Washable	-	Yes (inlay)	-	-
Purchasable	No	Yes	Yes	No
Price	-	€ 1990,-	\$ 599,-	-
Source(s)	("HaptX   Haptic gloves for VR training, simulation, and design," n.d.; "Technology   HaptX," n.d.)	("Manus VR   Order the Manus VR Development Kit," n.d.; "Product information datasheet," 2017)	("Senso   Senso Glove   Senso Suit," 2017; "Senso VR   Interactive virtual and augmented reality," n.d.)	("VRfree glove system," 2017; "VRfree glove system   Indiegogo," n.d.)



Figure 1. Captoglove ("Captoglove," n.d.).

Captoglove started out as a tool for the rehabilitation of stroke victims (Morgan, 2018). The gloves are touch screen compatible and with them you can use gestures to control for example drones that are controlled by a smartphone ("Plug & Play, cross platform compatibility and more features - Captoglove," n.d.)



Figure 2. Dexmo exoskeleton ("Dextra Robotics," n.d.).

The Dexmo exoskeleton by Dextra Robotics uses NRF (2.4 Ghz radio frequencies) for wireless communication as Bluetooth and Wifi were deemed inefficient for data transfer (Morgan, 2018). The glove features 11 degrees of freedom and has an overall input latency between 25ms and 50ms due to the roundtrip the data makes because the glove is also receiving ("Dextra Robotics," n.d.). The force feedback can deliver a maximum torque of 0.3N.m for each finger ("Preorder - Dextra Robotics," n.d.).



*Figure 3. Gloveone ("Gloveone: Feel Virtual Reality," n.d.).*

Gloveone is a Kickstarter project by NeuroDigital Technologies that can be used with Leap Motion and Intel RealSense for better tracking. The early version only had haptic feedback and didn't have tracking. Each glove features a 9-axis IMU (Inertial Measurement Unit) sensor and features a sensor for each finger to track movement. For gestures the gloves have conductive area on the palm, thumb, index and middle finger for detection without false positives or negatives. For haptic feedback each glove has 10 actuators for located at the finger tips and in the palm area ("Gloveone: Feel Virtual Reality," n.d.).



*Figure 4. Hi5 Glove ("Home | Hi5 VR Glove," n.d.).*

The Hi5 glove by Noitom tracks the hand with a 9 degrees of freedom IMU. The glove is designed for use with the HTC Vive tracker for arm tracking. For haptic feedback each glove has a vibration motor on the wrist. The fabric used is breathable and antibacterial ("Home | Hi5 VR Glove," n.d.).



*Figure 5. HaptX glove ("HaptX | Haptic gloves for VR training, simulation, and design," n.d.)*

Designed for industrial use, the gloves being developed by HaptX can provide five pounds of resistive force per finger for force feedback. Custom magnetic tracking of the fingers and software simulation gives each finger 6 degrees of freedom and develops an accurate hand model without any coding. This way tracking is sub millimeter precise and can be done without occlusion. Patented microfluidic technology used in flexible silicone-base material contain actuators that are controlled with air providing continuous haptic feedback. A second layer of microchannels is used to add temperature feedback with hot and cold water. This way you can to feel shape, movement, texture and temperature of virtual objects. This technology can also be applied to other areas than gloves. The ultimate goal of HaptX is to use this technology to develop a full body suit including a large scale exoskeleton capable of applying forces to arms and legs ("Technology | HaptX," n.d.). The gloves have to be connected to a machine that regulates airflow to tiny actuators fitted in the glove for haptic feedback (Morgan, 2018).



*Figure 6. Manus VR gloves ("Manus VR | The Pinnacle of Virtual Reality Controllers.," n.d.).*

Each Manus VR glove has an IMU for detecting hand orientation. Arm tracking the gloves has been tested with multiple third party tracking solutions. Each finger contains two sensors for tracking except for the thumb which has one extra to measure rotation. Each glove has a vibration motor located at the wrist area that can be felt at the back of the hand. ("Product information datasheet," 2017).



*Figure 7. Senso Glove ("Senso | Senso Glove | Senso Suit," 2017).*

The Senso Glove is equipped each with 7 IMU sensors for hand and finger tracking and has a built-in SteamVR module so it doesn't require additional trackers when a HTC Vive set up is used. For haptic feedback each finger has a vibration motor at the tip ("Senso | Senso Glove | Senso Suit," 2017).



*Figure 8. VRfree glove system ("VRfree glove system," 2017).*

This pair of gloves by Synsoryx comes with a device that is attached to the HMD (Head Mounted Device) of the VR systems. The hand tracking is done with the device attached to the HMD and the gloves with less than 30ms latency localization, so it doesn't require any third party tracking ("VRfree glove system," 2017). Communication goes from the gloves to the HMD mount to the system it is connected to. The finger tracking is done with IMUs placed on the finger segments for ("Finger tracking," 2017).



### 3.1.3. Sense Glove



*Figure 9. Sense Glove DK1 ("Develop | Sense Glove," n.d.).*

Originally the Sense Glove was intended to help with hand rehabilitation. With the gloves it's possible to record all the hand motions the users makes during rehabilitation sessions so progress can be measured while simulating daily tasks in a VRE (Virtual Reality Environment) ("Projects | Sense Glove," n.d.; "Sense Glove," n.d.).

The gloves are designed for VR and AR. Next to that the gloves can also be used as input device for tele-robotics, remote operating humanoid grippers. They can also be used for interaction with CAD (Computer Aided Design) software so users can interact with the virtual models before the physical version is created ("Sense Glove," n.d.).

The intended features for the gloves that are going to be sold are:

- 20 degrees of freedom finger tracking
- 10ms input latency
- IMU based tracking for each joint
- Haptic feedback
- Force feedback
- Physics based SDK

("Sense Glove," n.d.)

To use the gloves wirelessly an optional adaptor package will also become available. This package will use Bluetooth for communication and the battery included has a battery life of 3 hours. Third party tracking solutions can be mounted to these packages. A set of gloves will cost € 999,- and the wireless packages € 299,- ("Pre-order | Sense Glove," n.d.).

The force feedback only works in the grasping direction, being only able to brake the fingers with a maximum force up to 7N per fingertip. For the haptic feedback function the glove is equipped with haptic

motors for each finger for contextual cues. The gloves that are going to be sold should weigh 300 grams each without the wireless package ("Develop | Sense Glove," n.d.).



*Figure 10. Sense Glove prototypes*

The prototypes used in this project do not have sideways finger tracking, no haptic- and force- feedback functions and can't be made to work wirelessly.

### 3.1.4. Gloves compared

The companies behind the VR gloves set out with different objectives as some only featuring tracking like the CaptoGlove and VRfree glove as can be read from tables 1 and 2, or weird enough were developed other features first like the Gloveone having haptics before actual finger tracking ("Gloveone: Feel Virtual Reality," n.d.).

Surprisingly only the VRfree glove system comes with its own arm tracking ("VRfree glove system," 2017) and only the Senso Glove comes with build in tracking modules for the HTC Vive ("Senso | Senso Glove | Senso Suit," 2017).

The gloves feature varying degrees of freedom for the finger tracking where VRfree is marketed with a full degree of freedom for finger tracking ("VRfree glove system | Indiegogo," n.d.) others like CaptoGlove don't mention this value ("Plug & Play, cross platform compatibility and more features - CaptoGlove," n.d.) so quality is not expected to be the same. My estimation is that the Sense Glove is in the middle to high segment with the mentioned 20 degree of freedom finger tracking ("Sense Glove," n.d.).

There are different ideas about haptic feedback as the Hi5 ("Home | Hi5 VR Glove," n.d.) and the Manus gloves only have vibration motors at the wrist location ("Product information datasheet," 2017) and the gloves like the Gloveone ("Gloveone: Feel Virtual Reality," n.d.) and the Senso Glove have vibration motors for each finger ("Senso | Senso Glove | Senso Suit," 2017) as will the Sense Glove DK1 ("Develop | Sense Glove," n.d.).

It's important to keep input latency low as can be read from the tables 1 & 2 everyone tries to do this with their gloves but some systems not only send data but also receive data so direct comparisons can't be made ("Dexta Robotics," n.d.; "VRfree glove system," 2017).

As can be read from the tables 1 and 2 wireless functionality is very important since all VR gloves being sold have the function but sadly for the Sense Glove DK1 wireless packages are sold optionally ("Pre-order | Sense Glove," n.d.).

Sense Glove is ambitious featuring force feedback ("Sense Glove," n.d.) as only the Dexmo exoskeleton is a commercial glove that also features it ("Dexta Robotics," n.d.) that has been priced at \$ 12.000 (My digital life, 2017, p. 0) way higher than the price of a set of Sense Gloves with optional wireless packages with a combined price of € 1.298,- ("Pre-order | Sense Glove," n.d.).

### 3.2. Virtual reality music instruments

There's a lot of information to be found about virtual music instruments synthesizing sound with software, less about VRMI (Virtual Reality Music Instruments) which also delivers a visual component being displayed by something like an HMD. Due to low cost solutions like the Oculus Rift and the HTC Vive becoming available VRMI's have become more interesting (Serafin, Erkut, Kojs, Nilsson, & Nordahl, 2016).

#### 3.2.1. VRMI Design principles

In the article titled 'Virtual Reality Musical Instruments: State of the Art, Design Principles, and Future Directions' by Serafin, Erkut, Kojs, Nilsson and Nordahl (2016) nine design principles are outlined for designing VRMI's.

##### **Design for feedback**

Design instruments for sound, visual, touch and a sense of position (proprioception) to work together and recognize the ratio between these subjects. It's important to develop these senses in tandem. For sound it is important to utilize 3D sound for the origins of the sounds to match up to the visual objects locations. Development of musical skills rely heavily on haptic and tactile feedback and is highly relevant to musical performance (Serafin et al., 2016).

##### **Reduce latency**

Lag between the sensory perceptions (audio, visual and touch) should be minimal because this can influence the perceptual binding that occurs while responding to an event. It is critical that VRMI's respond timely and synchronized to user actions. Reducing latency also helps decreasing the chance of cyber sickness (Serafin et al., 2016). In academia this is often called 'simulator sickness' and is quite common among people using a HMD (Lewis-Evans, 2014).

##### **Reduce the chance of cyber sickness**

Cyber sickness can occur when there is a conflict in the information from the visual and vestibular senses. This can occur when a player would be moving in game but in reality standing still (Lewis-Evans, 2014; Serafin et al., 2016). People experienced with a certain activity in real life might be more susceptible to cyber sickness than novices when performing the activity due to being more sensitive to the expected movement not lining up (Lewis-Evans, 2014).

Other factors might be display flicker, low framerate, uncontrolled movement, bad ergonomics and uncalibrated VR hardware. Unrealistic movement like a tie camera instead of a turret like camera for a human character or uncontrolled movement are also factors (Lewis-Evans, 2014; Serafin et al., 2016).

The effects of cyber sickness can be eye strain, headaches, having problems standing up, sweating, disorientation, vertigo, loss of color to the skin, nausea and vomiting. This can occur during usage but also afterwards and can persist for hours. It can sometimes even come back later (Lewis-Evans, 2014).

Movement and rotations should be mapped one-to-one between the VR and the real world. While a player should be moving in VR but is stationary in the real world acceleration and deceleration should be kept to a minimum (Lewis-Evans, 2014; Serafin et al., 2016). Rapid tilting, rolling and sinewave like movement (in particular between 0.05 and 0.8 Hz) should be avoided. The height of camera is important, the closer it is to the ground results in a higher sense of speed. By limiting the field of view you can reduce the sense of speed thus reducing the chance of cyber sickness (Lewis-Evans, 2014).

### **Make use of existing skills**

Replicated interfaces of traditional instruments can be made more interesting by extending them with additional controls. Familiarity with the original instruments helps playing the virtual counterpart but this experience might also mean that the users dislike the virtual instrument if it doesn't behave the same way. Adding controls with real world metaphors can offer interesting outcomes (Serafin et al., 2016).

