Interactive Fulldome

Gesture tracking-based interaction for an immersive video projection environment

Master's thesis in Interaction Design and Technology

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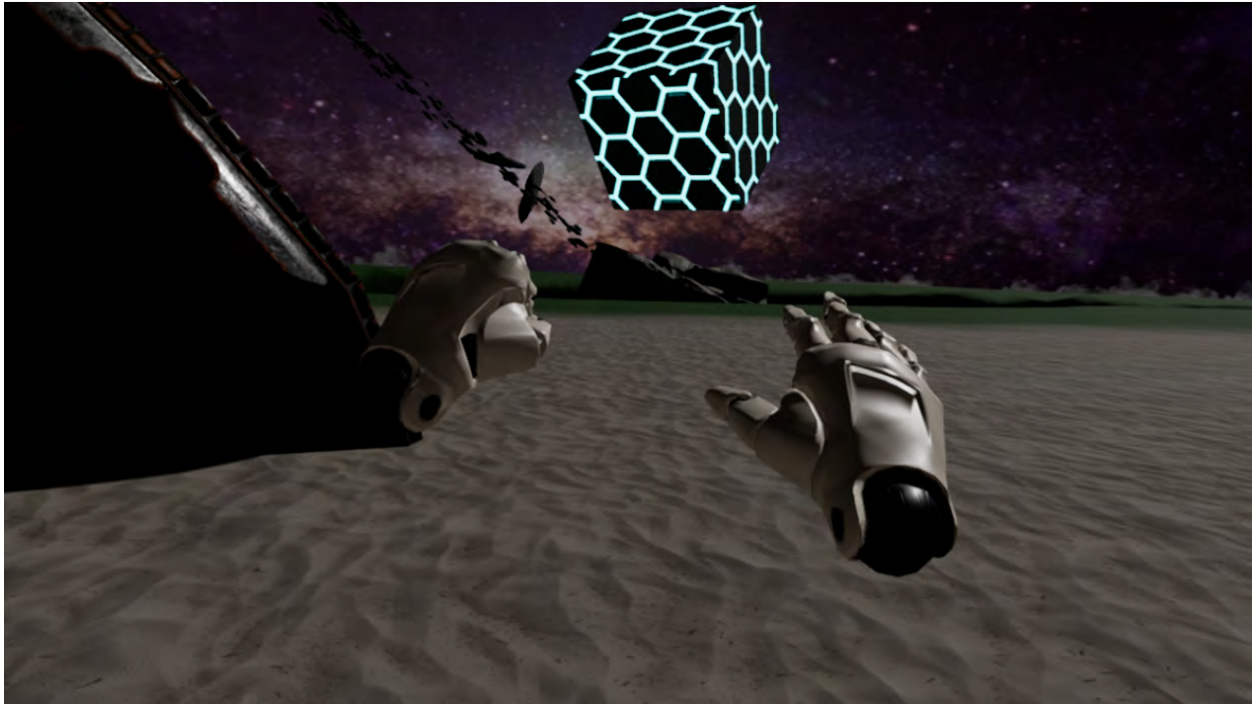
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Cover: Vizualization of the world design created during the project.

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Abstract

This thesis presents a gesture based interaction to enhance the immersive experience provided by a fulldome. The interface implements leap motion technology to use hand-gesture recognition in order to control and explore 3D content displayed in a fulldome. The result of this work are: a functional prototype which includes a list of hand gestures to control the content displayed in the fulldome, and a list of guidelines divided in gestural interfaces, designing for a fulldome, and designing for leap motion controller.

The prototype of the interface is non-standard developed with the 3D capabilities of Unreal Engine 4 and visual scripting (blueprints). The prototype was tested using usability tests, UX curves, and SUS questionnaires, with users specialized in presenting while interacting with both the audience and a fulldome, as well as with new users that had no experience in the context whatsoever. The results of the tests revealed that the users didn't have strong opinions over the gestures and generally liked using the interface to perform the tasks. There were a couple of issues with the usability as the system proved to be quite sensible and sometimes presented bugs. More testing is required to reach a conclusive resolution regarding the interface. Further development of the interface is needed to achieve a functional interface for the fulldome.

Keywords: fulldome, interaction, interface, leap motion, hand gestures, 3D content, blueprints, usability test, UX curve, guidelines.

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Most of all we are grateful to our families in Mexico for supporting us in this journey and for always pushing us to become better.

<div align="center">Erick Hernández and Mariana Manrique, Gothenburg, October 2019</div>

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Introduction

In this project the focus was towards interaction with fulldomes. The fulldome is an immersive environment in a shape of half a hemisphere used by many viewers, as such, presenters or guides of it need to be able to control and sometimes manipulate what is being shown in the fulldome. Having a half hemisphere with a 360° space for the content, together with an audience that needs to be involved makes the interaction with the content difficult. In this case the interaction is a quintessential part of the exposition or presentation, and has to aid the immersion experience of the viewers that is expected when using a fulldome. Recent investments have shown that fulldomes are gaining more importance, and as an area in its early stages of development with pioneer content, an interaction that can potentiate the immersive experience and exploit what domes can offer is crucial for this new area to succeed.

1.1 Research Problem

The Norrköping Visualization Center-C will produce new content for all new centers. Therefore there is a need to evaluate which current technology might be suitable and explore how it could be applied for a dynamic interaction in the existing installation. The current interaction with domes or immersive screens is detached, opposite to the immersive experience that they could provide. As of now fulldome presentations and shows are mostly done by two people in the staff. The presenter and the pilot, who is the technician controlling the show.

In order to have an interactive show for the audience in the fulldome there have to be two people working in tandem. A well trained technical person situated in the top part of the fulldome auditorium that manages the software, what is displayed in the dome surface, the paths, and the movements that are done in the environment. All of these aspects are directed by the presenter which is located at the bottom part of the fulldome auditorium facing the audience that is seated in between the pilot and the presenter. In this setup the presenter has little control on the content and completely relies in what the pilot decides to do. The issue with this kind of interactive show is that the presenter might have a spur of the moment decision to go somewhere else in the environment and the only way that they have to communicate with the pilot is to say it in the microphone where the audience is able to hear and

even when the pilot may understand, they might not be able to do it or might misunderstand and do something not expected for the presenter. All this confusion could lead to a break in the immersion the audience was experiencing until that point. Giving the presenter more control in the interaction can in some cases lead to a more fluid presentation where the presenter is able to adjust their presentation to suit the feedback they get from the audience in real-time, as well as eliminate or significantly reduce the pilot's role.

1.2   Aim

The aim with this project is to explore new ways to interact directly in a fulldome environment, enhancing the use of this technology and the feeling of immersion for the user. During this project proper technology will be chosen and used to develop a prototype creating a setup for both of the possible users. Such experiment will help to understand the implications and possible technologies available to create content for the fulldome and a proper interaction with such display.

1.3   Research Question

After some research in the field the questions decided upon to answer through this work are:

How to design an interface with a gestural interaction to control and explore 3D content displayed in a fulldome?

- **Sub-question 1:** How can existing gestural tracking technology be mapped to make an interface suitable for immersive interaction?

- **Sub-question 2:** What could be a suitable set up design guidelines for free spacial exploration when designing an interaction for a fulldome?

The purpose with this research question and sub-questions is to contribute to design research for gestural interaction generally and within a fulldome specifically, by answering the hypothesis underlying this research, namely gesture-based input offers rich interaction possibilities in an audience targeted presentation due to its versatility and freedom from fixed physical controllers, compared to current input techniques used in fulldome environments. Demonstrating the possibility of rich interaction for gestural interaction through the design and prototyping of a tool that uses gesture recognition, and documenting the practicalities and challenges of a setup for such an interaction technique. Demonstrating the suitability of the controllers chosen by testing the developed prototype with target users, and documenting the perceived experience as well as the ease of learning how to use the tool. Documenting the essential requirements to be considered when designing a similar

gestural interaction within this specific context, and corroborating the essential requirements documented with experts in the area of immersive visualization to concur in base guidelines. Also to empower presenters in the fulldome by providing them more control of the presentation in real-time which is thought will aid in increasing the immersion of the interaction. Increasing the immersion of the interaction for the presenter but not at the cost of the audience's immersion. As in any presentation the presenter has to be connected to the audience so as to not lose the audience's interest and possible learning they might get from it.

A relevant consideration that this thesis has kept present during the development of the interface is the positioning of the presenter within the fulldome auditorium. If the presenter has full control of the content, they have to be able to see the fulldome to either manipulate and explore the content or to know what the audience is seeing. So if they're placed in the bottom part of the auditorium they would mostly give have their back to the audience and lose their interest or lead to misinterpretations of important information or another possibility is that the audience could pay more attention to the presenter instead of the content and break the immersion. On the other hand, in the top part of the auditorium the presenter might lose connection or engagement with the audience and thus lose relevance.

1.4 Delimitations

To answer the questions of this project, a prototype is going to be developed, exploring two main technologies as controllers: the HTC Vive controllers and the Leap Motion Controller. Such technologies will be tested choosing in early stages the one that provides more freedom for the user and a better setup considering the space available in the fulldome environment located in the Visualization Center-C in Norrköping, Sweden.

Additionally such prototype will include basic gestural interactions as the purpose is to understand how to interact directly with a large-scale screen and manipulate objects in a designed virtual world. A virtual environment is going to be created to test such interactions, while main considerations will be extracted considering that the content is for a fulldome environment. The virtual environment will be tested with real users in large-scale screens, together with the interaction to evaluate what the users think about the gestural interaction and define whether is a good approach or not.

2

Background

This chapter will explain domain and the different work related to a fulldome interaction and the stakeholder involved in this project. Additionally, the previous interactive content made by such stakeholder for the fulldome environment is presented.

2.1 Project WISDOME

Alice Wallenberg Foundation, the largest private financier of scientific research in Sweden, had an important contribution to update the current fulldome located in in Norrköping and install new domes at science centers in Malmö, Gothenburg, Stockholm and Umeå as this environment offers a fantastic opportunity to explain complex interrelationships and phenomena typical for our time[9]. This initiative to a national world class visualization platform has the ambition to promote interest in science and technology.

To make this possible the project WISDOME, short for Wallenberg Immersive Science Communication Dome, was created with the aim of reaching millions of students through immersive science communication all over Sweden [10]. The Visualization Center C in Norrköping takes lead in the project owing to the world leading visualization research being the fulldome with the highest technology in northern Europe. In such environment not only 3D movies are displayed, but also real-time interactive shows are presented, enhancing the immersive feeling.

2.2 Visualization Center-C

The Norrköping Visualization Center-C is a research and science center located in Norrköping Sweden. It has a unique mix of visualization research and public outreach activities hosting a large-scale arena for public visits and events including media labs, interactive exhibitions and an immersive 3D fulldome theatre [11]. The exhibitions has as the main topic interaction and digital imagery, and combines the state-of-the-art visualization technology with intuitive interaction design to bring a

bigger audience to the world of visualization. The fulldome contained in the center is the most important dome installation in Northern Europe with a 8k resolution projection and 360° view [9]. The fulldome theater has seats for 102 visitors, where on a daily basis, their own productions are screened as well as films from international producers. Additionally, such fulldome has the capabilities to project the best 3D content quality in the industry, including interactive content where the audience is involved.

Additionally, this center is pioneer on research and development with projects in advanced graphics and visualization made by different teams. While some teams develop new ways to visualize large and complex amounts of data and ultra-realistic synthetic images, other teams focus on how visualization can improve the human learning capacity [11]. This center is the result of a collaboration of Municipality of Norrköping, Linköping university, Norrköping Science Park and Interactive Institute Swedish ICT.

2.3   Fulldome

Schnall et al. [12] define a fulldome as an immersive dome-based video projection environment filled with animation or a composed environment, with different applications such as education or entertainment within different disciplines. This author describes that such environment use a spherical surface where typically one ore more projectors are used to display images in the inside of a dome surface, that together create a high quality display with the intention of completely filling the viewer's Field of View (FOV).

This surface of the digital fulldome can be used as a canvas for real-time or pre-rendered computer animations, live-capture images, or any other visual projection accompanied by surround sound. The particular benefit of the fulldome is the ability to accommodate large groups of viewers making possible to share experiences with the potential use in education [12].

2.4   Gesture-based Interfaces

Gesture-based interface is defined by J. Rico et. al [13] as the use of arbitrary postures or signs language to control different type of interfaces. Such gestures include finger and hand position, and movements which are easy to perform and that help to achieve a specific goal. Is worth to mention that the gestures used for a gesture-based interface are the called "gesture languages" which might not fall into the everyday gestures, as it is described by the same authors definition where there is also the "conventional gestures" that occur naturally with the speech.

To create a gesture interaction, defined in section section 3.1, the movements need

to be tracked by a sensor or camera that has the capability to detect the part of the body where the gestures are based, and translate the positions and movements into coordinates, which later on can be processed to an specific action [14]. Such systems that allow the tracking and processing of the gestures are called gesture recognition systems, there are many examples of them being the Kinect and WiiMote the most popular ones used for video games [15]. This is defined in the subsection 3.1.1.

For this project, the Leap Motion Controller is going to be used as the gesture recognition system, which would allow the team to develop the customized gestural interface.

2.5   Related Work

There are projects and studies done that that work in the realm of large-scale screens and mapping, demonstrating that this technology is suitable for different purposes. They are related to this project whether for being interactive content for a fulldome environment, work with big large-scale screens interaction, hand tracking work for gestural interaction, or previous interactive content made for the Visualization Center-C. This projects are described in the following subsections.

2.5.1   Archive Dreaming

Archive Dreaming 2.1 is an immersive architectural space created as a canvas with light and data applied as materials[16]. In this project, it's possible to navigate through 1,700 documents with the aid of a tablet device using different gestures. The architectural immersive installation was presented as part of The Uses of Art: Final Exhibition. The interaction and use of space presented in this immersive environment is interesting as they use somewhat known technology in an innovative fashion.

2.5.2   Secret Detour

In the Secret Detour project there are different audio visual experiences 2.2 that deal with the scale of immersion of the users that are exemplified in the Secret Detour 360° video[1]. This research paper describes the development of an immersive environment using different technologies for the users: a VR Headsets, a fulldome, and a Cylindrical panorama [1]. Each of those technologies are then carefully analyzed and it's explained how they create the immersive environment for the users. The content used in the video was recorded in different locations of the Chinese Garden in Singapore. As with the last project mentioned, this research paper can inspire this thesis in how it handles the user experience. Furthermore it's also a good example of environment mapping of customized content in a fulldome.

Figure 2.1: Archive dreaming immersive environment.

Figure 2.2: Secret Detour fulldome projection. Image retrieved from [1]

Figure 2.3: Interaction done using a wheel to control a boat in the projection. Image retrieved from the official video [2]

2.5.3   iLAND

iLAND project[2] makes use of different physical pieces to control and affect the projections. However in this case the objects are comprised by levers, a steering wheel, etc. to control what happens in the virtual environment 2.3. The other more noticeable difference is that the projection covers the surface of a dome which make this project more pertinent for this thesis.

2.5.4   Event Horizon

Event Horizon[17] is a project developed in unreal engine and projected in a dome with 4K resolution thus creating a real 3D environment to interact with in the fulldome. The content created is a scientific interactive visualization of the known universe based on accurate up to date scientific data, allowing the user to interact with it through a tablet device. The presenter is able to travel to different places , simulate movements, choose different angles to visualize different things. As mentioned before this project is a projection in a fulldome environment using Unreal Engine, which is the same engine motor that will most likely be used for the development of this thesis, paired with an interaction with wireless controllers to manipulate the content displayed.

Figure 2.4: Helmet 3D printed that together with the Leap Motion Controller allows hand tracking. Image retrieved from the official website [3]

2.5.5 Northstar

The Project North Star[3] uses the leap motion sensors for augmented reality(AR). Leap Motion sensor together with a VR equipment, is used for hand tracking 2.4 with low latency and high accuracy. The accuracy of the latest versions of the sensors allowed this project to use the hands and different gestures as controllers. The importance of this project is that the AR is used as a complement to what the user is usually doing, in that way if the user look at some point of interest they will see more information related to that item. It's a tool that aims to help accomplish an activity and not the main focus of the activity, similar to what this thesis intends to do.

2.5.6 Interactive theater-sized dome

In this project is explored the edutainment and immersing training by having a setup that consists in the 9 meters diameter dome screen tilted at an angle of 45 degree above the floor plane [4], 3 projectors to display the content in the dome, multi-sensors motion seats , and various multi-user interactive devices used for audience.

The content developed was called mine coaster 2.5, a shooting game were players go on an underground roller coaster at a spooky mining site, shooting crystals along the ride to earn points[4]. The main interest from this project is the interaction developed for the fulldome using a set of controllers per user. The devices used were the Sony Navigation controllers and the only button available where the bottom triggers to shoot the different targets. Each device has a set of optical-camera

Figure 2.5: Interaction with a fulldome using customized controllers. Image retrieved from [4]

tracking markers together with 6 Vicon cameras to track their position, which are mounted on two pillars in the dome structure[4]. The combination with the set of optical-camera based tracking markers with the Sony Navigation Controller made possible the interaction multiple interaction with the dome. This is a good example of the use of controllers to interact with a fulldome.

2.5.7 Below the Surface

Content shown in the Visualization Center that explores the bottom of the Baltic Sea [18]. Below The Surface is produced by Visualization Center-C together with Sjöfartsverket, and is based on measurements and studies that Sjöfartsverket has done. This exploration is an example of how the pilot and the presenter work together to explore a custom content in the fulldome. Such exploration is done using an Xbox Controller connected to the main CPU where the content is running.

2.5.8 Cosmos 3D

An interactive show with a presenter who guides the visitor on an amazing journey out into the universe [19]. In this projection, the presenter and pilot navigate through the universe, going from well known planets in our solar system to distant galaxies and constellations. The presenter explains to the audience the different planets and constellations while making the audience more involved by asking the places where they would like to visit. In the mean time the pilot is in charge to move to such location.

3

Theory

Concepts that are relevant for interaction were researched. Not only for fulldome interaction, but also technology and hardware that could be modified and applied to this thesis was explored. Furthermore concepts directly related to the fulldome were more thoroughly examined so they could be understood. An example of this is the concept of dome mapping. Dome mapping affects how the content looks in the dome and thus how it can be interacted with and also the users' perception of the content displayed.

3.1   Gesture Interaction

The basic communication form between human beings is given through gestures in the form of specific body movements with for example arms, hands, and facial expressions. This gestures result in a natural and fluid way to express certain information to others sometimes complex information like in musical conducting [20]. However this is not always the case for communication between humans and technology which is reflected in the loss of expressiveness and naturalness when using a system [21].

Gesture recognition is a type of perceptual computing user interface where computers can capture and interpret human gestures as specific commands [22]. A gesture can be any physical movement that can be interpreted by a motion sensor. As such, gesture recognition includes a variety of technology. Hardware that requires the user to hold controllers such as VR systems like HTC VIVE, or Oculus, and other systems that track the body such as Xbox Kinect, or Leap Motion.

These technologies have sensors and cameras that allow the capture of gestures as input for controlling different type of computer-based systems, making it possible to develop gesture applications. Hand-gesture applications are systems that use as main input different hand-gestures for example grab, point, and pinch to control different options within the system.

This type of interaction has three main advantages. First is regarding the access of information meaning the ability to manipulate the system to access different options using a touch-less interaction. Second is having easy access, giving the opportunity

to use different type of inputs for different parts of the body, which has proven helpful for people with physical handicaps or users with impaired mobility [23] [24] [25]. And thirdly big data exploration, gesture based interactions allow the users to explore large complex sets of data in a different and efficient way through intuitive actions [26] [27]. However there are also distinctive challenges in gesture recognition specially regarding accuracy [21] which consists on three criteria: detection, tracking, and recognition. Detection is a really complicated problem as the variables differ depending on the user due to hand shape, size, skin color, and light conditions. The complications with tracking come from cluttered spaces, rapid motions that cause blurs, and occlusions. Solving these issues grants good recognition accuracy. Another challenge is in regards to user adaptability and feedback [21], some systems can recognize only a predetermined number of gestures selected by the designer while other systems adapt to a spectrum of gestures chosen by the user. It's important to consider the presentation of the feedback as a balance between indicating the correctness of the gesture performed and not increasing the cognitive load for the user is necessary for a successful interaction.

3.1.1 Hand-Gesture Recognition

There are different methods for hand gesture recognition [5], they differ from some stages but in general a typical gesture recognition system contains three main stages: acquiring image, pre-processing, feature extraction, and data classification.

There are some authors like [5] that categorize the gesture recognition systems on model-based and feature-based. The first category are the recognition systems that creates a three dimensional (3D) model of the hands, with the disadvantage of the speed of processing; while the second category belongs to those systems that extract some images to be used later on in the classification process. Even though this last classification has some limitations, it is faster that the other model-based. There are other authors like [28] that categorize the gesture recognition systems depending on the feature extraction method, making also two categories: appearance-based and three dimensional hand-based methods, which are very similar to the previous categories. The first category are those sensors that take image parameters, that later on in the process are compared to a trained model. The second category are those systems that rely on the 3D kinematic model that estimates the angular and linear parameters of the model.

Additionally from the categories, is important to understand the pipeline of the process. There are different pipelines mentioned by different authors, but the most common pipeline is mentioned in the article *A Performance Evaluation of Feature Extraction Techniques for Hand Gesture Recognition* [5]: acquiring image, reprocessing, feature extraction, and data classification (Figure 3.1). The first stage is when the image is capture by the device, if there is some need to make a processing e.g, and segmentation or noise removal, then the post processing is done, otherwise it goes to the next stage. In the feature extraction stage the characteristics of images taken are extracted, then these images are analyzed and classified depending
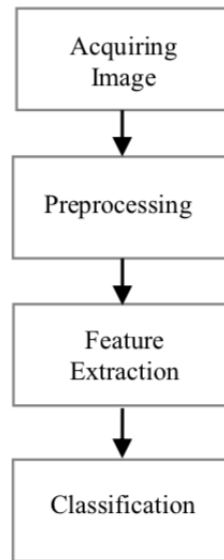
Figure 3.1: Pipeline of the process. Image retrieved from [5]

on the algorithm used. Finally the data classification is done when the features are compared with data stored in a trained data base.

3.2   Leap Motion Controller

There are different sensors to capture hand gestures, the Kinect, and Leap Motion Controller (LMC) the most known. Both sensors detect the three-dimensional (3D) depth data of the scene bringing the opportunity to track the hands gestures and position naturally. It was decided to use the LMC sensor since is more accurate on the hand detection, and because of its API (Application Programming Interface) that provides an easy access to the data that the sensor tracks.

The LMC allows to track individual digits in the hand, allowing finger position detection and hand gestures [29] To achieve this, the sensor contains three IR emitters and two CCD cameras (Figure 3.2). To track the position of the objects a set of calculations are performed on the computer using its own algorithm. The accuracy for the fingertip position detection is about 0.01 mm, and are measured in Cartesian coordinates relative to the centre of the sensor in a right-handed coordinate system (Figure 3.3). The hand tracking speed is up to 200 frames per second in a 150° field of view with approximately 1m of interactive 3D space [6].

Different from other hand-gesture detection systems, the Leap Motion Controller uses three different stages to capture the hands and translate the information to a virtual representation: data acquisition, feature extraction, and gesture definition and recognition [6]. For the data acquisition, the LMC capture different images that are going to be used to retrieve the relevant points of the hand that will result on the
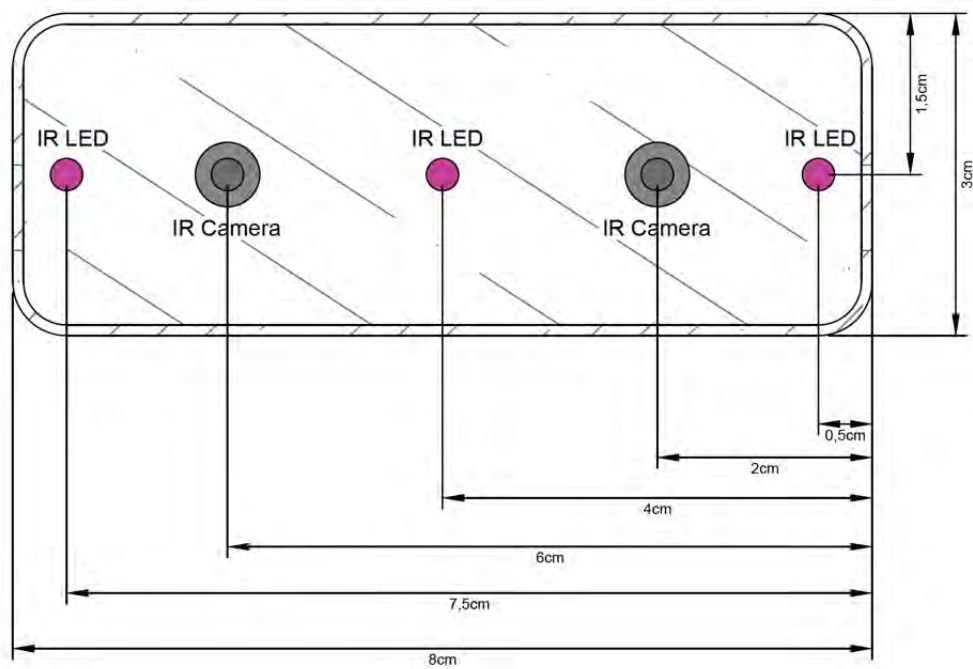
Figure 3.2: Leap Motion Controller diagram
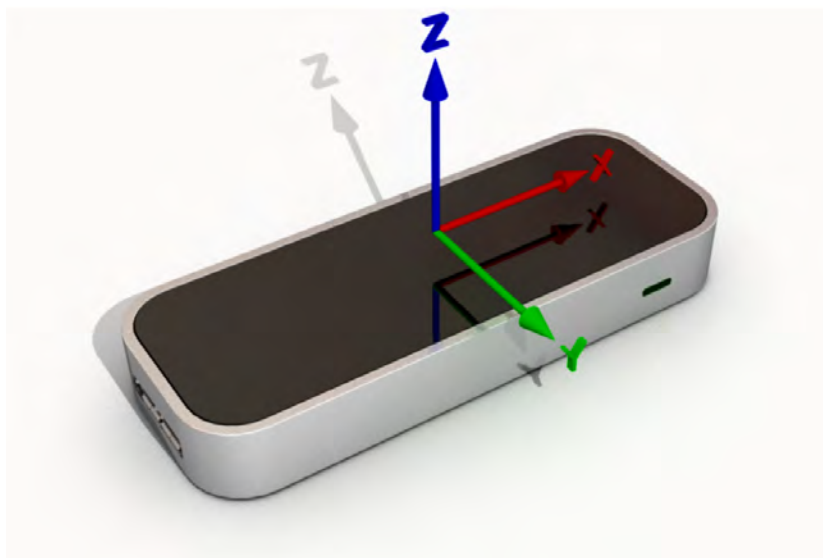
Figure 3.3: Cartesian coordinates relative to the centre of the sensor. Image retrieved from [6]
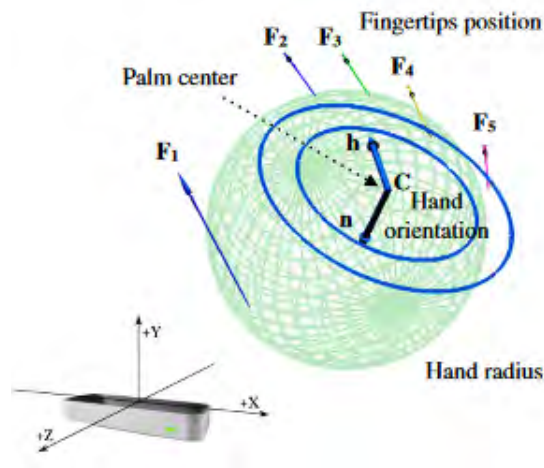
Figure 3.4: Leap Motion Controller main points. Image retrieved from [7]