### **Consider natural and magical interaction**

Not designing instruments by real world constraints (laws of physics, human anatomy) qualifies an instruments as magical. Both interaction types (natural and magical) can be used at the same time extending controls by for example scaling instruments or the player so instruments normally out of their reach can be played without much movement (Serafin et al., 2016).

### **Display ergonomics**

With designing VRMI's you should take note of the strain and discomfort that the setup used imposes on the user improving ergonomics. For instance the HMD in the case of the HTC Vive and the Oculus Rift normally are still tethered by wire to the computer. The weight of the HMD is also notable (Serafin et al., 2016).

### **Sense of presence**

The sensation of presence or 'place illusion' is the experience of 'being there'. The illusion for the biggest part is up to the VR systems used, this can be characterized by the range of normal sensorimotor contingences supported by the system. It's advisable to design VRMIs with the limitations of the system in mind, not relying on the areas where the VR system is limited. Next to this body ownership is also a tool for the illusion (Serafin et al., 2016).

### **Represent the player's body**

Virtual body ownership is what is created when the virtual body is tracked and mapped correctly with the player's real world body. This can not only help with the immersion but also help training gestures for the player. Studies exploring the effects of realistic looking hands show that using abstract and iconic hands in VR gives a greater sense of agency then realistic versions. This might be due to users expecting more natural interaction with realistic looking hands (Serafin et al., 2016).

### **Social experience**

HMDs normally keep you from seeing the real world, blocking your vision of the people in the room having only one person immersed in the virtual world. To negate this multiplayer can be introduced using a similar setup or when performing on stage the audience can be shown the virtual world with the performer. When players are asked to play in front of a virtual (surrogate) audience they tend to respond in similar way to when they would play for a real audience (Serafin et al., 2016).

### 3.2.2. VRMI Evaluation framework

With these design principles a three layer evaluation framework can be created, also described in the article:

#### **Modalities of interaction**

1. Alignment between input and output modality/range for sound, visual, touch and a sense of position (these should be considered simultaneously).
2. Perceptual integration and mapping (based on perceptual, sensorimotor and cognitive abilities)
3. Latency for sensory perceptions (perceptual binding of audio, visual and touch senses)
4. Social or player performance factors
5. Ergonomics (fatigue, design for the limits of the VR solution)

(Serafin et al., 2016)

#### **VR specific**

1. Revisit latency for VR specifically (perceptual and motor tolerance) concerning cyber sickness
2. Concept of presence ( 'place illusion' and plausibility (is the scenario actually occurring?)) or engagement (keep the player interested), which might be better suited for VRMI's
3. Concept of agency (virtual body ownership and the ability to make meaningful actions)

(Serafin et al., 2016)

#### **Quality of goals and interaction ( 'meaning-making')**

1. Magical/natural mechanisms involved
2. Leveraging of expert techniques (musical expression)
3. Avoid breaks in presence (assess user experience without interrupting, take questionnaires after testing)

(Serafin et al., 2016)

### 3.2.3. Existing VRMI applications



Figure 11. The Music Room ("The Music Room: Unique Instruments, Inspiring Spaces in VR," n.d.).

With The Music Room created by Chroma Coda you can select from multiple drum kits, a laser harp, and the chord harp designed for The Music Room. For interaction you use regular VR controller like those of the HTC Vive. To simulate a kick drum the application comes bundled with a plugin so you can use regular headphone or microphone connected to the mic or line in on the computer as one. When tapping on the body of the headphone with your foot it triggers like a kick drum would. With the instruments you can control pitch, volume, timbre, velocity and more per note. The drum kits support positional sensing on the snares, 3 zones each cymbal and variable hi-hat control. Some features like rim shots or chocking cymbals requires you to hold a button when hitting for example a cymbal. For the environment you can pick from a studio, a practice room or a on stage area. The Music Room can be used as a MIDI or MPE controller for the use with DAWs (Digital Audio Workstations), it comes bundled with the Bitwig 8-Track DAW ("The Music Room: Unique Instruments, Inspiring Spaces in VR," n.d.).

You can use the following URL to see a demonstration video: <https://youtu.be/ggB5VJyArpQ>.

This application seems to be set up as to be an extension for DAWs. This way there are no problems with samples or recording you performance. Very early on when we were brainstorming we also had this idea but we were lacking the expertise to build it. There doesn't seem to be any lag when playing and controls seem intuitive although I imagine seeing the VR controllers don't help the sense of agency. The input isn't only done by how you hit something but also by holding buttons which can't be done really when you use all the fingers to interact with the instrument. From the videos the environments at times look like 360 degree photo's slapped to the inside of a sphere (or very simple geometry) which doesn't help the immersion.





Figure 12. MuX ("MuX op Steam," n.d.).

MuX by Decochon is available since December 2017 as early access title in the Steam store for a year. The developers take this time to see how the application is used and to take user feedback into account in the development process for the final version. User interaction is done with regular VR controllers ("MuX op Steam," n.d.). MuX is a sandbox where you can create your own modular synthesizer by connecting components, under the hood MuX is more like an audiovisual programming language. You are able to pick from more than 100 different components, divided up into generators, modifiers and event components. Signals created by generator components like oscillators, noise and metronomes can be used to create sound or to control other components. Modifier components like filters or arithmetic components can be used to change signals with operations like add, multiply and divide. With event components you can wire together multiple components and perform dispatch, compare and gate operations ("MuX - Build Sound," n.d.). You can for example also build things like Rube Goldberg devices to use gravity and marbles to trigger sounds ("MuX op Steam," n.d.).

For a video showing some of the components you can use this URL: <https://youtu.be/zCmDfq97hqs>.

This application is more about creating your own instruments than playing them but there are a lot of possibilities that most certainly will keep you engaged. It's very unlike anything we came up with during early brainstorming although at some point we had the idea to use building blocks for looping music like beats. It's very technical and doesn't really rely on user input for triggering the sound in a certain way (like velocity for example). The visual style creates an environment you can't visit in real life which might help with immersion. From what I have seen from videos the application at times has some video lag which I imagine only increases with the amount of components.



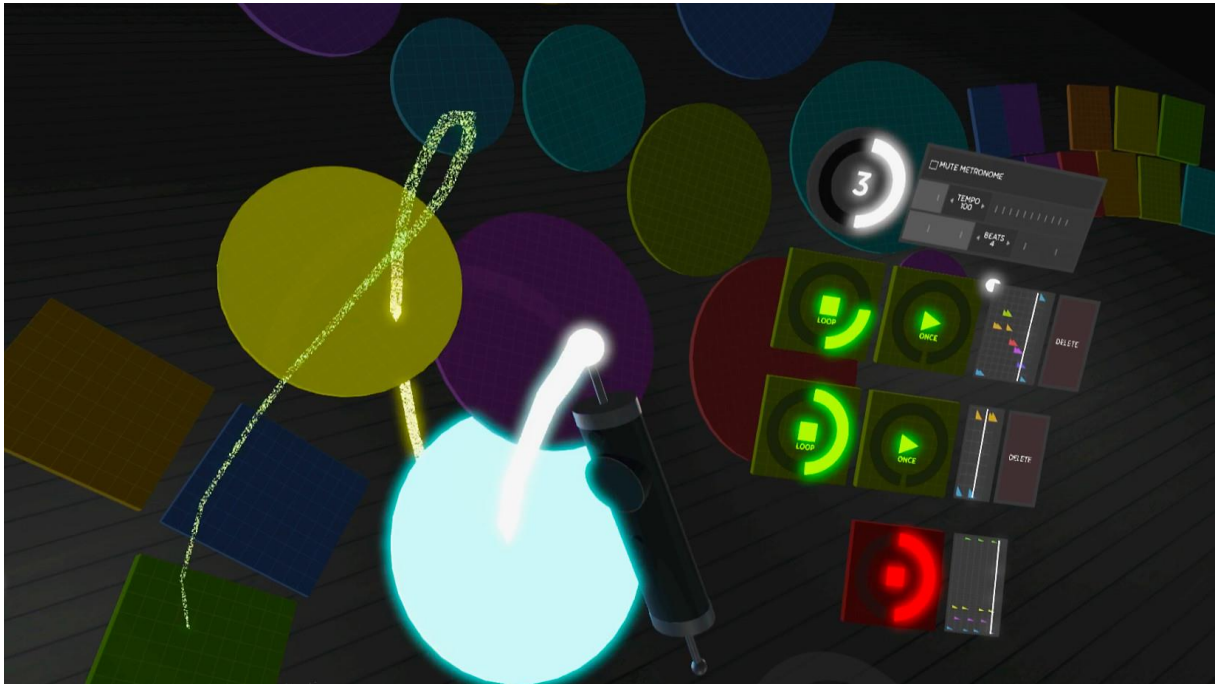


Figure 13. EXA: The Infinite Instrument ("EXA: The Infinite Instrument," n.d.).

EXA is a work in progress VR application that is available with early access in the Steam store since March 2017. New features are still being implemented and it is being perfected with feedback by the users. For user input only regular VR controllers are used. To trigger sound musical flat shapes or lines are used called ringers. Ellipse, square and triangular ringers behave like drums, line ringers behave like strings. Both types can be drawn with drawing tool. Tools like for example drawing, selecting, striking and muting can be attached to the controllers in the VRE to the top end and some can be attached to the bottom end of the controller. The ringers glow and resonate visibly when being hit. The audio samples come from Soundfont packages. EXA comes with multiple piano, drum, guitar, string and synth packages while other packages can also be loaded and used. Furthermore you are able to record your performance and make multiple loops who all respond to changing the project tempo and can be played and stopped individually ("EXA: The Infinite Instrument," n.d.).

For a demonstration video you can use the following URL: <https://youtu.be/WB22jFgcRko>.

EXA has a simple visual style which is very responsive to the music performance, I haven't noticed any audiovisual latency. You can create your own instrument but the focus is still on the performance. Input can be very precise with just regular VR controllers. The recording of the performance and using loops is something we wanted to build into the project but we won't have enough time to do so. Being able to load sample packages opens the door to a lot of genres. We are adding sample presets to the instrument but without external sample package loading.

### 3.3. Three-dimensional audio in Unity with headphones

In the previous theory chapter about VRMI it got mentioned that 3D audio is an important component to the immersion and I think it also opens the door to creative options.

When searching for information on 3D audio in conjunction with VR and Unity you quickly end up with information about audio spatializers. When using a VR system like the HTC Vive or Oculus Rift you will probably also make use of headphones. Spatial audio is also known as 3D stereo sound and can also be used when listening to music or watching a movie ("Spatial Audio - Microsoft Research," n.d.).

To simulate how human ears would perceive sound in the virtual environment audio spatializers take HRTFs (Head Related Transfer Functions) into account ("Unity - Manual: VR Audio Spatializers," n.d.). HRTF is a set of measurements describing the directivity pattern of human ears. These measurements depend on the direction, elevation, distance and the frequency of the sound and is used to calculate how a sound reaches the left and right ear separately. ("Spatial Audio - Microsoft Research," n.d.).

HRTFs were first used when binaural recordings were made of live concerts in 1950. These were recorded by using a mannequin head with two microphones placed at the ears. When listening to these recordings with headphones it creates to effect of being acoustically there ("Spatial Audio - Microsoft Research," n.d.).

Unity has native support for audio spatializers and comes with two out of the box which can be selected in the audio manager of the Unity project. The 'Oculus Spatializer' which supports the Android, OSX and PC platforms and the 'Microsoft HRTF Spatializer' which runs on UWP (Universal Windows Platform) and Windows 10. After selecting an audio spatializer you only need to check the 'spatialize' checkbox on the audio sources you want spatialized ("Unity - Manual: VR Audio Spatializers," n.d.)

There's also support for third party spatializers like Steam Audio by Valve and Google's Resonance Audio ("Getting started with Resonance Audio for Unity | Resonance Audio | Google Developers," n.d.; "Steam Audio," n.d.). Both plugins support Unity on Windows, Mac OS X, Android and Linux, with the exception of Google Resonance also supporting iOS (Gould, 2018).

Microsoft's HRTF Spatializer while being designed for mixed reality is being rather featureless, basically only having the setting to set the room size to small, medium or large for audio sources in Unity (Turner, Park, Zeller, Cowley, & Bray, 2018). Because of this I continue this chapter only with the other three plugins.