digital skeleton model of the hand and fingers, which are transformed in coordinates that are going to be used later on in the process. In the feature extraction stage, the images taken from the LMC are classified in order to get the main points: the number of fingers, position of finger tips, palm center, hand orientation, and the hand radius (Figure 3.4). Different vectors are calculated from point to point to estimate the digital model, allowing to decrease the necessity of complex computations needed to extract depth and color data [7]. Finally in the definition and recognition stage the digital skeleton model detects and recognize the gestures, this is where the development of the gestures for this project took place, making the development and recognition of the gestures the main focus, and leaving the tracking techniques behind. It's worth to mention that four gestures are provided by default by the LMC API: grab gesture, release gesture, pinch gesture, and pinch gesture release.

As mentioned earlier the API of the LMC is one of the biggest advantages of this technology. With it, the skeleton model tracked result in a digital 3D model hand that includes the position of the different parts of the finger bones: metacarpal, proximal, phalanx, intermediate phalanx and distal phalanx (Figure 3.5). Additionally, the skeleton contains the information about position in the three-dimensional space together with the hand rotation, fist closed and open, and pinch with two fingers, between others [6] as mentioned in the previous paragraph. With all this information is possible to develop different actions to interact in a digital environment, and develop gestures to perform different actions. This API can be used in different platforms such as Unity and Unreal Engine 4 (UE4).

3.3 Dome mapping

It was decided to research about dome mapping, even when the actual mapping it's outside of this thesis scope, because it is deemed important to understand all the main aspects involved in the thesis so there can be a complete perception and

(a) LMC hand model

(b) View of detected hand
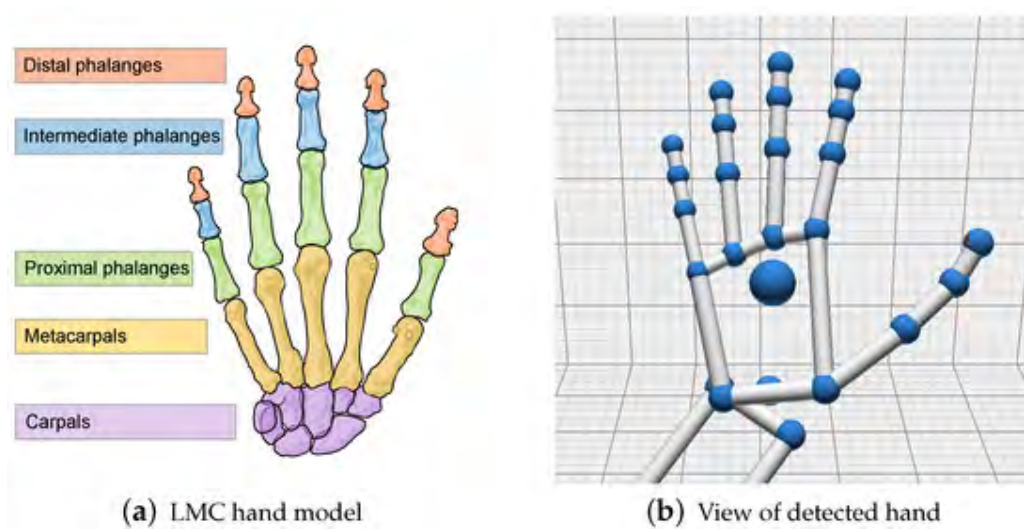
Figure 3.5: Leap Motion Controller hand detection. Image retrieved from [6]

to make sure that the design solution can be integrated logically and within the capabilities of what the fulldome technology can offer.

Therefore, it's important to understand the theories about mapping images to the dome, and also the consequences when displaying content using such a display. There are two main techniques used to achieve the displaying of content in a fulldome. Fish-eye is the technique most used as it's well known and have been used frequently in different projects [1][30][31]. The technique nDisplay is not as well known and has a more complicated setup than the fish-eye, but it allows for higher resolution rendering for the projection.

3.3.1 Fish-eye

In this technique the mapping is done in three render stages in order to achieve a correct mapping [8]. The stages are the following:

1. Virtual scene: The cameras used in the 1st stage capture four views, perpendicular to each other facing outward from a shared origin each with a 90 degree field of view (Figure 3.6). Two "sides" of the cube are wholly discarded as the dome is a hemisphere. This camera assemblage afforded unlimited rotation on any axis while creating an intuitive mapping from virtual to projected space.

2. Fish-eye Distortion: The textures generated in the last step are each mapped onto a curved mesh moving the textures to a curved surface inevitably distorts the scene (Figure 3.7). So these meshes are then rendered to a fish-eye render using an orthographic projection (Figure 3.7).

3. Projector mapping: The final render stage, the cameras render to display output instead of textures. A 16:5 projection captures 8 quads (Figure 3.8) where each quad is UV mapped to a subset go the fish-eye render. And finally
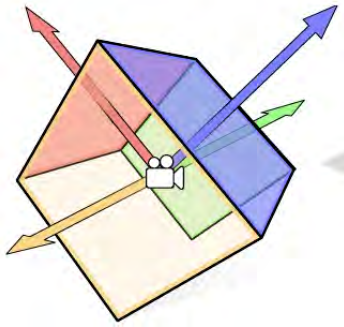
Figure 3.6: Virtual scene: 90° camera arrangement. Image retrieved from [8]
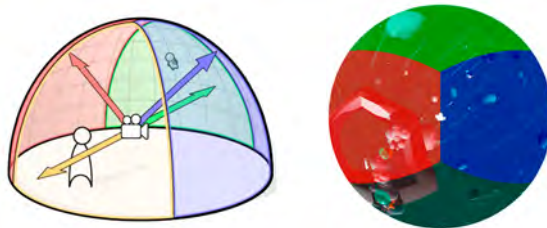
Figure 3.7: Fish-eye: Textures in curved surface on the left, Fish-eye mapping on the right. Image retrieved from [8]

they used NVIDIA's Mosaic multi-display setup as it allowed the whole scene to be rendered as one display.

3.3.2 nDisplay

For this technique the projection in the fulldome is done by 8 projectors different to usual interactive content displayed on a single screen or in a single dual-screen device like a VR headset. It has to be rendered to multiple displays simultaneously to project the 3D environment onto the physical surface of the fulldome. The Unreal Engine software to develop content supports this usage scenario through a system called nDisplay [32]. nDisplay addresses some of the most important challenges in rendering 3D content simultaneously to multiple displays. It allows to deploy and launch multiple instances of the project created in Unreal Engine across different computers in a network such as the one used in the fulldome in Norrköping, each
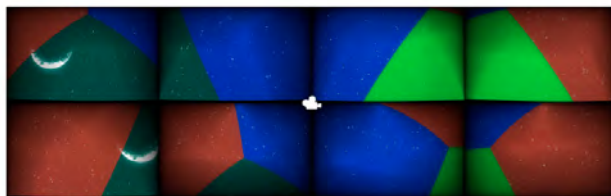
Figure 3.8: UV mapped quads dissect a portion of the render to provide video for each of the 8 projectors. Image retrieved from [8]
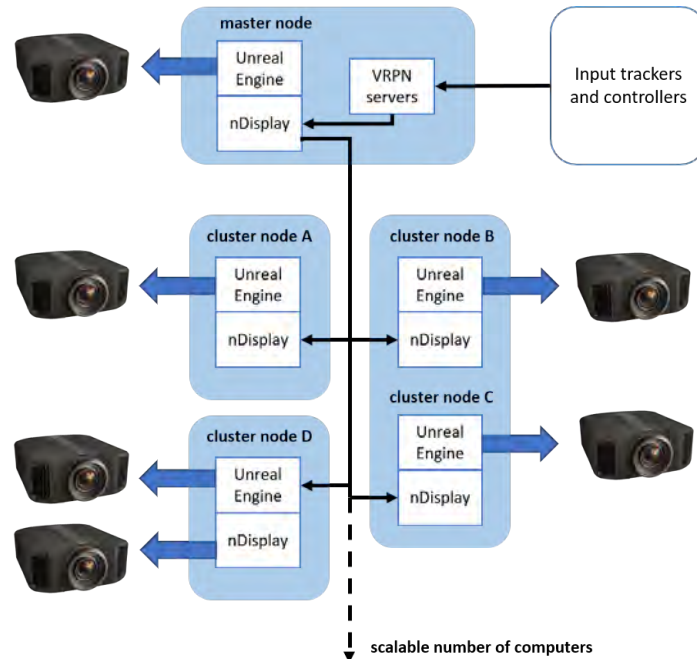
Figure 3.9: Set up for master computer and additional computers to projectors.

rendering for the eight projectors to display on the fulldome. nDisplay also ensures that the content stays exactly in sync with each other even when shown in various screens.

As nDisplay is flexible to support any number of screens in any relative orientation, it fits adequately to the requirements of the fulldome in this thesis. The nDisplay system is often driven by input from VR tracking systems [33], so pairing it with input from Leap Motion should be a smooth implementation once the set up of the computers is done. This allows the viewpoint in the displays to follow the point of view of a moving viewer in real life. Furthermore nDisplay has been used to project onto a fulldome before, as seen in the concert of Childish Gambino for his Pharos concert series [34] where 3D content created in Unreal Engine was displayed in the surface of an inflatable dome.

3.3.2.1 Overview

In the nDisplay setup [32] there is a single master computer, and any number of additional computers (Figure 3.9).

Each computer in the network runs one or more instances of the project's packaged executable file created in Unreal Engine. Each Unreal Engine instance handles rendering to the eight projectors. For each of the projectors a single viewport is rendered on the same 3D scene. This aids the viewers with the immersion as the mapping of the viewports matches the physical locations of the surface, in this case the fulldome. The master node (shown in figure 3.9) is also responsible for

accepting input from the leap motion as it works as the tracker for the gestures that will control the 3D content through connections to Virtual-Reality Peripheral Networks (VRPNs), and replicating that input to all the other connected computers.

3.3.2.2   Components

There are different components that are comprised in the nDisplay system. The first one is the nDisplay plugin that mainly communicates and synchronizes information between all the application instances that make up the cluster, it also makes sure all instances render the same frame at the same time, and it makes sure that each display device renders the correct frustum of the game world [32]. The second one is the nDisplay system that provides a network provisioning and management application called nDisplayLauncher [32]. This application is run by a single computer in the network so the packaged project can be launched and quit automatically on all the computers connected to the network. The third one is the nDisplayListener [32], a listener application that is run on each computer, that receives incoming requests from the nDisplayLauncher, and that also process those requests on a local computer.

Finally a shared configuration file [32] that contains all the settings that nDisplay needs to start up the right number of instances on the right computers, each rendering the right points of view on the game's 3D world to produce a seamless rendering across all the projectors.

The prototype was made with the possibility of adapting it to either the Fish-eye or nDisplay technique as the Visualization Center sometimes uses Fish-eye but intend to use nDisplay in the future.

3.3.3   Challenges in Creating Dome Content

Research was done to find literature and articles that addressed general challenges when designing in a fulldome, however almost all of the papers found addressed project specific challenges [1] [27] [30] [31] [34] [35] [8]. One paper was found about a project coincidentally developed in the fulldome in Norrköping. Luciani and Lundberg [36] describe and discuss general design challenges when designing for a fulldome. They interviewed previous users, and content creators for the fulldome whose statements were consequently compiled into seven challenges.

The seven challenges are:

1. The Presenters have a hard time dimensioning and planning their presentation for the dome as they usually do it on pen and paper. Also there is no mock-up capability.

2. They have difficulty visualizing the 360° space. They express a need for regular

testing. However, it is hard to get access and oftentimes the depth of the content created or presented is wrong in the first trial run and they need to keep revising.

3. Presenters have limited access to the dome and dependency on other individuals when creating content a collaboration between designers, programmers, and dome engineers, is needed during the creative part which slows down the process and often leads to misunderstandings.

4. The presenters find complicated to know where to place the content and how it's going to be perceived. As it doesn't look the same when they're working with it to when it is displayed on the dome. It is not clear for them how to use the dome capabilities. It's challenging to envision the audience's field of view as it depends on where they are seated.

5. The people in charge have pure technical background and as such the decisions taken are technological based only.

6. Difficult to describe the feeling a presentation in the dome can evoke if someone hasn't experienced it. The people working with the dome wish to understand more in order to take full advantage of the capabilities of the dome.

7. Presenters have limited access to the dome and as it's not commercial technology it's difficult to have direct interaction in order to understand it or try out the content they are creating.

It is worth mentioning that in this study [36] the interviewees expressed a wish for design guidelines to rely on when creating a presentation for the fulldome.

Additionally, there are some problems that need to be considered when working on fulldome environments, problems regarding the size since they are big environments that immerse the user. The screen size and the input style as mentioned in the article *Literature Survey on Interaction Techniques for Large Display* [37] represent a problem when interacting, since the target needs to be identified in vector coordinates done by pointing the controller to the target who's position might not be accessible for the user. Also, the size of the screen is related to the velocity of how the cursor and how the interaction is going to be done when having direct manipulation.

3.4 Unreal Engine Architecture

As the prototype was developed on Unreal Engine 4 (URE4), is relevant to explain the basic concepts to understand the development section. Such concepts are retrieved from the official documentation from URE4 [38], in the following subsections those concepts are explained.
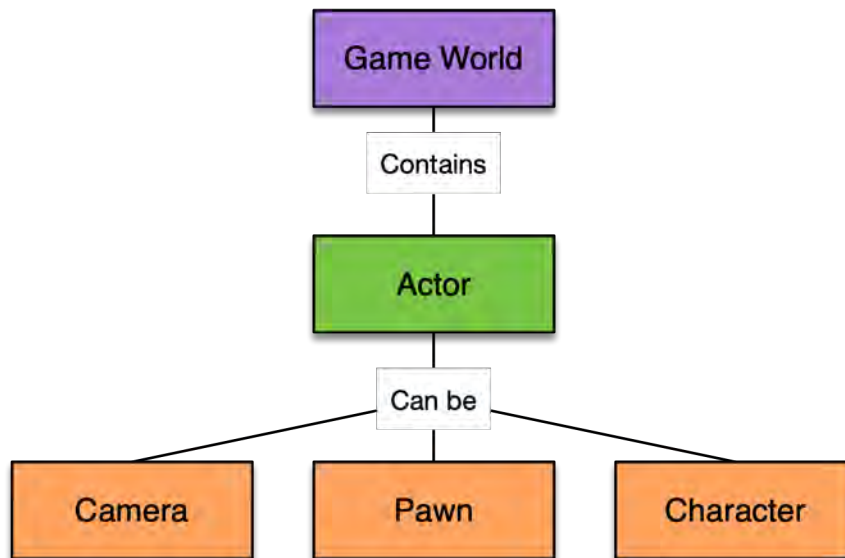
Figure 3.10: Basic architecture used in Unreal Engine

3.4.1 Actors

An actor is an instance of classes that derive from an AActor class which is the base class of all games, an object that can be placed into a level, they are usually generic and support different type of transformations in 3D such such as rotation, translation, and scale [39]. They can be created and destroyed as necessary. In the documentation this information is explained in detailed.

All instances are actors in URE4, being the term Actors the most common name to refer to. There are many types of actors, being the camera, pawn, and character the most relevant for this project (Figure 3.10).

3.4.2 Camera

The camera represents the player's point of view of the character, in other words, how the character sees the world. This is the "eyeball" where the player or user of the system is going to manage, which will define how behave in the system [40].

3.4.3 Pawn

A Pawn is an Actor that can be possessed by a Controller, it's the base class of all actors that can be controlled by players or an Artificial Intelligence (AI). This class not only defines how such actor looks like, but also how is going to interact with the virtual world such as physical interactions. They can easily accept inputs of many types, being the HTC Vive controller and the Leap Motion Controller the main

inputs for this project. Is worth to mention that a pawn can also be a Character that has the ability to walk around [41].

3.4.4 Character

A character is a humanoid-style pawn, it includes a movement component, capsule component, and skeleton mesh component. Such character is designed to be a vertical-oriented player that thanks to such components, can perform different actions such as walk, run, jump, fly, and swim in the virtual world [42].

3.4.4.1 Skeletal Meshes

As described in the official documentation [43], skeletal meshes are used in Unreal Engine 4 to represent characters or other animating objects, composed by two parts: a set of polygons composed to make up the surface of the Skeletal Mesh, and a hierarchical set of interconnected bones which can be used to animate the vertices of the polygons. They are based on 3D models that can be designed using programs such as 3DSMax, Maya, and Softimage. For this project, such meshes are the hands controlled by wither the HTC Vive controllers or the LMC.

3.4.5 Blueprints

Blueprints Visual Scripting or blueprints is a gameplay visual scripting system that use the concept of node-based interface used to define object-oriented (OO) classes or objects in the engine [44]. Such classes are used by the different types of actors to program the different type of behaviors and actions between others.

As mentioned in the documentation, there are different types of blueprints being the actor, pawn, character, player controller, and game mode the most common ones. In the official documentation of Unreal Engine detailed information can me be found.

4

Methods

Regarding methodology for this thesis, two aspects were considered. First the design model for the thesis structure, and then the design methods for each stage of the process. In this chapter such information is going to be explained in detail.

4.1   Design Model

Different models were discussed and what was considered as most beneficial for this thesis were the iterative and incremental development [45], the spiral model [46], and the double diamond [47]. To decide between the models all three of them were explored.

The iterative and incremental development method [45] was considered for its flexibility when adapting to changes as it goes through short cycles that allow the designers to understand, adapt and modify the direction in the next iteration, which could prove valuable considering the nature of this thesis. As this thesis delves in a relatively unexplored area, the ability to revise with the target users between each iteration would help keep the thesis in track of the research question and if it starts deviating, the feedback from the users after each iteration would help reroute the project. This method also encourages a certain level of inter-dependency among team members which would increase the shared knowledge, and considering that the backgrounds of the thesis writers are different it could lead to a better understanding of areas unknown for each writer. However the iterative and incremental method also requires a high level of technical expertise, which the team members lack for this specific use of hardware and software. Which goes hand in hand with being able to provide a high level of automation in the process so the successful iterations allow a quicker detection of problems and thus a more efficient and reliable process overall.

The spiral model [46] is similar to the iterative and incremental model and thus also was considered for this thesis. However this method has more emphasis placed on risk analysis. Having the risk analysis includes identifying and managing the risks, also recognizing the technical feasibility of the iterations, or in this model "spirals". As in the iterative and incremental method this model allows the design team to add

elements gradually when they are brought up after feedback. The positive impact that using this method would have on this thesis is that it forces the user to be involved early in the development process. Due to the several iterations involved, the requirements can be applied more accurately and can be accommodated as they change. It would also help with the complexity of the requirements embedded in the research question as this model allows the development to be divided into smaller parts. However this could also be detrimental to the thesis because this would also call for the development of a larger number of prototypes for which this thesis doesn't have the resources for. The last hindrance is that this model's risk analysis requires a very specific expertise, which is not a resource available in this team.

And lastly, the double diamond model [47] was considered for its adaptability and nature that can fit almost any type of design problem. As the double diamond is commonly divided in four distinct phases, it encourages the gathering of information. This model switches between divergent and convergent thinking during its four phases, helping the creative process enabling the team to expand and consider a lot of possible routes to solve the research questions while still remaining focused in the objective set on it. An important similarity with the previous two models is that this model has an iterative creative process. So this would aid to develop, test and refine ideas several times, with unfit or weak ideas being discarded in the process so a suitable solution can be found. However this method does not consider risks and usually it requires the complete development of an idea which ends up with the possibility of the idea being discarded if it's found ill fitted even after resources have been spent on developing it. Which differs from the other methods where the project is divided and added upon on cycles.

The double diamond approach was decided upon on the grounds that it's the one that matches the most what was to be accomplished in this thesis. Specially considering the nature of the research questions where it was needed to diverge to understand what surrounds the question as the team's expertise in fulldomes required to be increased and then converge in order to get one solution that will be appropriate.

4.2   Design Methods

Concerning design methods for the process, the methods that were being considered for the thesis comply with the four phases of the double diamond model, discover, define, develop, and deliver.

4.2.1   Research

The design methods that were contemplated for the gathering of information to get the understanding of the domain and the challenges that the situation created are first and foremost secondary research [48] which helps in exploring a wide range of

published information about the context, domain, state of the art, technology, alternatives, and such. It also can aid in finding what has and hasn't worked regarding interaction and gestures in different parts of the world and among different fields not only games, but also visualizations in museums, libraries, etc. Additionally, papers in which is mentioned when the user is not able to interact directly to the screen for its large dimensions are also relevant, making the use of other technologies important so the interaction with the content displayed in the fulldome can be done, such as small devices with touch screens, controllers from the virtual reality (VR) equipment, sensors for hand tracking, or eye tracking for pointing and select. Since there are not specifications for the content that is going to be displayed in the dome for interaction, papers that contain some information about how to present and navigate through different type of content displayed in large-scale screens are relevant for the project. Other interesting literature were the ones that talked about the best practices to point and select when interacting with large-scale screens. There are parts of the screen that are not reachable for the user and the technology presented could be as efficient for this problem. With proper research in this area, specifications and points to consider when working with the dome were found.

A survey [48] was another method that was considered due to its nature of reaching many people to gather data and insights, however since the target group for this thesis is specialized and small, and most users haven't used a fulldome more than a couple of times, using surveys was not the best option for gathering much data nor reliable information.

Keeping in mind the location of the project, bodystorming [48] was contemplated for its potential to help in understanding how the presence and positioning of the user in regards to the audience is important and different in a fulldome compared with any other format specially when attempting to design an interaction for it. Through bodystorming, the design team immerse themselves in user situations through loosely simulated contexts, moving through the situation while paying close attention to decisions, interactive experiences, and emotional responses. The difference between role-playing and bodystorming is that the primary function of traditional role-playing is to gain an empathic sense of users by acting their part whereas bodystorming encourages active design ideation, and concept generation.

And lastly in order to get more information on the specific context an interview with an expert [49] was decided upon as soon as it was considered. By developing this thesis in cooperation with a research center the possibility of meeting with an expert was not far fetched and would get important insights and key points to focus upon for the development of the prototype.

4.2.2   Research Evaluation

In order to analyze the information gathered during research there were different methods contemplated. A weighted matrix [48] was considered to identify and prioritize the most promising opportunities such as the technology to be used in the

prototype which is an essential part of this thesis. It is a helpful method because the assessment of the alternatives can be done based on characteristics regarding both the environment and capabilities where the technology will be applied and has the flexibility to choose other pertinent categories to make a decision. The weighted matrix was used because it's a good way to visualize the team priorities and maybe even switch them so the priorities match the outcome wanted.

Developing a persona [48] was considered. A persona is a consolidate archetypal description of user behavior patterns made into representative profiles that help give a face to the user and test scenarios. Even though it would provide a well defined target user, it was discarded because it would also restrict the design alternatives. Creating a user journey map [48] helps to know the current user experiences with the interface so they can be compared with the experiences from the new interface but it was discarded because to be created it requires knowledge of previous experiences of the interaction to arrive to accurate conclusions and contacting more than one user that have used the current interface proved to be arduous, so it was decided to drop this method in favor of investing the available resources in other more adequate methods for the thesis.