The plugins vary a little bit when it comes to 'acoustic shadowing' with what lower frequencies get filtered out. The simulated ear closest to the audio source will receive the full frequency range of the sound while the other ear will have a slight delay and high frequencies will be filtered because of the head that is supposed to be in between the audio source and the ear (Gould, 2018).

Periphony, or vertical sound, is not the easiest thing to achieve. The plugins differ slightly for example in how dark an audio source sounds when it is below the user, sometimes this might sound a bit towards being muffled. Also what is left intact of the lower frequencies of the sound might differ slightly. For sound sources above the user the tone color differs slightly between the plugins. It helps a lot for the sound source to have a visual representation and/or changes in the position of the audio source to be extreme for being more obvious (Gould, 2018).

For more specialized features the three plugins offer extended functionality with their own Unity components that extend standard Unity components (Gould, 2018). These features are not easily compared as directly as the ones previously mentioned.

The Oculus Spatializer provides its own attenuation curve which can be used instead of Unity's standard logarithmic curve to determine at what volume a sound should be heard at what distance, also providing minimum and maximum distance customization option for the audio source. Next to that another feature is provided that lets you set a volumetric radius. In this radius the sound should give a positional feel of Omni-presence not just being loud alone. There's also a build in 'near-field effect' feature that automatically switches special rendering on and off if a sound is within arms-length away. There is a gain control provided with this feature because some sounds can become too loud this way (Gould, 2018).

Steam Audio provides a physics based attenuation model that is designed to have a realistic decrease of volume over distance. Next to that there is the feature called 'air absorption' which when enabled decreases the volume of higher frequencies earlier than the lower frequencies making sound at a distance less bright. Steam Audio also features sound occlusion, with this feature you can tag geometry with different materials like wood and stone. Sound would bleed more through wood than it would through stone. The default mode uses a single Raycast. This is like drawing a line from the audio source to the audio listener to see what material it comes into contact with. The second option has a higher CPU usage is called 'partial' and uses multiple lines instead of one, the size of the column of lines can be adjusted with the 'source radius' setting. This way the occlusion can be done gradually evaluating with the lines which get obstructed and which who aren't obstructed. Changes happening to the occlusion geometry model on the fly (like opening and closing a door) isn't taken into account, therefore the system is static (Gould, 2018).

Resonance Audio doesn't come with custom attenuation and uses Unity's attenuation by default but has a feature called 'directivity'. With this feature you can control the shape of the audio source, with this you can make it narrower than the standard spherical shape. This will effect what is heard when the audio source is behind the user or when the user is at the back of the audio source, muffling the sound, extending the HRTF feature. The occlusion method build into Resonance Audio uses a single Raycast and doesn't make use of a material system but instead has an intensity option you can customize on the audio source to set the maximum occlusion level. Unlike the occlusion system used in Steam Audio this occlusion system does handle live changes. Like the Oculus Spatializer there's also a 'near-field effect' feature which unlike the Oculus Spatializer you have to enable yourself in the audio source settings (Gould, 2018).

#### 4. Problem definition

In a discussion with the company supervisor and my graduation teacher in week 5 of my graduation the assignment was adjusted to not require carbon copies of the instruments but to give us the freedom to be more creative. This was done because at that point it was already expected there was only a slim chance we would receive the newer prototypes to work with during the project.

The assignment is to create a VR application where the users can play music in VR in an intuitive way. The aim is to develop one or more VRMI, these don't necessarily need to be a carbon copies of real-world counterparts. During the iterative process the project now can also head into the direction of developing and designing something unique for VR together with the gloves.

The main interest of The Virtual Dutch Men is to create a video to be displayed on the internet demonstrating the application to create exposure, preferably featuring a famous professional musician. This ups the difficulty of the project as learned from the research about VRMI, musicians will expect more precise response than novices because of what they expect from playing in the real world.

Secondly the application could be used by Sense Glove in the future as a demonstration tool for when they are visiting conventions demonstrating their gloves.

My graduation will be about the designing of the VRMI and focus on the quality to the musicians, not the video. Making sure the senses are linked and decrease the chance of cyber sickness. It's also important to strive for good immersion with the user having feeling of being in the VRE and working player body representation. Having an environment where you can't go in real life and using iconic hands help with this. An easy way of adding immersion is to add audio spatialization since VR users often use headphones, so I will install an audio spatializer plugin in the project. During the development I will keep the design principles to designing VRMI in mind and test for them by developing a questionnaire for the testing of the prototype with musicians at the end of iterations.

## 5. Main and sub questions

### 5.1. Main question

"How to design virtual reality music instruments in Unity using the Sense Glove virtual reality gloves"

### 5.2. Sub questions

**"What are the features of the Sense Glove virtual reality gloves and how can they be used for VRMIs?"**

I have added this question to help figure out the possibilities and limitations of VR gloves in general and the prototypes and how the features can be used to design VRMI.

**"What has to be considered to design virtual reality music instruments?"**

I ask this question to see if there are existing best practices for designing music instruments for virtual reality environments.

**"How to set up 3D audio for headphones up in Unity?"**

This question got added during researching previous question. Immersion is factor in pulling off a VRMI therefore I added this question since 3D audio can aid immersion a lot.

## 6. Scope

Where the main project will be about the complete experience this report will be focused on the development of an VRMI (or multiple) using the Sense Gloves. Due to it being unclear when or even if we will receive the newer glove prototypes my primary focus will be on the feature set of the gloves we already received to work with (this is excluding the haptic- and force- feedback features).

Hardware problems with the gloves is off limits to us since we were told not to try and fix the gloves ourselves if problems arise and just send the gloves to Sense Gloves.

Since there is only one VR development pc with an HTC Vive and one set of gloves available for the project I will have to work on it together with another student.

I will not be researching areas like the psychology behind the gloves or the VR experience since this is not my area of expertise.

## 7. Methodology

Throughout the project the design principles found in the theory framework were followed.

At the end of each sprint a meeting should be arranged with the musician(s) onboard with our project to come by and test the progress at that point and provide us with feedback for the next iteration by speaking/thinking aloud during the test and also by doing a questionnaire afterwards.

I developed the questionnaire with the design principles for designing VRMIs from the theory chapter (this includes 3D audio) and the workings of the gloves in mind and can be found in the annexes section, the annex is called "Questionnaire 1.0".

The first group of questions of the questionnaire is about responsiveness. The participant is asked about the responsiveness of sound, visuals (broken down into instrument and environment) and touch (tracking) at the moment of playing the instrument. For each of these senses the participant is asked to rate the latency on scale from 1 to 10. It's also asked if one of these senses distract from one another. One use for this data is to check if the moments of feedback get linked, like the feeling of actually playing the instrument and not for it to feel detached because of maybe there's too much latency between hitting a key and hearing it.

The next group of questions is about cyber sickness, which should be reduced as much as possible. For this topic the participant is asked about the video smoothness (framerate) and if there are any (annoying) flickering lights displayed during testing. Furthermore the participant is asked for thoughts on locomotion (like teleporting) when it is implemented. For ergonomony questions about real world to virtual environment mapping for the tracking would normally be included here but since this is done by the HTC Vive and Sense Glove systems this is out of our hands and won't be asked. However the participant is asked how much of hassle the VR set up is to put on and use and to rate this on a scale from 1 to 10.

The following group of questions is about existing skills. The participant is asked about how familiar and intuitive the instrument feels for checking with existing skills the participant has.

For the magic factor there's another group of questions where the participant is asked what his or her opinions are on how the instrument is extended beyond the possibilities of the real world and if he or she has feedback or ideas for extending the instrument beyond the laws of physics and or human anatomy.

For immersion the participant is asked if he or she has the feeling of actually being in the virtual environment, to see whether or not the 'place illusion' is working. Which is a question standing on its own. For the topic of player body representation the questions about the correctness of the body tracking and if the virtual hands feel real to see if there is a sense of agency are grouped.

Concerning the social experience the participant is asked the single question if the response of the virtual environment to the playing of the instrument is giving a sense like performing in front of an audience. Other features like incorporating a virtual crowd or recording features so performances can be captured potentially making the application have a multiplayer experience are beyond the project time frame and therefore not included.

I later updated the questionnaire because at first I designed it to ask the questions myself at the end of test sessions and then to write down the answers myself but when testing with Rob Maas, the musician

onboard with our project, he already started to fill in the questionnaire himself. So I clarified a lot of the questions and added hints to steer towards certain answers I wanted to receive because in some cases they were off and not really usable. I removed hints being too technical and removed the question about locomotion since that feature got scrapped. For the question about rating the hassle of using the VR setup I added the indicated that it ranges from bad to good. The updated questionnaire can be found in the annexes section as the annex with the title "Questionnaire 1.1".



## 8. Results

Questionnaire answers by:				
Cas ter Horst after testing during iteration 5	Sven Ordelman after testing during iteration 5	Rob Maas asked about previous progress evaluation at iteration 6 (without testing)	Rob Maas after testing at the end of iteration 6	Rob Maas after testing during iteration 7
<b>Responsiveness</b>				
<ul style="list-style-type: none"> <li>How do you like the sound responsiveness when playing the instrument? Is the sound linked to what you play are does it feel detached?</li> <li>How would you rate the latency from 1 to 10?</li> </ul>				
Good, 7	Good, 8	There is still a lot of latency to deal with. 5	Good. 8	Good. 8
<ul style="list-style-type: none"> <li>What do you think of the visual response of the instrument when playing? Is there for example lag to the animation?</li> <li>How would you rate this on a scale from 1 to 10?</li> </ul>				
This wasn't really visible (key movement), 5	Nice, 8	In general good, except for some glitches due to retriggering mistakes. 6	Good. 8	Good. 8
<ul style="list-style-type: none"> <li>What do you think of the response of the dynamic visuals of the environment when you play the instrument?</li> <li>How would you rate this on a scale from 1 to 10?</li> </ul>				
This question wasn't asked because this feature was missing at the time.	This question wasn't asked because this feature was missing at the time.	This question wasn't asked because this feature was missing at the time.	The spectrum bars are too small. 5	Good. 8
<ul style="list-style-type: none"> <li>What do you think of the response of the instrument to your movement? (tracking)</li> <li>How would you rate this on a scale from 1 to 10?</li> </ul>				
You auto correct for inaccuracy, 7	Let's not talk about that (pretty bad). The hand in game seems to small (length of the fingers don't match up) , 6	In general almost OK, although the position of lower arm and hand are sometimes awkward from a pianistic perspective. 5	It's very bad. 2	Very bad. 2

Does one of the senses (sound, visual, tracking) distract from one another?				
The flashing on the hands is standing out	No doesn't distract	No	The finger tracking does!	Yes, the tracking
<b>Cyber sickness</b>				
How did you experience the framerate? Is it smooth? Was there any stuttering?				
Okay	Good	Good	Good	Smooth
Did you experience any (annoying) flickering? Like, did lights flicker to fast?				
Yes, flashing on the hand	Weird flickering lights on hand	No	No	No
<ul style="list-style-type: none"> <li>How much of a hassle is the VR setup to use?</li> <li>From bad to good how would you rate this on a scale from 1 to 10?</li> </ul>				
Okay, not too heavy to use (fatigue), 8	If it would work immediately it would be fine	A lot! 2	Very much! 2	A lot. 4
<b>Existing skills</b>				
How familiar does the virtual instrument feel?				
Visually the keyboard seems off. Pinky finger wasn't responding. Keyboard is a bit small (amount of keys)	Okay, but you can pass through. You somehow have to rest your hands in the air (fatigue).	Not familiar due to (arm/hand) positioning, missing haptics and playability	Still feels unfamiliar	n/a (because of the tracking)
How intuitive would you rate the instrument (on a scale from 1 to 10)?				
This was not asked as the keyboard was still being pretty standard.	This was not asked as the keyboard was still being pretty standard.	3	4	n/a
<b>Magical (go past the laws of physics / human anatomy)</b>				
What do you think of how we extended instrument usage beyond the possibilities in the real world?				
...	Passing through is not an advantage	There's no extension (yet)	There's no extension	n/a
Do you have feedback or ideas for us extending the instrument in ways not possible in real life?				
Be able to turn on a beat, be able to trigger samples like animal sounds (pads), have real keyboard functions (presets).	Swiping trough octaves on the keyboard. Swiping trough instruments (guitar/bass guitar).	Using gestures for sound control with one hand while playing with the other	Playing with one hand and gesturing with the other to control all sorts of parameters	Same as last time

Sense of presence				
Do you have the feeling of 'being there'?				
The keyboard is a bit out of place in the environment. The world isn't lively. Add shooting stars maybe.	You do know you're using VR.	Yes	Yes	Yes
Player body representation				
What do you think of the tracking of the arms and hands?				
In this case not really well, in-game the hand seems not wide enough. Wrist tracking is offsetting overtime.	Hands in game were smaller compared to the real world.	Still unrealistic due to lag and retriggering's	It's bad	Very bad
Do you feel like the hands in the virtual environment are yours?				
The fingers in the VRE seem to narrow.	Okay	Nope, they look like glitchy abstracts	Kind of...	Not like this
Social experience				
Do you feel that the dynamic visuals responding to what you play give a sense of giving a performance (like for a crowd)?				
The dynamic environment features weren't in place so this question wasn't asked.	The dynamic environment features weren't in place so this question wasn't asked.	The dynamic environment features weren't in place so this question wasn't asked.	Not yet...	n/a

Figure 14. Questionnaire answers combined.