4.2.3 Ideation

For ideation, methods that produced a lot of ideas in order to explore different angles and directions were needed. Which is why brainstorming [48] and sketchstorming [50] were a main focus. These methods are similar in that they aid in producing a large number of ideas.

Sketchstorming [50] is a method where designers need to quickly sketch possible design solutions with no words or symbols, and the other designers try to guess what's being sketched. This is a good method to produce a large number of ideas, however for this specific thesis and team it's not a good fit because the team doesn't feel comfortable with drawing their ideas when they can write them down. Instead of sketchstorming a brainstorming [48] session was held. This was a better fit as the team is familiar with each other so one word post-its and short-explanations are enough to understand each others idea, and then easy to build upon ideas that seem to have potential.

To be able to visualize all the ideas and what aspect of the design they would impact an affinity diagram [48] was used. Affinity diagramming is a process used to meaningfully cluster observations and insights from the research and the ideas generated. It complemented well with the brainstorming [48] where sticky notes were used. The sticky notes allowed the team to easily see and move all the ideas so they could be categorized and merged with similar or complimentary ideas.

Lastly dot voting [51] was used as a method for deciding on valuable ideas to be fleshed out further. In dot voting, all members are given three votes in order to choose their favorite ideas. Everyone can vote by using a marker to make a dot on

the sticky note corresponding to the ideas they like. At the end the most voted ideas are the ones that will move forward in the process. Dot-voting was also a good match with the methods used as it paired well with the sticky notes and it's also a quick way to identify the team's inclinations towards ideas and the direction of the design.

4.2.4 Prototype

To build the prototype there were several approaches considered. One way to have early feedback and thoughts about the design was by making a paper prototype [52] it was argued that using this method early in the process could help identify risks and user's feelings while there is still time to make major changes. However it was clear that this method was not optimal for this thesis, as it is relevant for the process that the user feels some degree of immersion so that the conditions and feelings generated could be as close to the real case scenario as possible. Also, considering that this thesis deals with gesture interaction, simulating that on paper was estimated to be really complex and would spend a lot of valuable time for little profit.

As the design worked in a specific set of conditions within the fulldome using role-playing [48] was considered because it could give further insight while developing the prototype. The gestures were programmed for the use and understanding of the user so by trying them from the point of view of the user before the actual testing took place was a good way of getting a feeling of what to expect and what to modify. So it was decided that the construction of the prototype would happen in tandem with role-playing by simulating the user's actions in the fulldome during the development.

Being a presenter in the fulldome implicates an environment with a lot of different variables and thus hard to replicate due to the specific times, variation on the audience, having a time limit, and the pressure of presenting information correctly. Because of this it's important to consider methods that could aid in simulating this environment outside of the fulldome. The simulation exercises method [48] gave the developed prototype the ability to imitate the real conditions. The prototype was developed in Unreal Engine which is an environment that allows the use of a virtual reality headset so it would not be a big strain on the team to produce a virtual context where the immersion could simulate the conditions provided by the fulldome. This method could easily be paired with experience prototyping [48] due to the nature of virtual reality. Experience prototyping involves exercises completed by design teams to foster a vivid sense of the user's potential experience. The aim was to produce a functional interactive prototype close to a possible final product. This method was used to be certain that the users could be in the intended final environment during the testing.

And finally a method worth considering was parallel prototyping [48] in the interest of trying more than one idea at a time and comparing them during user testing, it

was considered that the team could potentially divide resources between alternatives to be able to compare suitability and emotions provided by different alternatives. After evaluation and discussion within the team it was decided that parallel prototyping was not a possibility. Even though developing two different alternatives with different controllers might have been a great way to explore which controller had the best suitability when interacting with a fulldome it also meant completely dividing resources, and all the resources had to be focused in just one alternative in order to cover the demand of finalizing it with full functionality.

4.2.5   Evaluation

Complimentary methods to evaluate the prototype were used. The tests were structured with usability testing [48] in mind. Which was good for the testing as the prototype had specific gestures that perform actions, so by directing the tests with set tasks the team was able to evaluate the gestures. The aim was to seek empirical evidence about the usability of the interface.

After testing, methods such as the UX curve [53] were decided to be employed to get further insight and to know how the experience was perceived by the user. The user draws a curve which aims at assisting them in retrospectively reporting how and why their experience using the prototype changed during testing. The UX curve has an emphasis in emotions so it was a great source to understand what the users felt and when. This method gave the team insights about both the emotions and the immersion created. It is also a visual representation of the user experience with the prototype.

The System Usability Scale (SUS) questionnaire [54] was chosen to be completed by the users so a fast and fairly accurate usability assessment of the prototype could be done. This questionnaire is the most used for measuring perceptions of usability. It is a simple, ten-item scale giving a global view of subjective assessments of usability. SUS is technology independent as it has been tested on hardware, consumer software, websites, cell-phones, interactive voice response (IVRs), and even the yellow-pages [54].

To finish the testing and to expand on any vague or unclear points, another method was chosen. An unstructured interview [48] with the users was considered imperative to expand upon the user's experience. In this interview the users were asked to explain their UX curve. This is where the team learned what made the users feel positive or negative emotions towards the prototype and the experience.

To analyze the information given by the evaluation the methods to be used are somewhat dependent on the ones applied during testing. The usability report [48] is the result of the usability testing which works as a summary of the number of problems found, the problems to be fixed, the positive findings and this should allow to draw conclusions regarding aspects of the prototype to be improved, as well as what gestures work, and what actions need to be added or removed. The answers of

the SUS questionnaire [55] were the direct way of analyzing the results of the testing. When analyzed the team was able to obtain the pertinent highlights and insights to the thesis as well as the issues that must be addressed in a new iteration of the design. For the UX curves [53] a direct comparison to find patterns and meaningful singularities was useful. This way specific consequences created by the prototype can be found.

5

Process

There are four phases in this thesis process, discover, define, develop, and delivery (Figure 5.1). These phases were used so that they support what Gaver [56] established as one of the most fundamentally consented statements "the practice of making is a route to discovery, and that the synthetic nature of design allows for richer and more situated understandings than those produced through more analytic means." Where a prototype was made as well as evaluations that provides an exploration of a new interaction and guidelines for future works regarding this specific context.

5.1 Discover

In this first phase of the project the aim was to understand the fulldome technology its capabilities and what has been done in terms of interaction.

The method secondary research [48] was used to find what has and has not worked regarding interaction and gestures among different fields. As such literature that relate to this area was found. Fulldome research is still in its infancy and even more so interaction with them. As such literature regarding this specific type of interaction was scarce and barely there. For this reason it was decided to broaden the research to interaction with large-scale screens [57] [37], where some considerations for the interaction with large screens are mentioned and can and were applied during the developing of the prototype. When discussing large-scale screens or displays most of the authors make use of other technologies so that the user can interact with the content displayed in the fulldome. Different hardware and controllers are used, such as small devices with touch screens [16], controllers from the VR equipment [4], sensors for hand tracking [58], or eye tracking for pointing and selection [59].

It's worth mentioning that initial talks with the mentor of this thesis Patric Ljung revealed a lack of specifications for the development of the content that is displayed in the dome. However relevant literature that contained guidelines or bases directly concerning this topic were not found.

Another essential part that had to be researched for this thesis, is the user. The target group for this thesis is specialized and small, and most users haven't used a
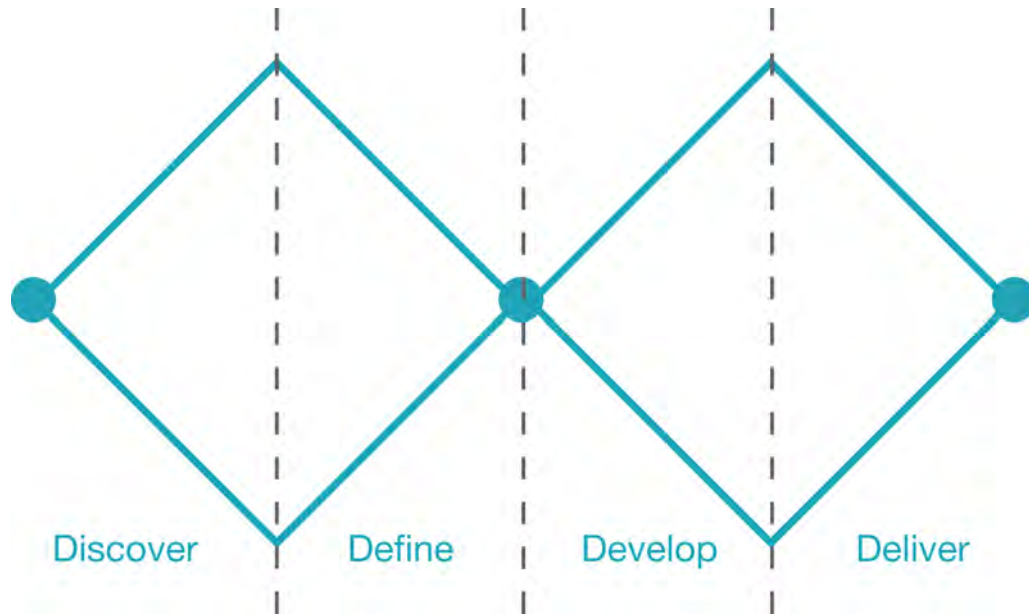
Figure 5.1: Double diamond model

fulldome more than a couple of times, which was why it was difficult to find reliable sources and information of the target users. Bodystorming [48] was used by the design team to provide a sense of understanding of the space and dimensions to work with. A bodystorming session was done in the Visualization Center-C in the fulldome theater, the session was about 15 minutes long and it was done while some content was being displayed. One member of the team was performing a different set of gestures while asking different questions, while the other member was analyzing such gestures and the availability of the space. The result of this session was the first set of gestures, to be presented in the subsubsection 5.3.1.1. Additionally, in order to get a deeper and more technical understanding of the current interaction and its process an interview with and expert [49] was decided upon and it resulted in important insights and key points to focus upon when designing a possible solution. Two meetings with an unstructured interview [48] were set up with the fulldome expert Eric Sundén technology manager at Norrköping's Visualization center, researcher and developer in immersive visualization. Eric Sundén has both presented in the fulldome, developed, and adapted content for it. As Eric is deeply involved in everything related to the fulldome, he has a tight grasp on the issues and capabilities of the dome.

5.1.1 Scenarios

From the unstructured interview [48] different scenarios in the fulldome were exposed. This helped delimit the variables depending on which scenario was being considered and what implications it has on the interaction. As presented by Eric Sundén [personal communication, Mar. 2019] the presentations done in the fulldome are divided in three main scenarios.

The first scenario is where a video is displayed in the fulldome, usually with 3D animation and the camera moves in predefined paths before displaying the video. The only external input is the presenter commenting on certain parts during the video. This scenario is the most commonly used to show educational movies, documentaries or informational videos.

In the second scenario 3D content is displayed in the fulldome and can be explored in real-time by the pilot who controls the camera direction and movement through a desktop computer while the presenter is teaching information and getting feedback from the audience. This scenario is used as of now for what is called "interactive shows" in the visualization center.

And the third scenario also has 3D content displayed in the fulldome and can be explored in real-time. However in this scenario the controller is a Xbox controller used to steer and change speed of the camera. This controller can be used by either the presenter or the pilot, but it's mainly used by the presenter. The presenter is usually commenting on whatever is being displayed. This scenario is still being developed in the visualization center and is intended as an alternative for the desktop computer in "interactive shows" such as is done in *Cosmos 3D* described in subsection 2.5.8.

5.1.2 Challenges

Considering the research done in the discover phase, challenges have been identified that delimit the thesis.

The mapping of the fulldome(Figure 5.2) makes it difficult to find a place within the space where the presenter is able to see everything being displayed. Which is connected to the need of addressing the audience if it's the second or third scenario without losing the audience attention or focus.

External hardware connection to the existing hardware in the fulldome. Specially when trying to connect sensors and controllers which was an essential part to this thesis' prototype.

Most presenters are in contact with the interface once or a couple of times at most every few weeks for approximately from 30 minutes to 1 hour so the learning curve of the interface has to be intuitive enough and have a low cognitive load on the user.

5.2 Define

From what was learnt in the unstructured interview [48] with Eric Sundén, the scenarios where the interface is used differ a lot from each other. It was decided to focus in the third scenario where there is a 3D environment that the presenter explains and can explore with input from the audience. As it is the scenario that
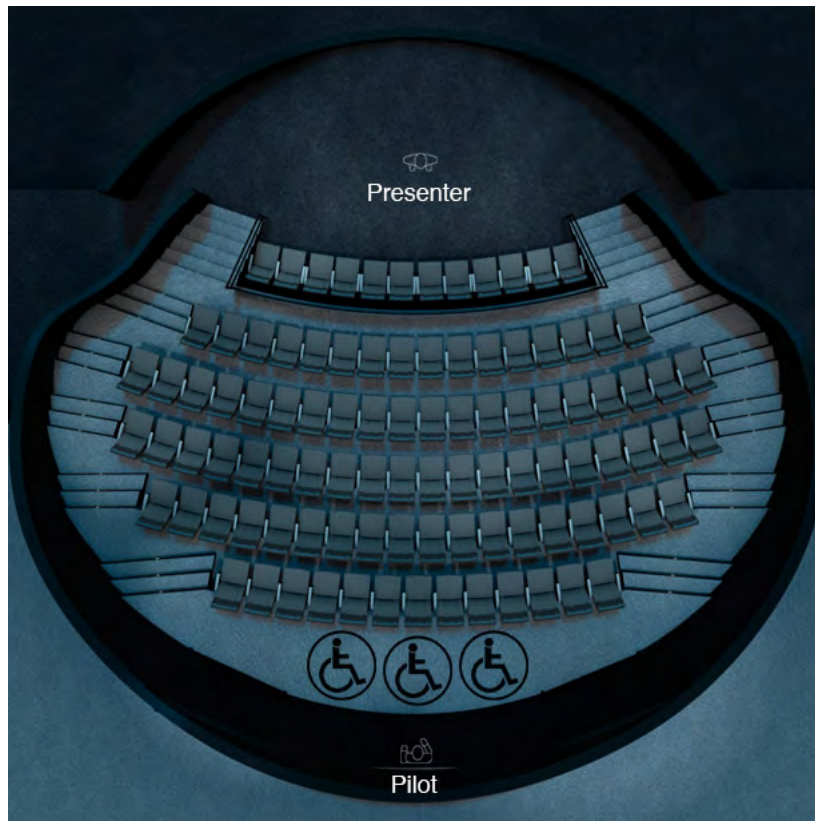
Figure 5.2: Visualisering Center C Fulldome top view

would get more benefits from a gestural interaction.

The relevant literature was analyzed and the considerations and alternatives that could have significant impact in the context were highlighted in order to define the generalities of the projects before developing a specific prototype. These generalities were divided in four categories so there could be clarity as well as allow the team to discuss more specific points. The areas were: Narrative of the 3D content to be used, Controllers, User Interaction, and Emotions evoked.

For each of the categories a brainstorming [48] session was done. Each session consisted on 10 minutes where each member wrote every idea in a sticky note and after the set time passed every idea was explained. When all brainstorming sessions were done to be able to visualize all the ideas and what aspect of the design they would impact affinity diagrams [48] were used. This allowed the team to easily see and move all the ideas in the sticky notes so they were categorized and merged with similar or complimentary ideas.

The first affinity diagram regarding the narrative of the 3D content (Figure 5.3) showed a preference for educational content as well as an environment that could be adapted and used later by the Visualization Center. The narrative wasn't as important because the prototype only needed it to try out the gestural interaction in a possible environment.

Figure 5.3: Affinity diagram for Narrative of the 3D content

The dot voting [51] for the first affinity diagram (Figure 5.4) revealed the team was partial for a free exploration narrative, themed as a floating island in space was mainly because the 3D graphic resources to create it were more readily available.

With the affinity diagram for the controllers (Figure 5.5) the main alternatives regarded technology that were the most appealing and suitable. The involvement of the audience and the simplification of tangible controllers was considered.

After the dot voting (Figure 5.6) there was a clear decision to make regarding the HTC VIVE controllers and the Leap Motion sensor. An assessment was made of the availability and possibilities the controllers offered as well as the characteristics regarding the environment. A weighted matrix [48] was used to help with the decision. Other technologies were also added in the weighted matrix to have a direct comparison. With the results from the weighted matrix it was decided to move forward with the leap motion and the HTC VIVE 5.7. So the first iteration considered an environment where both technologies could be interchangeable. The Leap Motion offered more freedom regarding hand gestures and thus more possibilities when deciding on specific gestures. The HTC VIVE controllers provided tangibility and familiarity of use.

In the affinity diagram for User interaction (Figure 5.8) the ideas were more scattered than in the other diagrams. However this helped the team define what the prototype shouldn't have. It also helped delimit the scope more clearly.
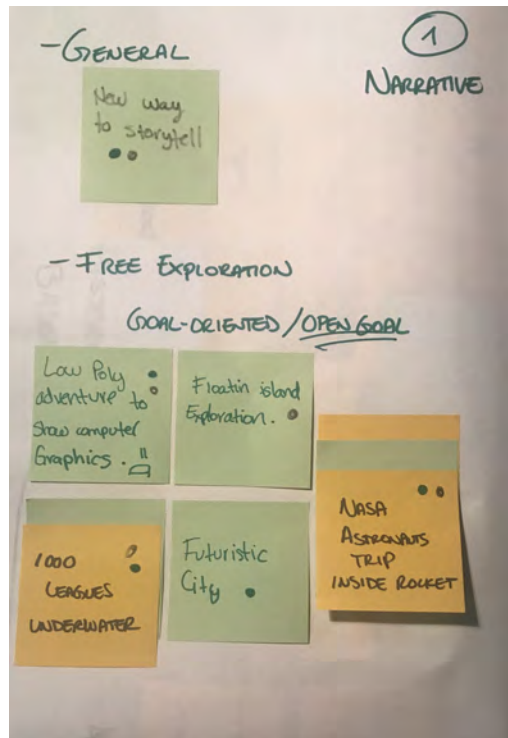
Figure 5.4: Dot Voting results for Narrative of the 3D content
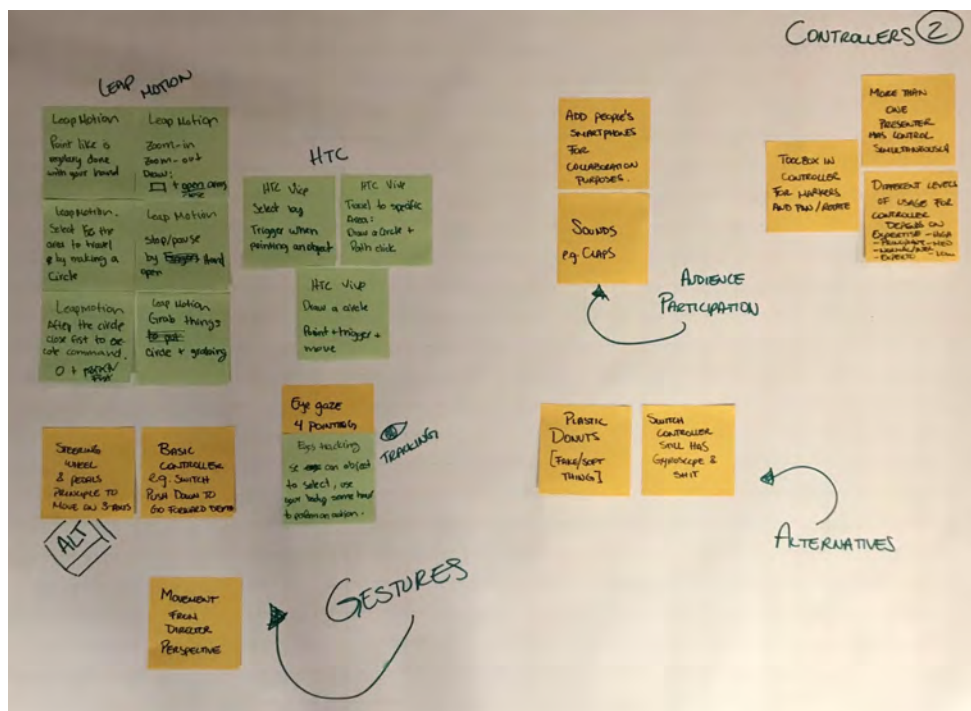
Figure 5.5: Affinity diagram for Controllers
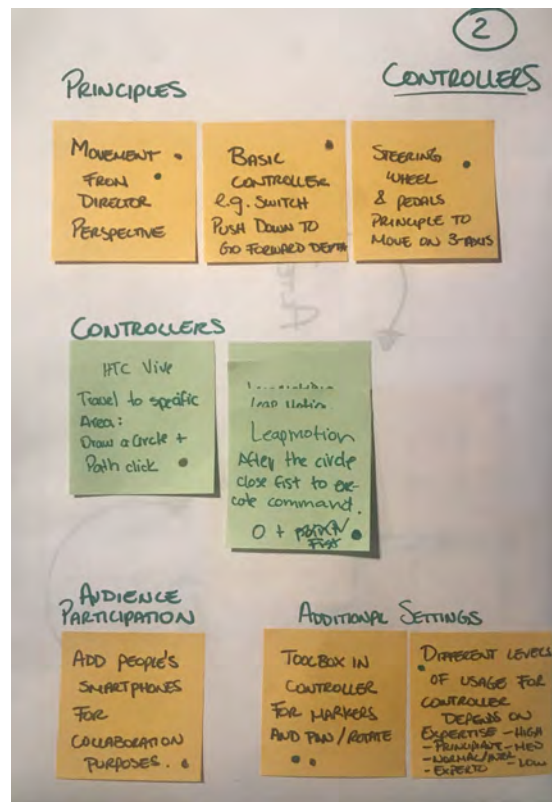
Figure 5.6: Dot voting for controllers

Criteria	Weight	Tangible dome	HTC Vive	Touchscreens	Oculus Rift	Leap Motion
Availability	5	1	4	5	5	4
Ease of use	3	5	5	5	3	5
Movement restriction	2	1	3	2	3	5
Sensor sensibility	4	5	5	5	4	4
Accuracy	3	5	4	5	3	4
SDK	5	1	5	3	5	5
Disponibility of assets	5	1	5	3	5	5
Total		67	123	109	115	123

Figure 5.7: Results of the weighted matrix
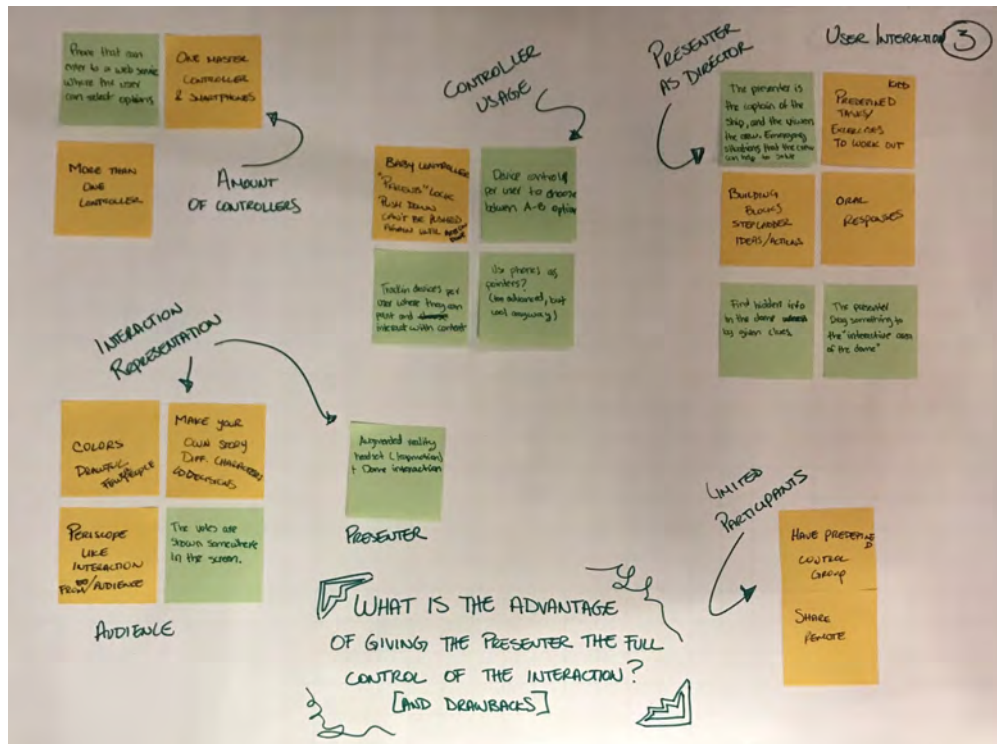
Figure 5.8: Affinity diagram for user interaction

With the dot voting (Figure 5.9) two things that could be perceived were, one that the goal of the interface was to give the presenter control over the presentation and autonomy from the pilot. And the second were ideas that even when liked by the team, were outside of the current scope such as, augmented reality as a possibility for the presenter to have a toolbox with more options, and have the audience take a more active role during the presentation by having real-time input.

The affinity diagram for Emotions evoked (Figure 5.10) was mostly to have a goal to compare to when the results of the testing were being analyzed. And this way there was a base to know the objective was met with the tested prototype.

The dot voting for emotions (Figure 5.11) displayed the alignment of intentions for the emotions that the team wanted to evoke with the prototype.

5.2.1   Alternative ideas

Before the development phase there were other ideas that were considered that mainly changed the technology they used but where the presenter still had full control.