Just before the gloves had to be sent away to Sense Glove for repairs I did some testing with the students Cas ter Horst and Sven Ordelman working in the same room as us, in case the gloves wouldn't return in time. For these tests only the right glove was used. Due to inexperience, the physics problem, scheduling conflicts and the gloves being away for repairs testing with Rob Maas was delayed until late in the project. The general theme in the answers given by Rob to the questionnaires is that the tracking is bad and it distracts from the other features. I could only arrange for two test moments after we received the gloves back. With the first test I was a bit overwhelmed by how bad the gloves were responding. Defects the gloves were sent away for were returning and wrist movement was behaving very unnatural. Before the second test with Rob I have tried to see what could be done about the tracking by testing the different modes of the SDK and wrote a script so we were able to use manual calibration for both gloves. While I wasn't having the same extreme problems they returned when Rob came by for testing again (even a Vive tracker holder broke). Resulting in the testing not being very fruitful.

### 8.1. "What are the features of the Sense Glove virtual reality gloves and how can they be used for VRMIs?"

Sadly I didn't get any development time with the newer prototypes during the course of this graduation report, so I will write about the old prototypes.

General finger tracking is the most basic feature a VR glove should have, for playing pieces of music the gloves fell short and the missing sideways finger tracking is a huge miss. In that sense, solutions that are already available on the market with finger tracking being their only feature seem a better option.

I can really imagine the haptic feedback being a nice addition, without having experienced gloves that have the feature I could already tell it would be a welcome addition to actually feel something when you touch a key in the application. Because sometimes even when using see through hand models fingers will still be somewhat obscured and when trying to play music softly it's not knowing when you hit but waiting for when you hit. The continuous feeling sensation like the HaptX gloves are capable of would be awesome but that won't be featured on any commercially available glove for a long time but short instances are better than nothing ("Technology | HaptX," n.d.).

All of the gloves researched in the theory framework except for the HaptX glove have a wireless ability which really would be a welcome feature (tables 1 and 2). Especially since the USB cables didn't click into the connector or is held into place another way and thus disconnected easy during usage. Related to this was an unwanted 'feature' was the internal chip going into sleep, only to be fixed by reconnecting the glove.

At the end of the project itself, after the timeframe of this report we will have development time with the newer prototype and I would be very happy to make use of the haptic and force feedback functions. The tracking will also be way better with also having the sideways finger tracking. We already got to experience this with a demonstration. For the price the development kits will become available including the wireless packages, I think customers get a good deal. The only other glove I have come across that also features haptic and force feedback is the HaptX glove which isn't purchasable any time soon (table 2).

### 8.2. "What has to be considered to design virtual reality music instruments?"

Early on we were developing multiple instruments like a piano, drum and a xylophone. After the first few sprints we realized it was better to focus on one instrument and finalize it to maybe then work on another when there's still time available.

The synthesizer keyboard was the instrument that we decided to build first as we were advised by Tim Moelard of The Virtual Dutch Men at the start of the project from his experience with the newer prototypes and by Rob because of the possibility of playing music with samples of different instruments while focusing on one instrument.

When I tried to implement the script I made to change the volume of the sample being played when a user hits a key it didn't work. This was because of the colliders of the fingers were set to be kinematic and therefore weren't giving a relative velocity value. Because of this I have written a script that can be put on objects like the fingers that compares the distance between the position of the object on the previous frame and the current frame returning a velocity value that can be accessed by other scripts. The kinematic setting for the colliders are probably enabled because the fingers of the gloves and the Vive

trackers (for the arms) get updated each frame and shouldn't be affected by physics to be positioned to the real world positions.

For the keys to be animated originally we tried to use hinges, which are build-in Unity components that also enable you to create doors for example. The problem was that even after locking positional and rotational axis you were still able to push the keys away in ways that shouldn't happen. I tried to see if we could make use of configurable joints (that also come with Unity) but they didn't seem to be the fix we were looking for.

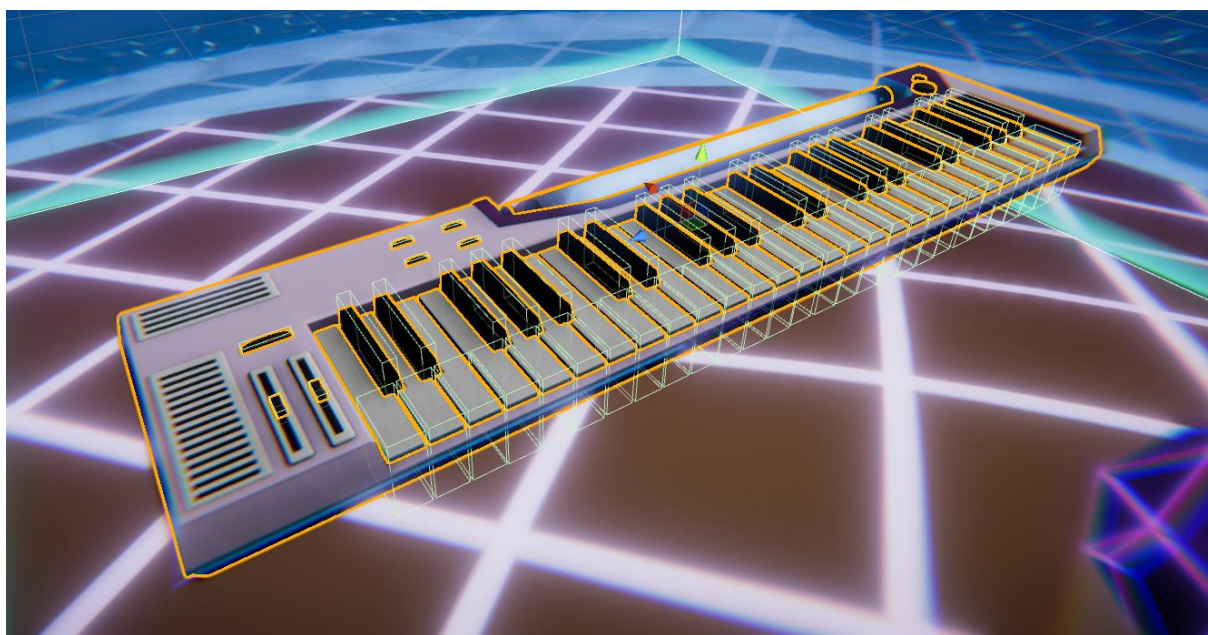


Figure 15. The synthesizer keyboard shown with the colliders visible

After there was no real progress for a week I contacted Hans Wichman, a teacher at Saxion, to help us fix the problem. The solution by Hans doesn't use physics but uses a collider area for each key, spanning from just the top surface of the key downwards to be just tall enough for keys to be pressed down like in the real world. The user now only interacts with the collider area not with the visual key object. The rotation of the visual key is calculated by how far a finger is down from the top of the collider. This happens only when the finger travels downward, also fixing the problem being able to trigger sound when the finger came from below. At the same time the velocity of the 'hit' is measured for the volume.

To load different sample presets the keyboard has four buttons to change between them. For the key objects to load the different samples I created a script that when one of these buttons is pressed an event gets triggered where the key objects script are subscribed to. With the event the preset name from the preset enumerator housed in the keyboard script is also passed (like Piano or Synth). To show which preset is currently active we have the button glowing and pulsing slightly to hint that a user can interact with the buttons. Each preset button has a different color which can be changed in the Unity editor. For the glow to toggle on and off I created a script that on

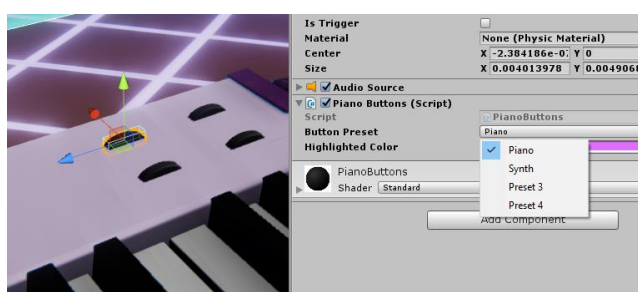


Figure 16. Preset button script component

triggering the event first toggles the current preset button's glow off and then toggles the glow for the pressed button on. Because the first preset, the Piano preset, is loaded in the key objects at initialization of the application the first button is toggled to glow by script at the start also. As Figure 14 shows it got pointed out to us by all the test participants the scale of the keys were off so when Rob came by for the first test we scaled the entire keyboard down to when it felt right.

For the keys I wrote a script that is applied to all the key objects, that loads and plays the samples. To be able to select what sample should be played I created an enumerator listing all the notes. There's a variable that stores the note for that key that can be selected in the Unity editor. When a sample is loaded on initialization or when the event is triggered the current selected preset name gets used for the sub folder name (these are the same) in the resources folder and for the audio file the note of the key is used for the filename. When touched the keys were made to also glow to indicate interaction as the animation of the key wasn't always as noticeable very well as was pointed out by Cas and Sven during testing as can be read in Figure 14.

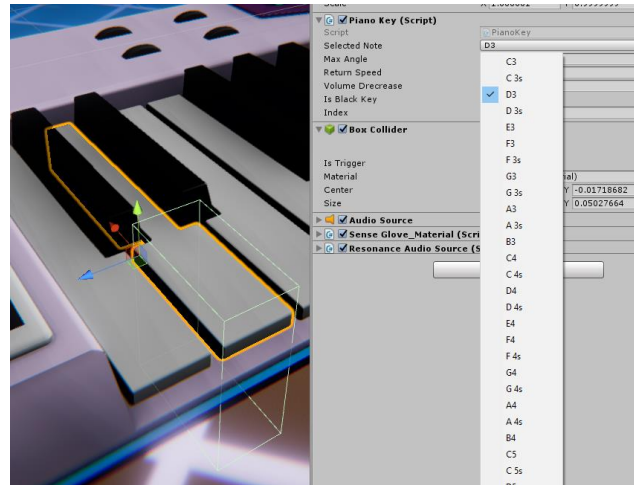


Figure 17. Key script component

The keyboard also features a toggle button for sustain which I didn't create but helped out to add a fade out effect, the volume immediately being zero when you let go of a key was too drastic.

For a dynamic environment effect we used a script found online that created spectrum bars. We adapted it to appear at the horizon, having more bars, scaled up much bigger and changed the appearance.

The environment as also pointed out by the test participants is important to the 'place illusion' giving the sense of being in the VRE which is important for the experience with the instrument. Since the first tests with Cas and Sven features like planets in the sky, little boats in the distance and an animated waves on the beach got introduced to aid the effect. The instrument itself also got an visual update to better fit the environment.