The Dollhouse idea, is a tangible interface that uses a miniature fulldome (half sphere) where what is displayed in the dome is shown. The presenter would manipulate this world as a "god" allowing them to move things as they desire. This idea was discarded because it required a lot of external hardware that would become
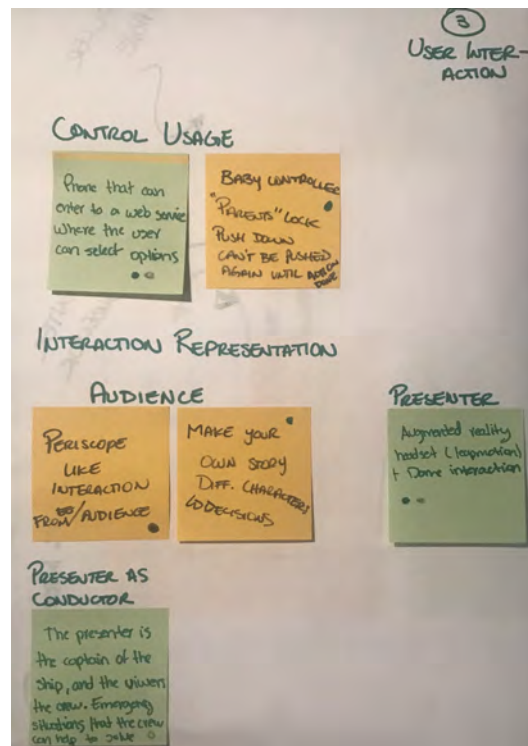
Figure 5.9: Dot voting for user interaction
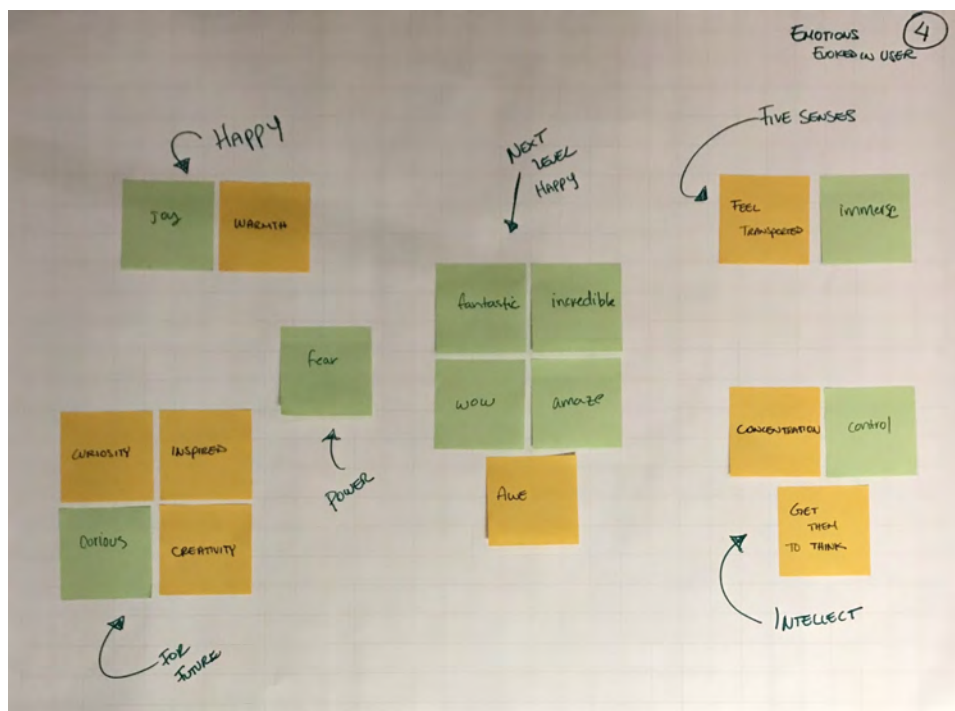
Figure 5.10: Affinity diagram for emotions evoked
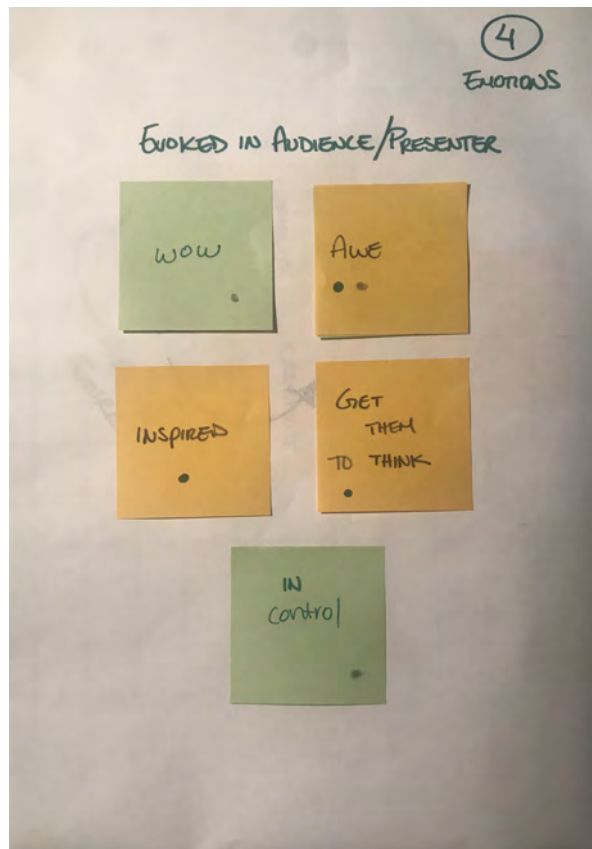
Figure 5.11: Dot voting for emotions evoked

impractical to install and uninstall every time it was to be used.

The VR idea, where the presenter uses a virtual reality device with the headset where multiple options could be shown only to the presenter, there they could manipulate the content. This was discarded because it completely disconnected the presenter from the audience and undermined the experience of being in a fulldome.

The North Star inspired idea, using augmented reality so that the presenter has a toolbox to interact with the fulldome without losing the immersion of the audience as the tools are not shown to them. It also allows the presenter to choose actions without breaking the connection with the audience. This idea was discarded because it required the construction of additional hardware and the resources weren't enough to explore and flesh out this idea further.

The Nintendo Switch idea, consisted on using the controllers for input as they can track position and use the different buttons and joystick to control the content. It was seen as a simplified and familiar control for users and thus not as daunting. This was discarded as the team wanted to explore an idea that involved the least possible external hardware for the user as possible.

5.3 Develop

Using the parameters defined in the last phase helped get a precise direction and enough clarity for the development of the solution. In this phase the team had several ideas and alternatives that then became one prototype developed in 4 iterations. In this chapter such prototype is described along the iterations made.

5.3.1 Prototype

To make possible the prototype, the different gestures needed to be define in order to develop the custom prototype. Once this was done, the iterations of the development took place, ending with a prototype tested and gestures defined.

5.3.1.1 Gestures

The lack of documentation on hand gestures for the specific tasks needed for this prototype pushed the design team to turn the focus to other areas in the research. It was proposed to look into speculative design as an approach for the development of the gestures. Speculative design encompasses practices from across a range of disciplines, including futuristic forms of architecture, design fiction, and critical design [60]. From here the focus turned to design fiction. Design fiction is a more recent manifestation of speculative design and draws inspiration from science fiction literature and cinema [61]. On occasion, sci-fi prognostications do become actual

objects and services [62][63][64]. So it seemed like a viable source of knowledge for hand gestures.

With design fiction in mind, a database of hand gestures performed in sci-fi movies created by Figueiredo et al. [65] was found. In this database, hand gestures are described and can be filtered by the type of gesture and the action they trigger. Considering this database goes as far as 2015 the team decided to examine posterior media e.g. *Black Panther (2018), The Magicians (2015-Present).* Oftentimes the gestures used in sci-fi are not user friendly, however they might prove helpful as a base to build up to intuitive gestures.

Afterwards, the team was able to agree on a list (Table 5.1) of hand gestures to develop for the prototype.

List of Gestures for Iteration I	
Gesture	Action
Draw a circle in the air around the object with hand	Selection
Extend index finger and close all the other fingers	Point
Open hand parallel to body	Stop
Selection and then move hands closer together	Zoom-in
Selection and then move hands apart from each other	Zoom-out
Selection and then close hand into fist	Grab object
Point and then close index finger	Teletransport

Table 5.1: List of Gestures for Iteration I

5.3.1.2   Iteration I

Based on the gestures thought at this point, the prototype phase started by finding the technology that suits the setup and that cover the gesture tracking. The mentor of this project at the Visualization Center in Norrköping recommended to use the HTC Vive Controllers, for what they where considered to be explored along to the Leap Motion Controller.

Unreal Engine 4 was used develop the prototype, since offers a good performance and fast integration with both technologies. Additionally the use of blueprints, a visual scripting system that use the concept of node-based interface used to define object-oriented (OO) classes or objects in the engine [44], brought a dynamic development. It also gave a more structured way to program along to a visual interface that help to organize the actions developed for the gesture interaction and an excellent way to debug the written code.
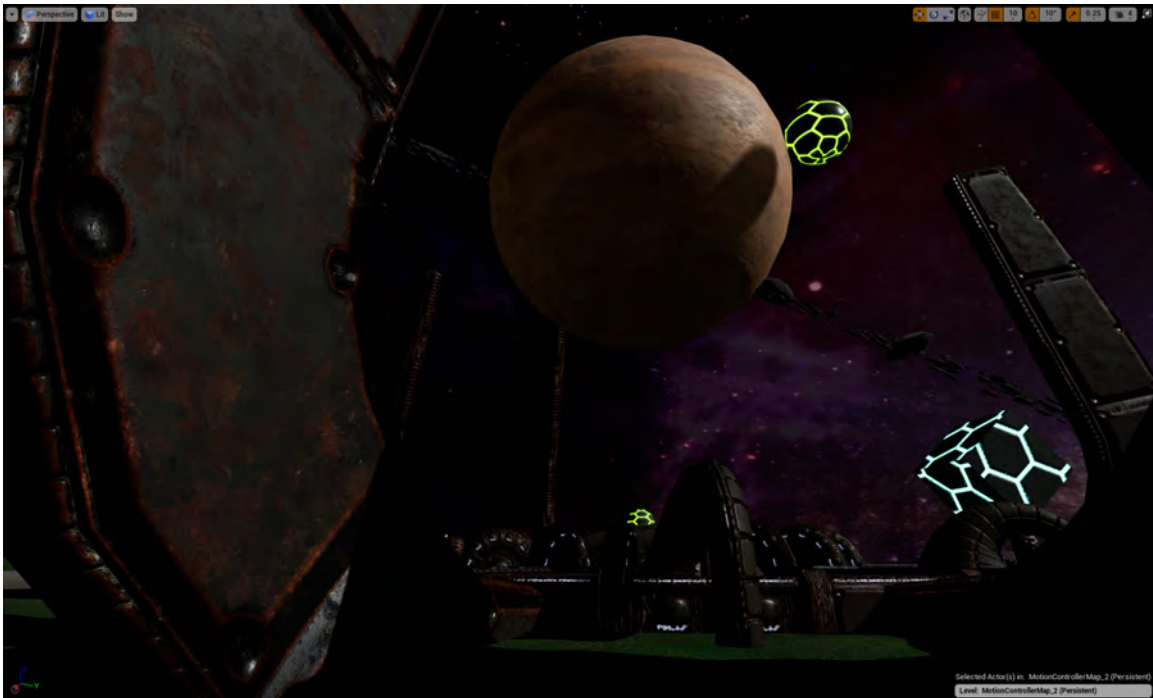
Figure 5.12: World Design in Unreal Engine

5.3.1.2.1 Prototype Development .

For this first prototype there was two projects created for URE4, one for the world design and other one for the development of the gestures. GitHub was used to store both projects and make easier the testing, since there were different locations where they were performed.

The aim of the world design was to have an environment that resembled a planet so that scales could be played with 5.12. This means that it wouldn't be off-putting to have a big moon-like sphere and small cubes in the same space, specially when projecting to the dome as the scales could be distorted. With this environment we intended to test the usefulness of the gestures in regards to the size and location of the objects. When creating this world the modeling and texturing of the 3D surfaces was done with the surface of the fulldome in mind. The quality of the 3D objects as well of the animations is high because the projectors in the fulldome have a projection capacity of 8k and we wanted to take advantage of this to aid the immersion in the world.