### 8.3. “How to set up 3D audio for headphones up in Unity?”

The spatializer plugin I chose is Google’s Resonance Audio. The feature set is very close to that of Steam Audio only we didn’t need the material based occlusions system since the teleportation got scrapped. Resonance Audio also requires a little bit less of set up. Because we are working with HTC Vive and thus the Steam VR SDK the Resonance Audio Listener script had to be applied to the ‘Camera (ears)’ object within Steam VR’s camera rig hierarchy to enable the user hearing spatialized sound. For the keyboard instrument each key object had already been set up with a standard Unity Audio Source. To have spatialized sound it must be enabled in the standard Audio Source and the Resonance Audio Source script needs to be added. For an extra effect I added a Resonance Audio Room to the area where the user is located to add some reflectivity to the floor with the properties of grass, leaving the other sides of the room transparent as the location is outside.

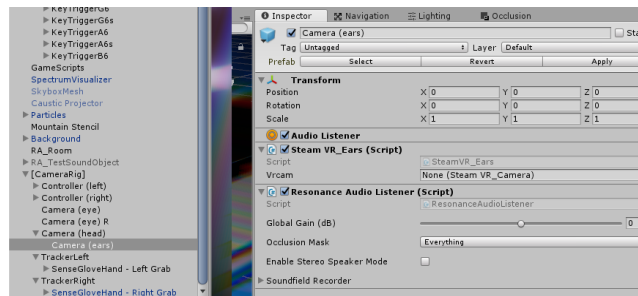


Figure 18. Steam VR camera rig & Resonance Audio Listener

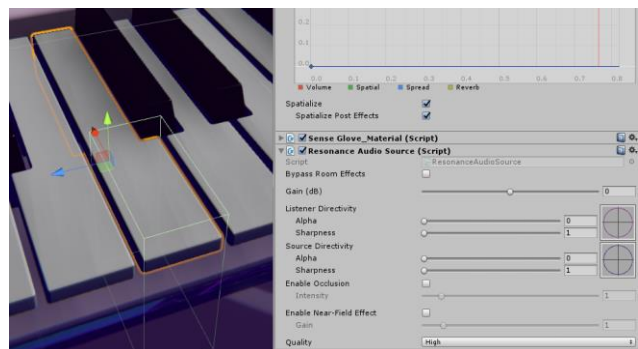


Figure 19. Resonance Audio Source

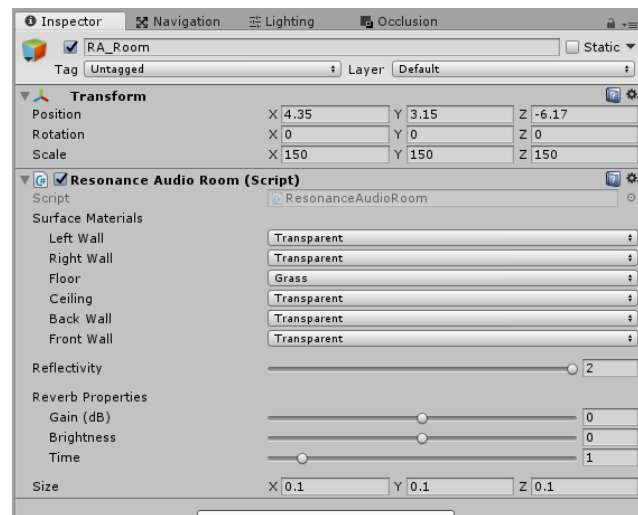


Figure 20. Resonance Audio Room settings

## 9. Conclusion and discussion

Early on we did have a few feedback moments with Rob Maas but the instrument's development hadn't progressed enough for extensive testing and the questionnaire wasn't ready at that stage. Progress was slow due to the level of programming experience and small team size. Scheduling conflicts, the gloves being sent away for repairs and these problems all following each other up were the cause of having little time left for testing, resulting in me being able to arrange for two test moments with Rob. It would have been nice to have had multiple musicians onboard with the project but that didn't happen because of the same reasons.

Because the colliders in Unity placed at the fingers tips of the gloves are kinematic you can basically push anything that collides away. Therefore you cannot solely rely on physics based solutions for controls to VRMI but have to develop your own response for interaction.

For drawing the conclusions on the instrument designed I will make use of the VRMI evaluation framework described in the theory framework:

As testing with Rob proved the instrument shows no delay with audiovisual feedback that disconnects the senses so the responses feel linked to the user input. The sense of touch (tracking) for that matter was problematic and here the haptic feedback would have been a great addition. The arm tracking is fine which is done by the HTC Vive trackers but each time the wrist positions got reset it started to offset over time and finger tracking was off to start with. This caused the mapping of the instruments velocity response to go unnoticed. The reconnecting and recalibration required during testing are negative factors to the ergonomics of the entire setup. The design of the instrument also didn't stay clear within the limits of the prototypes with the missing sideways finger tracking which is required to play music pieces, but I suspect the newer versions we get to use after the timeframe of the report won't have these drawbacks. As the answers to the questionnaires show the dynamic environment effect in place didn't give a sense of giving a performance so the instrument has no social factor for that matter.

During testing there were no problems with cyber sickness reported. As the visuals were smooth and the audiovisual feedback was linked there was no reason to revisit the latency for these components. For touch or interaction it was a different case but out of our hands. As can be read from the tests with Rob the place illusion is working, 3D audio has been implemented but is not used in creative ways. The engagement factor can't really be measured with the gloves faulty tracking, which also negatively affected the virtual body ownership.

The instrument is very much like the real world counterparts ensuring natural mechanisms. Next to being able to pass through the instrument with your hands there are no magical mechanisms that extend the instruments functionality beyond what is possible in the real world. With the state of the gloves it couldn't be really tested how the instrument was leveraging expert techniques from playing instruments in the real world and it continuously caused pauses in the testing process, making it impossible to focus on the testing itself.



## 10. Recommendations

For future project developing VRMI I recommend to work iteratively and as we have tried to, test early on with multiple musicians. For designing the VRMI it's important to focus on magic mechanics extending the instrument beyond what is possible in the real world, this makes the instrument more engaging. For the development of controls for the VRMI I recommend to not use physics solutions but to program your own so you have more control over limits. For easily adding immersion and possibilities to your project I suggest making use of an audio spatializer.

For the time remaining after the timeframe of the graduation report I recommend working on the social experience and the magic mechanisms. By adding more dynamic environment effects responding to the music that are more notable to hopefully still give the feeling of giving a performance. For example for the magic mechanism of the instrument to add some sort of gestural control to control effects being applied to the music played.

At the end of the project we will have some development time with the newer prototypes so haptic feedback should get added, if possible the braking of the fingers by the force feedback would be a very welcome addition when touching the keys. It's important to use the newer prototypes wirelessly for recording the demonstration video for the best outcome.

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## 12. Annexes

### 12.1. Questionnaire 1.0

The questionnaire I develop with the information from the VRMI theory chapter.

<b>Responsiveness (latency)</b>	
How do you like the sound responsiveness when playing the instrument? How would you rate the latency from 1 to 10?	
What do you think of the visual responsiveness of the instrument when playing? How would you rate this on a scale from 1 to 10?	
What do you think of the visual responsiveness of the environment when playing the instrument? How would you rate this on a scale from 1 to 10?	
What do you think of the response to your movement? (tracking) How would you rate this on a scale from 1 to 10?	
Does one of the senses distract from one another? Do you feel that at times there is too much feedback? (of all the senses)	
<b>Cyber sickness</b>	
How did you experience the framerate? Is the video smooth? Was there any stuttering?	
Did you experience any (annoying) flickering? Did lights flicker to fast? (calm/smooth visuals)	
What do you think of the locomotion / teleporting?	
(Ergonomics) How much of a hassle is the VR setup to use? How would you rate this on a scale from 1 to 10?	
<b>Existing skills</b>	
How familiar does the virtual instrument feel?	
How intuitive would you rate the instrument (on a scale from 1 to 10)?	
<b>Magical (past the laws of physics, anatomy)</b>	
What do you think of how we extended instrument usage beyond the possibilities in the real world? laws of physics / human anatomy	
Do you have feedback or ideas for us extending the instrument in ways not possible in real life?	
<b>Sense of presence</b>	
Do you have the feeling of 'being there' (place illusion)?	
<b>Player body representation</b>	
What do you think of the tracking of the arms/hands/fingers?	
Do you feel like the hands in the virtual environment are yours? (Sense of agency (abstract/iconic hands help))	
<b>Social experience</b>	
Do you feel the interaction with the virtual environment does add something extra? (Like performing (for a crowd))	

## 12.2. Questionnaire 1.1

The updated questionnaire where I clarified the questions and use hints to steer towards certain answers I would like to receive because in some cases they were off. I removed hints being too technical and removed the question about locomotion since the feature got scrapped. For the question about rating the hassle of using the VR setup I have now indicated that the range is from bad to good.

<b>Responsiveness</b>	
How do you like the sound responsiveness when playing the instrument? Is the sound linked to what you play are does it feel detached?	
How would you rate the latency from 1 to 10?	
What do you think of the visual response of the instrument when playing? Is there for example lag to the animation?	
How would you rate this on a scale from 1 to 10?	
What do you think of the response of the dynamic visuals of the environment when you play the instrument?	
How would you rate this on a scale from 1 to 10?	
What do you think of the response of the instrument to your movement? (tracking)	
How would you rate this on a scale from 1 to 10?	
Does one of the senses (sound, visual, feel or tracking) distract from one another?	
<b>Cyber sickness</b>	
How did you experience the framerate? Is it smooth? Was there any stuttering?	
Did you experience any (annoying) flickering? Like, did lights flicker to fast?	
How much of a hassle is the VR setup to use?	
From bad to good how would you rate this on a scale from 1 to 10?	
<b>Existing skills</b>	
How familiar does the virtual instrument feel?	
How intuitive would you rate the instrument (on a scale from 1 to 10)?	
<b>Magical (go past the laws of physics / human anatomy)</b>	
What do you think of how we extended instrument usage beyond the possibilities in the real world?	
Do you have feedback or ideas for us extending the instrument in ways not possible in real life?	
<b>Sense of presence</b>	
Do you have the feeling of 'being there'?	
<b>Player body representation</b>	
What do you think of the tracking of the arms and hands?	
Do you feel like the hands in the virtual environment are yours?	
<b>Social experience</b>	
Do you feel that the dynamic visuals responding to what you play give a sense of giving a performance (like for a crowd)?	

### 12.3. Questionnaire 1.0 - Cas ter Horst (after testing during iteration 5)

The questionnaire was taken before the gloves were sent to Sense Glove for repairs. Only the right glove was used for testing, while also having defects the left glove was worse.

<b>Responsiveness (latency)</b>	
How do you like the sound responsiveness when playing the instrument? How would you rate the latency from 1 to 10?	Good, 7
What do you think of the visual responsiveness of the instrument when playing? How would you rate this on a scale from 1 to 10?	This wasn't really visible (key movement), 5
What do you think of the visual responsiveness of the environment when playing the instrument? How would you rate this on a scale from 1 to 10?	This question wasn't asked because this feature was missing at the time.
What do you think of the response to your movement? (tracking) How would you rate this on a scale from 1 to 10?	You auto correct for inaccuracy, 7
Does one of the senses distract from one another? Do you feel that at times there is too much feedback? (of all the senses)	The flashing on the hands is standing out
<b>Cyber sickness</b>	
How did you experience the framerate? Is the video smooth? Was there any stuttering?	Okay
Did you experience any (annoying) flickering? Did lights flicker to fast? (calm/smooth visuals)	Yes, flashing on the hand
What do you think of the locomotion / teleporting?	This question wasn't asked because teleportation wasn't implemented at the time.
(Ergonomics) How much of a hassle is the VR setup to use? How would you rate this on a scale from 1 to 10?	Okay, not too heavy to use (fatigue), 8
<b>Existing skills</b>	
How familiar does the virtual instrument feel?	Visually the keyboard seems off. Pinky finger wasn't responding. Keyboard is a bit small (amount of keys)
How intuitive would you rate the instrument (on a scale from 1 to 10)?	This was not asked as the keyboard was still being pretty standard.
<b>Magical (past the laws of physics, anatomy)</b>	
What do you think of how we extended instrument usage beyond the possibilities in the real world? laws of physics / human anatomy	...
Do you have feedback or ideas for us extending the instrument in ways not possible in real life?	Be able to turn on a beat, be able to trigger samples like animal sounds (pads), have real keyboard functions (presets).
<b>Sense of presence</b>	
Do you have the feeling of 'being there' (place illusion)?	The keyboard is a bit out of place in the environment. The world isn't lively. Add shooting stars maybe.
<b>Player body representation</b>	

What do you think of the tracking of the arms/hands/fingers?	In this case not really well, in-game the hand seems not wide enough. Wrist tracking is offsetting overtime.
Do you feel like the hands in the virtual environment are yours? (Sense of agency (abstract/iconic hands help))	The fingers in the VRE seem to narrow.
<b>Social experience</b>	
Do you feel the interaction with the virtual environment does add something extra? (Like performing (for a crowd))	The dynamic environment features weren't in place so this question wasn't asked.

#### 12.4. Questionnaire 1.0 - Sven Ordelman (after testing during iteration 5)

For these results it's the same story as previous questionnaire results by Cas ter Horst. It's taken before the gloves were sent to Sense Glove for repairs and only the right glove was used for testing.

<b>Responsiveness (latency)</b>	
How do you like the sound responsiveness when playing the instrument? How would you rate the latency from 1 to 10?	Good, 8
What do you think of the visual responsiveness of the instrument when playing? How would you rate this on a scale from 1 to 10?	Nice, 8
What do you think of the visual responsiveness of the environment when playing the instrument? How would you rate this on a scale from 1 to 10?	This question wasn't asked because this feature was missing at the time.
What do you think of the response to your movement? (tracking) How would you rate this on a scale from 1 to 10?	Let's not talk about that (pretty bad). The hand in game seems to small (length of the fingers don't match up), 6
Does one of the senses distract from one another?  Do you feel that at times there is too much feedback? (of all the senses)	No doesn't distract
<b>Cyber sickness</b>	
How did you experience the framerate? Is the video smooth? Was there any stuttering?	Good
Did you experience any (annoying) flickering? Did lights flicker to fast? (calm/smooth visuals)	Weird flickering lights on hand
What do you think of the locomotion / teleporting?	This question wasn't asked because teleportation wasn't implemented at the time.
(Ergonomics) How much of a hassle is the VR setup to use?  How would you rate this on a scale from 1 to 10?	If it would work immediately it would be fine
<b>Existing skills</b>	
How familiar does the virtual instrument feel?	Okay, but you can pass through. You somehow have to rest your hands in the air (fatigue).
How intuitive would you rate the instrument (on a scale from 1 to 10)?	This was not asked as the keyboard was still being pretty standard.
<b>Magical (past the laws of physics, anatomy)</b>	
What do you think of how we extended instrument usage beyond the possibilities in the real world? laws of physics / human anatomy	Passing through is not an advantage
Do you have feedback or ideas for us extending the instrument in ways not possible in real life?	Swiping trough octaves on the keyboard. Swiping trough instruments (guitar/bass guitar).
<b>Sense of presence</b>	
Do you have the feeling of 'being there' (place illusion)?	You do know you're using VR.
<b>Player body representation</b>	
What do you think of the tracking of the arms/hands/fingers?	Hands in game were smaller compared to the real world.



Do you feel like the hands in the virtual environment are yours? (Sense of agency (abstract/iconic hands help))	Okay
<b>Social experience</b>	
Do you feel the interaction with the virtual environment does add something extra? (Like performing (for a crowd))	The dynamic environment features weren't in place so this question wasn't asked.

### 12.5. Questionnaire 1.0 - Rob Maas (about previous progress at iteration 6)

This questionnaire was taken without testing directly prior to measure progress of the project until then.

<b>Responsiveness (latency)</b>	
How do you like the sound responsiveness when playing the instrument? How would you rate the latency from 1 to 10?	There is still a lot of latency to deal with 5
What do you think of the visual responsiveness of the instrument when playing? How would you rate this on a scale from 1 to 10?	In general good, except for some glitches due to retriggering mistakes. 6
What do you think of the visual responsiveness of the environment when playing the instrument?  How would you rate this on a scale from 1 to 10?	This question wasn't asked because this feature was missing at the time.
What do you think of the response to your movement? (tracking)  How would you rate this on a scale from 1 to 10?	In general almost OK, although the position of lower arm and hand are sometimes awkward from a pianistic perspective 5
Does one of the senses distract from one another?  Do you feel that at times there is too much feedback? (of all the senses)	No
<b>Cyber sickness</b>	
How did you experience the framerate? Is the video smooth? Was there any stuttering?	Good Yes None
Did you experience any (annoying) flickering? Did lights flicker to fast? (calm/smooth visuals)	No No
What do you think of the locomotion / teleporting?	This question wasn't asked because teleportation wasn't implemented at the time.
(Ergonomics) How much of a hassle is the VR setup to use?  How would you rate this on a scale from 1 to 10?	A lot! 2
<b>Existing skills</b>	
How familiar does the virtual instrument feel?	Not familiar due to (arm/hand) positioning, missing haptics and playability
How intuitive would you rate the instrument (on a scale from 1 to 10)?	3
<b>Magical (past the laws of physics, anatomy)</b>	
What do you think of how we extended instrument usage beyond the possibilities in the real world? laws of physics / human anatomy	There's no extension (yet)
Do you have feedback or ideas for us extending the instrument in ways not possible in real life?	Using gestures for sound control with one hand while playing with the other
<b>Sense of presence</b>	
Do you have the feeling of 'being there' (place illusion)?	Yes
<b>Player body representation</b>	
What do you think of the tracking of the arms/hands/fingers?	Still unrealistic due to lag and retriggering's

Do you feel like the hands in the virtual environment are yours? (Sense of agency (abstract/iconic hands help))	Nope, they look like glitchy abstracts
<b>Social experience</b>	
Do you feel the interaction with the virtual environment does add something extra? (Like performing (for a crowd))	The dynamic environment features weren't in place so this question wasn't asked.

### 12.6. Questionnaire 1.0 - Rob Maas (after testing at the end of iteration 6)

This questionnaire was taken the first available moment after the gloves were back from repairs. During the testing the gloves showed problems with tracking, disconnecting and even defects returning. This can be noticed as a returning theme in the answers of multiple questions.

<b>Responsiveness (latency)</b>	
How do you like the sound responsiveness when playing the instrument?	Good
How would you rate the latency from 1 to 10?	8
What do you think of the visual responsiveness of the instrument when playing?	Good
How would you rate this on a scale from 1 to 10?	8
What do you think of the visual responsiveness of the environment when playing the instrument?	The spectrum bars are too small
How would you rate this on a scale from 1 to 10?	5
What do you think of the response to your movement? (tracking)	It's very bad
How would you rate this on a scale from 1 to 10?	2
Does one of the senses distract from one another?	The finger tracking does!
Do you feel that at times there is too much feedback? (of all the senses)	
<b>Cyber sickness</b>	
How did you experience the framerate?	Good
Is the video smooth?	
Was there any stuttering?	No
Did you experience any (annoying) flickering?	No
Did lights flicker to fast? (calm/smooth visuals)	No
What do you think of the locomotion / teleporting?	This question wasn't asked because teleportation wasn't implemented at the time.
(Ergonomics) How much of a hassle is the VR setup to use?.	Very much!
How would you rate this on a scale from 1 to 10?	2
<b>Existing skills</b>	
How familiar does the virtual instrument feel?	Still feels unfamiliar
How intuitive would you rate the instrument (on a scale from 1 to 10)?	4
<b>Magical (past the laws of physics, anatomy)</b>	
What do you think of how we extended instrument usage beyond the possibilities in the real world? laws of physics / human anatomy	There's no extension
Do you have feedback or ideas for us extending the instrument in ways not possible in real life?	Playing with one hand and gesturing with the other to control all sorts of parameters
<b>Sense of presence</b>	

Do you have the feeling of 'being there' (place illusion)?	Yes
<b>Player body representation</b>	
What do you think of the tracking of the arms/hands/fingers?	It's bad
Do you feel like the hands in the virtual environment are yours? (Sense of agency (abstract/iconic hands help))	Kind of...
<b>Social experience</b>	
Do you feel the interaction with the virtual environment does add something extra? (Like performing (for a crowd))	Not yet...

### 12.7. Questionnaire 1.1 - Rob Maas (after testing during iteration 7)

Also during the testing before this questionnaire was taken, even with having tried fixing some problems, the behavior of the gloves was bad with the same problems returning as with the previous test.

<b>Responsiveness</b>	
How do you like the sound responsiveness when playing the instrument? Is the sound linked to what you play are does it feel detached?	Good
How would you rate the latency from 1 to 10?	8
What do you think of the visual response of the instrument when playing? Is there for example lag to the animation?	Good
How would you rate this on a scale from 1 to 10?	8
What do you think of the response of the dynamic visuals of the environment when you play the instrument?	Good
How would you rate this on a scale from 1 to 10?	8
What do you think of the response of the instrument to your movement? (tracking)	Very bad
How would you rate this on a scale from 1 to 10?	2
Does one of the senses (sound, visual, tracking) distract from one another?	Yes, the tracking
<b>Cyber sickness</b>	
How did you experience the framerate? Is it smooth? Was there any stuttering?	Smooth
Did you experience any (annoying) flickering? Like, did lights flicker to fast?	No
How much of a hassle is the VR setup to use?	A lot
From bad to good how would you rate this on a scale from 1 to 10?	4
<b>Existing skills</b>	
How familiar does the virtual instrument feel?	n/a (because of the tracking)
How intuitive would you rate the instrument (on a scale from 1 to 10)?	n/a
<b>Magical (go past the laws of physics / human anatomy)</b>	
What do you think of how we extended instrument usage beyond the possibilities in the real world?	n/a
Do you have feedback or ideas for us extending the instrument in ways not possible in real life?	Same as last time
<b>Sense of presence</b>	
Do you have the feeling of 'being there'?	Yes
<b>Player body representation</b>	
What do you think of the tracking of the arms and hands?	Very bad

Do you feel like the hands in the virtual environment are yours?	Not like this
<b>Social experience</b>	
Do you feel that the dynamic visuals responding to what you play give a sense of giving a performance (like for a crowd)?	n/a

## 12.8. Virtual DAW concept

At the start of the project I made my own concept. The team didn't agree with it but it served as the base for the concept that got used eventually when it got build off during a brainstorm session.

### Concept with elements of a DAW

#### Environment

Like a dark void but with fog in the distance and a faint hilly geometry in the distance. When no music is playing the general lighting is faint. When music plays (holographic) lights appear around you in forms like waveforms, sine waves, wave bars and effects like circuits on a circuit board, sparks/lightning (different effects for instruments). Drawing some inspiration from the 80s (from movies like TRON).

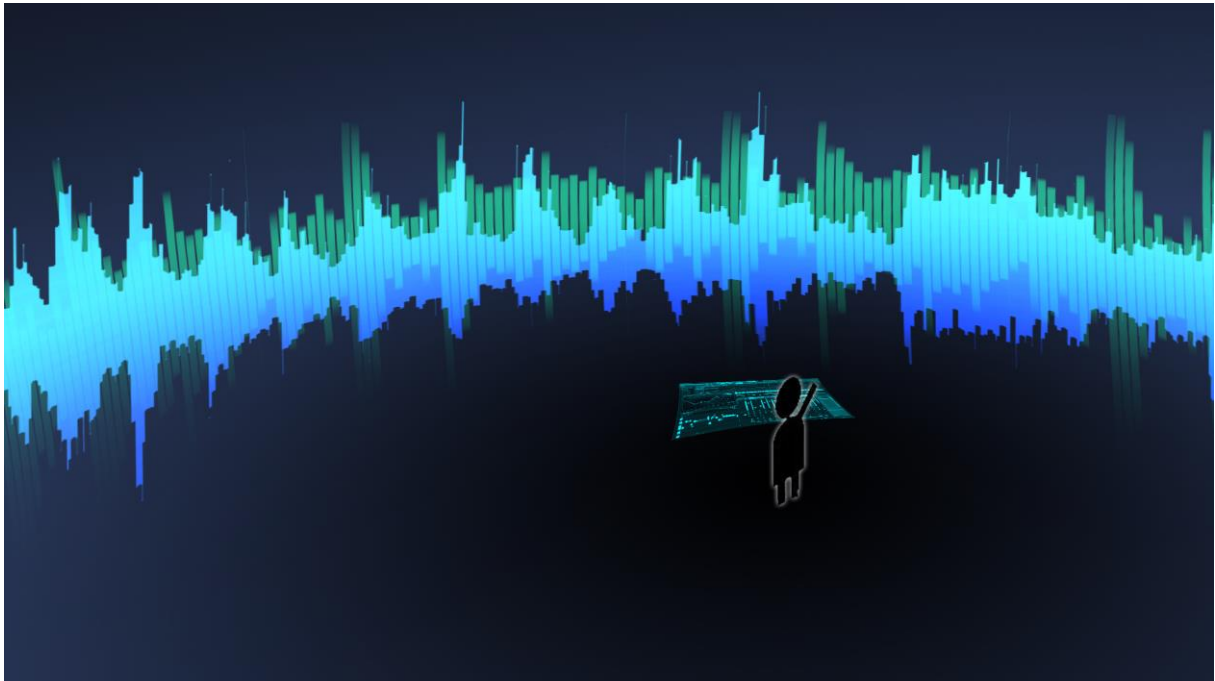


Figure 21. Environment mockup I created

#### Features

Have features you would have in a DAW like a mixer and some sort of track overview displayed in a holographic style. Per track you can select an instrument and 'activate' it there, so you can actually hold it and play it like in real life.

Also part of the features are: recording what you play, muting and soloing tracks, surround panning, a metronome and the ability to play instruments like:

- Keyboard/Synthesizer
- Hang Drum
- Shakers
- Xylophone
- Harp
- Bongos
- Flute
- Guitar



## **Audio**

To be more immersed in the virtual world we want to make use of HRTF audio. This will make the perceived sound seem more real and easy to locate in 3D space, enabling us to use the full potential of audio combined with VR. Enabling us to make use of surround panning.

## **Moscow**

### **Must have:**

- Be able to play at least 1 music instrument with the Sense Gloves in VR
- Have at least one type of visualization of sound in the environment to make for an exciting experience
- Recording object: tracks as virtual objects called 'recordings' being able record what is being played
- Pick an instrument at the object
- Volume distance based from center of environment
- Simple surround panning by moving the object
- Central mixing console object
- Spawn recording objects
- Faders for volume control of each object
- Mute/solo each recording object
- Play/stop session
- Start recording
- Session playback
- Deleting tracks

### **Should have:**

- Have multiple ways/types of visualizing music played in the environment
- HRTF audio
- Be able to play multiple instruments
- Import / export session file.
- Central mixing console
- Metronome toggle
- Project BPM settings
- Quantization of recordings
- Option to swap between center microphone and user hearing

### **Could have:**

- Render session to an audio file like a WAV file.
- Automated surround panning (record the position during playback)

## 12.9. Iteration progress write up

### 12.9.1. Starting out

At the very start of the project Bart Kok and Tim Moelard of Virtual Dutch Men came by delivering the glove prototypes and giving a mini workshop on how to set up the gloves. At this time Tim also gave us the advice to develop a keyboard or piano first. He already had the chance of trying the prototypes with the force and haptic feedback features and to him it seemed like that was our best option.

We also got informed that the read out on the right pinky finger was responding erratic and basically not working. Later it got explained to us by Max Lammers from Sense Glove that the problem with the old prototypes is that the contact surfaces wear over time, giving weird voltage readouts. Normally the gloves should be able to do up to 1 million of flexing and extending movements. In the newer prototypes magnetic parts are used to solve this.

### 12.9.2. Before the first iteration

As advised by the Tim a workaround for the faulty readout would be to in this case copy the data from the ring finger as we are discouraged to try and fix the hardware ourselves. I had figured out where the glove data gets read in the SDK, to duplicate sensor data, but then the pinky finger seemed working again.

Another problem we experienced during the project is that the left glove occasionally just stops working, without the USB connection being disconnected (which also happens a lot by accident). As explained by Max Lammers of Sense Glove this is due to the IMU sensor in the glove gathering all the data is going in to 'sleep' and the SDK not trying to 'wake it up'. This is solved by disconnecting and reconnecting the USB cable.

Upon delivery there was a wrist strap for one of the Vive Trackers missing. We use the trackers of the HTC Vive VR system to track arm movement. The Sense Gloves only track wrist and hand movement. An order was placed at Sense Glove but because this took time we build a solution ourselves by using Velcro and a 3D printed holder for the tracker, which uses a screw normally used by tripods to attach the tracker.

### 12.9.3. First iteration

A few weeks into the project working on the concept for the main project we decided on that the environment should a deserted island with 80's T.R.O.N. style wireframe graphics. This helps creating the experience you can't experience in real life and can help immersion. We also generated a list of instruments we wanted to try create like the piano, drum, harp and a Theremin.

The first stage was creating crude instruments, the first one we build was the drum. Made of simple shapes in Unity it played one simple sample on the same volume each time any object hit it. After that we continued creating a piano, also build with simple Unity shapes, with different samples for each key playing the same volume each time something hit it. The key's using hinges rotating according to objects hitting them.

### 12.9.4. Second iteration

The drum instrument was provided with multiple samples, triggering different samples each time it got hit. The idea was to link this to the velocity it got hit with.

At this stage we had a problem with samples being triggered too early again when it just was being played resulting into a stopping and playing again immediately. This becomes very noticeable when using samples with long tails. The problem was due to hitting the key from below again or multiple fingers hitting the same key.

To try and solve this we tried creating audio sources at the location where the finger hits the key that play the sample once and then are removed. Upon testing this proved to use up the sound channels very quickly resulting into not hearing new keystrokes after a short while. This is also noticeable faster when samples are used with long tails, because of the near silent parts still playing in the background.

At this time we were in contact with Rob Maas for future testing but also to bring us into contact with other musicians. No actual testing with musicians was done this iteration.

#### 12.9.5. Third iteration

The SoundOnCollision functions of the second iteration also proved unusable because there were too many audio sources very quickly by playing the piano. That way you don't hear the new samples that should be playing but the ones still playing finish. That's why we gave each key its own audio source.

Because of using the OnCollision function to trigger the sounds there was a latency introduced because of the order which Unity processes event functions. We decided to make use of the OnTriggerEnter function which seemed a better fit not having the latency when testing.

To determine how loud a sample should be played when testing I used the RelativeVelocity function available in Unity to measure how hard a key is hit. Because of the colliders at the fingertips set to kinematic the RelativeVelocity function just returns zero and the sample for the key would be played with zero volume. This is probably because of SteamVR and the Sense Glove SDK continuously setting the positions by script and basically aren't using the physics system in Unity. Because of this I build my own function comparing the distance of current position and the position the frame before.

We also noticed the hinges of the keys weren't set up how they should be. The keys were rotating around their center and not at the edge where they are attached. Only when we did try set this up correctly we noticed how troublesome this was. We did automate the loading of multiple samples from a folder for multiple keys and also tested sound synthesis with scripts but didn't get around fixing the hinges.

During the iteration we did have somewhat of a test with Rob and got some pointers but no actual data gathering has been done. Rob did let us know it probably was for the best pick one instrument to finalize for the sake of work but also bringing us into contact with musicians for the instrument. He also let us know the keyboard would probably be our best bet because with the same controls you could play multiple instruments with different samples.

#### 12.9.6. Fourth iteration

At the start of this iteration we had a meeting with Sense Glove and had Max Lammers over at Saxion. We did get some experience with the newer prototypes only to also find out we basically wouldn't have any development time with them since Sense Glove didn't have a set of them to spare. Only at the end of the main project, which is outside of the scope of this graduation report, there would be one week we could work with them.

During this iteration we decided with the amount of time it takes to work on a single instrument and the advice given by Rob and Tim (at the project start) we decided to finish the keyboard and then see if there would be time to finish another instrument.

For the huge physics problems we had with the hinges of the keys we were helped by Hans Wichman also a teacher at Saxion with a custom solution that doesn't use physics but calculates the rotation of the keys by how far down the finger is being placed.

Due to all kinds of scheduling problems no actual testing with Rob was done this iteration.

#### 12.9.7. Fifth iteration

The gloves were showing more faults and became unworkable for us and not suitable for testing. They couldn't be fixed when we had Max over so we had to decide to send them by mail to Sense Glove to be repaired.

We did start on one of the dynamic visual effects, we got spectrum bars reacting to sound being played to be displayed at the horizon.

Before sending the gloves away I did some testing with students to gather data. For these tests only the right glove was used. The answers to the questionnaires can be found in the annexes with the titles 'Questionnaire 1.0 - Cas ter Horst (after testing during iteration 5)' and 'Questionnaire 1.0 - Sven Ordelman (after testing during iteration 5)'.

The responsiveness is generally rated very well, a bit of a surprise was the visual response of the instrument not being noticed but this is something we wanted to address with extra visuals already.

A weird shader rendering problem got introduced this iteration that caused sporadic weird flickering on the gloves in the VRE and this didn't go unnoticed. It got confirmed the environment isn't lively yet that was indeed something on the to-do list.

I expected worse ratings for the ergonomics because the gloves aren't really that plug and play putting them on and aren't wireless. The left glove, not used with the testing, just cut out continuously.

The comments on the gloves in VRE being of in too narrow compared to real life I didn't expect, we haven't had that experience ourselves.

The comments about features on the instrument also show an area we are still working on. Features as presets (different sample sets) and modulation and pitch sliders is something we want to include.

#### 12.9.8. Sixth iteration

This iteration I lost an entire week of time because of problems with my jaw, making working impossible. I also worked less on the project because I needed to work on this report.

While still not having received the gloves back I did add a sample preset system to the keyboard. We also added a sustain feature and highlighting for the buttons so you can see what preset is active or if sustain is turned on. The keys of the instrument were also made to glow when being touched making the visual response more clear. We also researched how we could create sample presets more easily by automating part of the process.

After the gloves returned I immediately made appointments with Rob for testing, due to the little time left for this report I could only arrange for two tests.

Before the first test I asked Rob to fill in a questionnaire about the progress up until that point. It can be found in the annexes section with the title 'Questionnaire 1.0 - Rob Maas (about previous progress at iteration 6)'.

The first test, to end this iteration, didn't go very well. The tracking was off for both gloves, the wrist needed to be reset the entire time and the gloves kept disconnecting or had to be reconnected because of it going to sleep. The wrist movement for the right glove was twisting around instead of going from left to right and defects the gloves were sent away for were starting to show again. The bad tracking was distracting from other features as can be read in the answer to the questionnaire Rob filled in afterwards.

The questionnaire can be found in the annexes with the title 'Questionnaire 1.0 - Rob Maas (after testing at the end of iteration 6)'.

#### 12.9.9. Seventh iteration

For the second test with Rob I tried different solver modes of the Sense Glove SDK for handling the hand simulation to try improve the tracking and wrote a script for us to be able to use manual calibration and reset the wrist individually for both gloves with hotkeys.

I also added Google Resonance Audio to the project for spatialized audio for the instruments audio sources and added a Resonance Audio Room to the area where the instrument is located to add some grass reflection to the floor (or ground) to try and create a bit of an outside effect.

For future testing I updated the questionnaire since Rob started to fill in the answers himself at the previous test. Originally I meant to ask the questions and then note down the answers. It only needed a little clarifying and since the teleportation got scrapped I also removed the question about it.

While I was testing the gloves myself I didn't reproduce the faults to the same extremes but those returned when Rob came by for testing again, even a Vive tracker holder broke. The manual calibration only showed a slight improvement. The answers to the questionnaire were pretty similar compared to those of previous test. They can be found in the annexes with the title 'Questionnaire 1.1 - Rob Maas (after testing during iteration 7)'.

Afterwards I fixed a big problem with Resonance Audio not working correctly as the listening position and rotation didn't seem to update to the position of the HMD. It turned out that the Steam VR camera rig hierarchy got messed up while some other work was done to it and the Steam VR scripts couldn't update the position of the 'camera ears' anymore.

### 12.10. Proof video

A video showing what I have worked on during the graduation can be found at the following URL:

<https://youtu.be/BHFOjhqmKtQ>.

### 12.11. The 12 competences of CMGT (Creative Media & Gaming Technologies)

We were required by Saxion to add this annex to our graduation reports to provide feedback on how we worked on the competences used for assessing the graduation.

Technological   1. Technical research and analysis			
<ul style="list-style-type: none"> <li>has a thorough knowledge of the current digital technologies within the field of work of interactive media.</li> <li>is capable of conducting technical research and analysis.</li> </ul>			
Insufficient (0)	Sufficient (1)	Good (2)	Excellent (3)
Knowledge of current digital technologies was presented to the student. The student needed a lot of support by setting up and conducting research.	The student adequately applied the knowledge of current digital technologies that was presented to him during his study program. The student did independently set up and conducted research.	Sufficient + the student gained new knowledge of current digital technologies.	Good + the graduation process strongly focused on the development of an innovation or an application of current digital technologies that is innovative to the client.
<p>For what I had learned so far about programming and VR outside of researching only required help once when the physics solutions included in Unity wasn't sufficient for the application we were building. I've gained experience with programming and VR and learned about developing interactions for VR gloves.</p>			
Technological   2. Designing and prototyping			
<ul style="list-style-type: none"> <li>is capable of creating value by iteratively designing and prototyping, based on a (new) technology, creative idea or demand articulation.</li> <li>shows an innovating, creative attitude at defining, designing and elaborating a commission in the margin of what is technically and creatively feasible.</li> </ul>			
Insufficient (0)	Sufficient (1)	Good (2)	Excellent (3)
The design process was linear. The problem statement of the client was taken as starting point without critical consideration.	The design process was iterative. The student critically approached the problem statement of the client. The final product enables the client to create value.	Sufficient + the problem statement focused on the development of an innovation or application of current digital technologies that is innovative to the client.	Good + the student worked within the margin of what is technically and creatively feasible.
<p>The project and thus my graduation was set up to work iteratively in sprints designing the VRMI for the relatively new concept of VR gloves. Designing VRMIs for professional musicians makes it harder because of what they are used to in the real world. Faulty hardware interfered with the results and I couldn't really approach the limits of the hardware because of it (or the faults should count as limits).</p>			

Technological   3. Testing and rolling out			
<ul style="list-style-type: none"> <li>is capable of repeatedly testing the technical results, that come into being during the various stages of the designing process, on their value in behaviour and perception.</li> <li>delivers the prototype/product/service within the framework of the design, taking the user, the client and the technical context in due consideration.</li> </ul>			
Insufficient (0)	Sufficient (1)	Good (2)	Excellent (3)
Behavior and experience of the user were disregarded by the student.	During the design process the technical results are tested on their value for the behavior and experience of the user. The requirements from the user, the client and the technical context were applied to the final product. A standard prototype was developed.	Sufficient + the final product shows a clear connection to the design.	Good + various prototypes were developed based on the criteria that should be tested concerning the user, the client and the technical context.
<p>I have tested with participants during multiple iterations and have had multiple feedback moments also outside testing. With the designing and the development I have taken musicians (end user), in consideration the entire time. I also didn't forget the client with the demonstration video that is basically the end goal (of the Immersive Media project). We started out with multiple instruments but because of inexperience and time constraints only continued with one.</p>			
Designing   4. Investigating and analysing			
<ul style="list-style-type: none"> <li>is capable of substantiating a design commission by means of research and analysis.</li> <li>shows to have a repertoire of relevant research skills at his disposal and is able to select from this repertoire the proper method, given the research circumstances.</li> <li>is capable of developing prototypes as a communication tool within the context of implementation.</li> </ul>			
Insufficient (0)	Sufficient (1)	Good (2)	Excellent (3)
The research method and analysis is almost entirely provided to the student.	The student has used knowledge of research provided by his study program. One or more prototypes were developed to conduct the selected tests.	Multiple research methods have been considered, and relevant methods have been selected. The student learned and used newly acquired methods. One or more prototypes were developed to conduct the selected tests.	Good + the test results of the prototype, the conclusions, and the recommendations are seamlessly connected.
<p>I have researched VRMIs for best practices to help steer the iterative process towards a better VRMI. I developed a questionnaire based on design principles I found during VRMI research with open questions to gather feedback to help figure out the steps to take following iteration.</p>			



Designing   5. Conceptualizing			
<ul style="list-style-type: none"> <li>proves capable of being able to get to realistic (cross-sectoral) demand articulation and project definition.</li> <li>is capable of developing an innovative concept that creates value on the basis of his own idea or demand articulation.</li> </ul>			
Insufficient (0)	Sufficient (1)	Good (2)	Excellent (3)
The customers demand is literally adopted as problem statement.	The customers demand is translated into a proper problem statement, hatching the opportunity to creative innovate solutions.	The question behind the customers demand has been explored, resulting in a completely new problem statement with an open direction.	Good + the problem statement focused on innovation and value creation.
<p>It was quite apparent for me at the start that the question behind the question to build realistic VRMIs was to build an application that shows of the limits of the Sense Gloves. Interactions with instruments are really precise, especially when working with professional musicians. The keyboard then is a good instrument to build as it is impressive when pulled of correctly. That is why I was a proponent of it being the one we build first.</p>			
Designing   6. Designing			
<ul style="list-style-type: none"> <li>is capable of shaping concepts and elaborate these in a substantive, graphic and/or aural way.</li> </ul>			
Insufficient (0)	Sufficient (1)	Good (2)	Excellent (3)
For the design of the concept(s) that is (were) developed, the student exclusively applied knowledge gained during his study program.	For the design of the concept(s) that is (were) developed new knowledge was applied.	Sufficient + only small adjustments are needed to make the design of the concept(s) that is (were) developed "ready to market".	Sufficient + the design of the concept(s) that is (were) developed is "Ready to market" without any adjustments.
<p>The concept was to create one instrument as close to the real deal with the freedom to innovate. To help steer the innovative part I researched VRMI best practices. The timeframe to build the instrument was set up to the Immersive Media project, not the graduation report. So there is still time to work on it and add features like gestural control for effects to be added to have it done for the demonstration video.</p>			

Organising   7. Enterprising attitude			
<ul style="list-style-type: none"> <li>sees opportunities and possibilities and knows how to translate them from a market-oriented point of view into (new) concepts, products, services, in order to thus get to creating value and new revenue models.</li> </ul>			
Insufficient (0)	Sufficient (1)	Good (2)	Excellent (3)
For the signaling of chances on the market and the opportunities to create value, the student adopted the knowledge of the client without critical consideration.	The student signaled chances on the market at existing target audiences of the client. Innovative applications of the final product are possible, through which value can be created by existing business models.	The student signaled chances on new markets and/or new target audiences of the client, through which value can be created by new business models.	Good + valuable recommendations for the client are given regarding value creation and new business models.
<p>The most important product that is for the Immersive Media project is the flashy demonstration video to be shown on the internet. During a brainstorm session by our team for the concept we worked from we came up with another use for the application, it could be used for demonstrations at conventions by Sense Glove.</p>			
Organising   8. Enterprising skills			
<ul style="list-style-type: none"> <li>has enterprising skills in order to be able to function both as an employee and independently.</li> <li>is capable of converting commercial skills into innovative products, services or collections; bearing commercial feasibility in mind.</li> </ul>			
Insufficient (0)	Sufficient (1)	Good (2)	Excellent (3)
The student disregarded the commercial aspects that are related to the solution of the problem statement of the client.	The student took into account the commercial aspects that were presented to him by the client, related to the solution of the problem statement.	The student signaled himself commercial aspects that are related to the solution of the problem statement.	Good + valuable recommendations for the client are given regarding the commercial feasibility.
<p>As I was the one managing the team, did the organizing and planning for the team and then still did my own thing I think I got working independently down. Between educations I have worked fulltime for two and half years at another company so no problem working as an employee also. The entire project was about to creating a VRMI to the best of our abilities that was at a level acceptable for professional musicians for the demonstration video that is also a product to be delivered at the end of the project.</p>			

### Organising | 9. Working in a project-based way

- shows himself capable of being able to accept, set up and carry out projects from an engagement with stakeholders, whether or not in cooperation with others as a team.
- shows that he/she is capable of cooperating with others in a (multidisciplinary) team in a productive way, reaching a good balance between introducing his own expertise and relying on the complementary expertise of others.
- shows himself capable of directing team members.

Insufficient (0)	Sufficient (1)	Good (2)	Excellent (3)
The student disregarded the requirements from the stakeholders. The extent to which the student relies on his own expertise and that of others is out of balance.	The stakeholders and their requirements are pointed out by the student. The student worked in a team, keeping the contribution of his own expertise and that of others in balance.	Sufficient + the stakeholders were involved in various stages of the design process.	Good + the student managed team members.

As already mentioned I was the leader of the project so I did the managing, organizing and planning for the team. During the project I tried to keep the others on point and mentioned our goals for iterations and the project from time to time. Sometimes I also pointed out their requirements for the Immersive Media project I personally have nothing to do with, keeping a perspective on everything that needs to happen especially for the last stretch so everything doesn't need to happen at the same time. We had the The Virtual Dutch Men visiting a couple of times, there would have been more of we had progressed faster and the gloves didn't need repairing. We did keep them updated with a blog we had to set up for the Immersive Media project. It can be found with the following URL: <https://orchestravr.wordpress.com/>

### Organising | 10. Communication

- shows himself capable of presenting both his person and his work professionally and well-groomed to third parties.
- shows himself capable of being able to communicate with a client about choices and progress in the design process.

Insufficient (0)	Sufficient (1)	Good (2)	Excellent (3)
The design process is difficult to follow.	The final product is presented adequately. The cohesion between steps in the design process is comprehensible.	Sufficient + the student can justify the choices he made in the design process.	Good + the professional product is presented as part of a portfolio suitable for a starting professional.

When meeting with teachers for feedback I took the lead in the conversation from our side and when we had Rob Maas or Max Lammers from Sense Glove over I was the one acting as the host. I also did the email contact with all the parties (The Virtual Dutch Men, Sense Glove and the teachers).

### Professional | 11. Learning ability and reflectivity

- shows himself to be a 'reflective practitioner' by constantly analysing and adjusting his own action, fostered by feedback of others.
- shows himself permanently directed and capable of being able to keep up with relevant developments in the field of expertise.
- is able to further develop and deepen the craftsmanship, the personal substantiation of the professional situation and his creativity.

Insufficient (0)	Sufficient (1)	Good (2)	Excellent (3)
The student followed a linear process, without using feedback of others.	The student reflects on his graduation process.	The student uses feedback of others in his reflection. The student pays attention to new knowledge and skills in the discipline.	Good + the student takes a clear position as a starting CMGT professional in the discipline.

During the project I tried to get the team to work with Git and BitBucket to learn version control and gain experience but the team didn't share my interest and feared it would take up time instead of saving it. I also tried to up my programming skills by doing video tutorial courses about design patterns and algorithms but stopped doing this because of the time constraints and the small team size.

### Professional | 12. Responsibility

- has a capacity for empathy with other sectors and shows awareness of ethical issues in his role as a designer and is able to explicitly make such considerations in accounting for choices in the design process.

Insufficient (0)	Sufficient (1)	Good (2)	Excellent (3)
The student only focused on the current assignment, without keeping into account relevant sectors outside his own discipline.	The student was provided with relevant knowledge from outside his own discipline, and used it adequately. If applicable, ethical considerations were made.	The student has independently acquired new knowledge outside of his own discipline. If applicable, ethical considerations were made.	The student has independently acquired new knowledge outside his own discipline. Student had to make ethical considerations and he clearly justified the choices he made.

I noticed with the peer assessments that were required by the Immersive Media project that I was assessed high on 'feeling responsible' and 'taking initiative for action' by my team members, it's nice to see that being confirmed. There were no ethical decisions needed to be made within this project.