For the gesture prototype a simple environment was setup, using basic shapes and lighting. The architecture used at first was appropriate for the HTC Vive controllers (Figure 5.13), which was basically divided in two: the main actor and the pawns. The main actor is a camera with pawns that represents the users point of view and that contains the virtual hands (pawns). The pawns are the representation of the HTC Vive Controllers, that where replaced by the leap motion controller in later iterations. At this point we used this controllers to explore the technology and the potential of the setup.
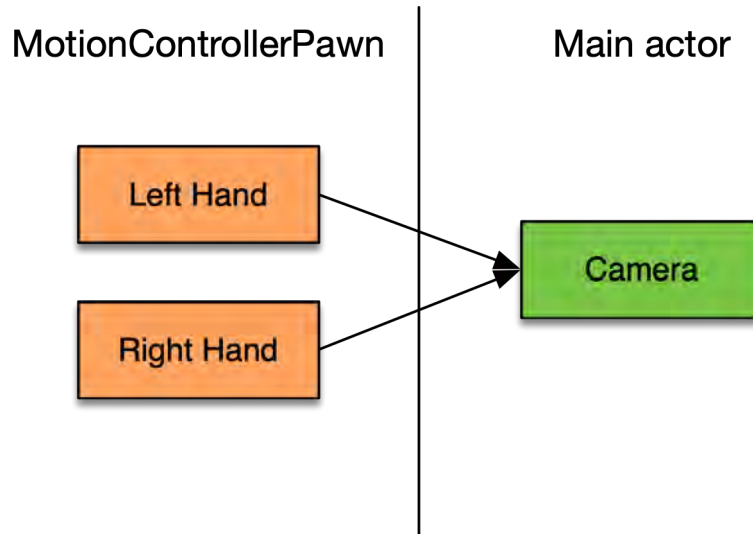
Figure 5.13: First architecture

The gesture tested in this iteration belong to a simple action: fire a beam to select or point to different objects. This beam starts from the hand location and ends 5000 units away in straight line, allowing the user to see which object can be grabbed and manipulated. Initially this beam was not visible, but in later iterations this was changed. To hold an object the trigger button [5.14]of the controller has to be pressed in order to close the virtual hands and grab such object. The object is grabbed if the beam touches an interactive cube, then the user can holds it at a distance. Once an object is selected, the trackpad. [5.14] When doing internal tests, it was found that using the Vive Controllers would affect the installation of the prototype, making it hard to setup in the real space where the fulldome is installed since it depends on two sensors that locate the controllers, and the head-mounted display (HMD) to match position of the user in the virtual space. For this it was decided to change the controllers for the prototype and use the Leap Motion controller instead.

5.3.1.3   Iteration II

The Leap Motion Controller was chosen since it provides more freedom for the user, and because its convenience to setup in the available installation of the fulldome. Its size has an important role, it can be placed almost anywhere in the installation and it only depends on one cable that connects to a computer, while the HTC Vive has two sensors an a HMD that required to be configured.

Because of this change both of the URE projects were updated. The Leap Motion plug-in was included in both of them, updating also the architecture of the system by adding the actor that handle the virtual hands. Also the blueprints were updated so they fit the requirements of the Leap Motion plug-in. This require to add an actor that handle the hands tracked, this actor belongs to a pawn provided by the plug-in that is updated according to the information acquired from the sensor
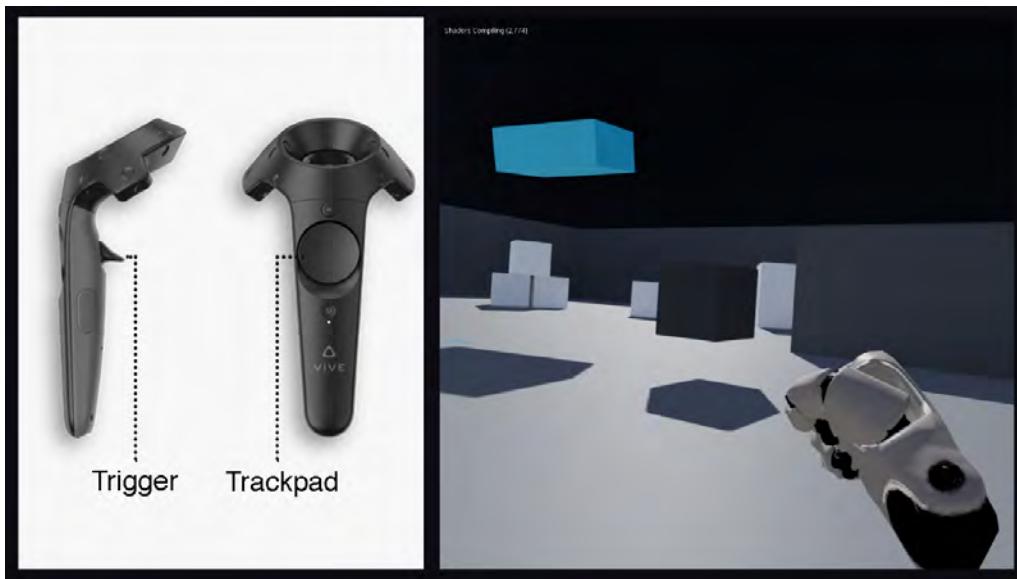
Figure 5.14: Hold the trigger button to grab the blue object and scroll the trackpad to manipulate it

when tracking the physical hands. It is also responsible to create the animations of the virtual hands from the same data acquired. The pawn is a class that controls all the actors that are controlled by players, in this case the digital representation of the hands. After this changes, the architecture of the prototype is the following: Character Actor Blueprint containing the hand pawns and the camera, the Hand Pawns Blueprint which contains the mesh for each hand, and the Custom Character Blueprint containing both hands and the camera as it can be seen in the Figure 5.15. The hand pawns are managed by the LMC plugin, translating the information gathered by the sensor into the different animations and location. The Leap Motion Hands Blueprint manages the beam and the hands physics being the collision detection, which allows the grabbing action, the main one. Finally the Custom Character Blueprint is the actor that handles the gestures and the camera, deciding what to do when the different gestures are performed such as fire the beam and grab and object.

While developing this prototype one problem was issued. It was found that the some gestures previously designed were not good for the HTC Vive Controllers. Gestures like zoom-in and point with one finger to fire the beam to grab objects at a distance, were limited due the technology for two main reasons: space and accuracy. When working with the HTC Vive controllers the movement is restricted by the room size where the sensors are placed to gather the movements data and the HMD position. The minimum size recommended shown in the website is about $2\,\text{m} \times 1.5\,\text{m}$, which limits the general setup to this scale. Additionally, there is a limit for the now called precise movements or fingertips movements [66]. According to the Leap Motion Guidelines, precise movements using fingers and overlapping hands are not recommended, since the algorithm could get confused when extracting the data.
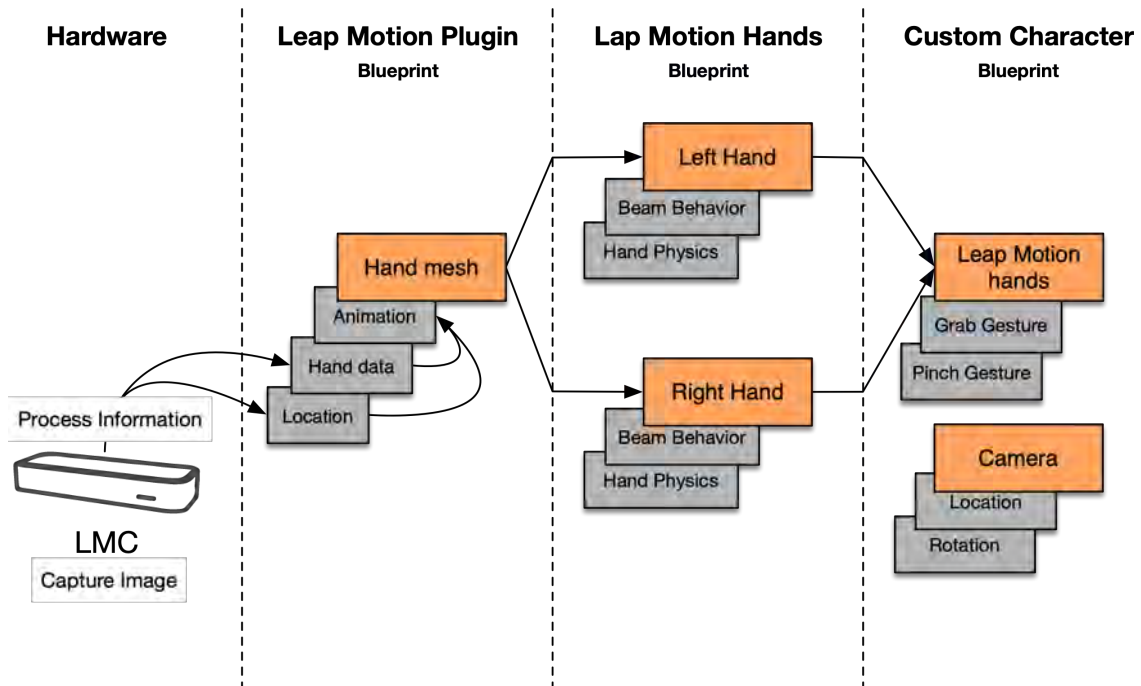
Figure 5.15: Modified architecture for the second iteration

5.3.1.4 Iteration III

Even though the latest version of the Leap Motion Controller has a very accurate tracking algorithm, the position of it affects the tracking of the hands. It was observed that having the sensor as a desktop application where the sensor is placed in a flat surface with no movements, is not as accurate as having a VR application where the sensor is attached to the headset. It created some problems when tracking the hands, specially both hands overlap, as the camera only captures the hands from down.

In addition performing the gestures zoom-in, zoom-out, and tele-transport weren't that efficient, since it required extra information to know exactly where to move or how much to zoom. When triggering the zoom-in and out, the main problem was the selection of the area, including the selection gesture since it requires to select objects at different distances, which resulted not that efficient when programming the prototype. The gesture needed to tele-transport was confusing for the sensor since this movement requires a very specific movement that glitches frequently.

This was a good reason to give a proper structure to the gestures, which was done by changing the way that the gestures were triggered and by removing difficult movements that required specific points of the hands, like pointing with the index finger. To be more efficient, it was decided to focus on the following gestures: manipulation of objects, and moving around the virtual world or manipulating the camera.

With this, it was intended to make the gestures more clear for the sensor, since
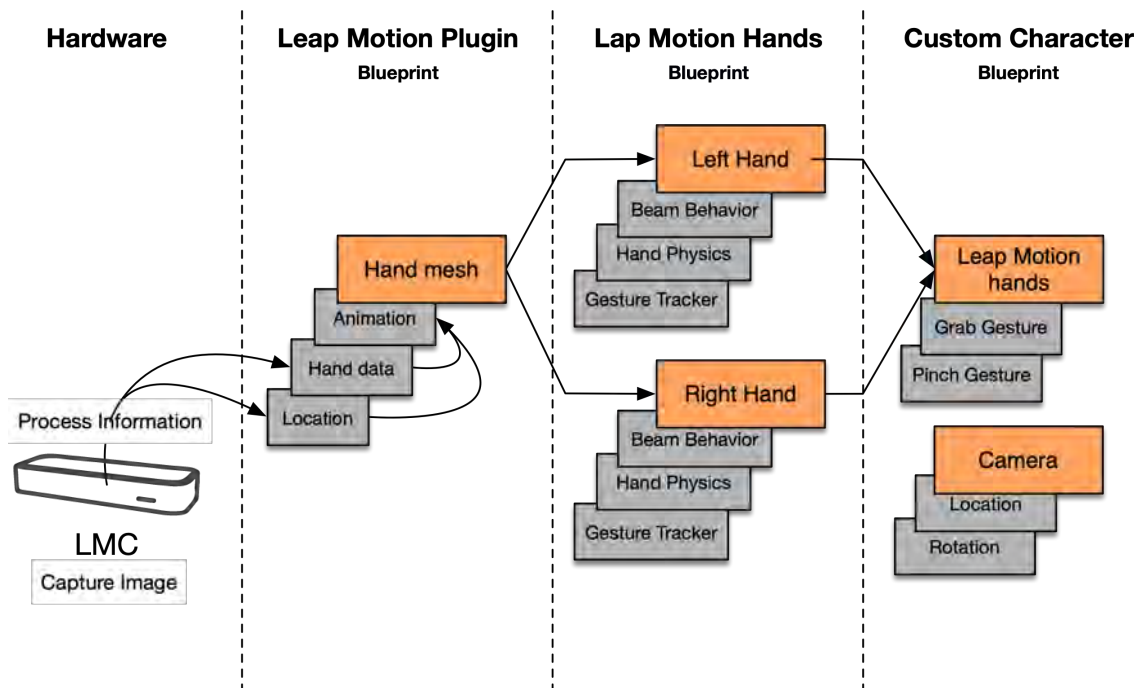
Figure 5.16: Modified architecture for the fourth iteration

it needs a structured way to know when to trigger the different actions, such as grabbing, when the user intends to use it and not triggering the actions by accident.

Finally, it was introduced a new concept: two hands level of interaction. With this concept the interactions are going to be done in two levels, having the primary and secondary hand, as first and second level. The primary hand triggers an action while the second hand has the option to perform more gestures to trigger more actions that are related to the primary gestures. This is like the right click with the mouse for a computer.

5.3.1.5 Iteration IV

After the previous changes, it was observed that there was the need to have a more controlled way to trigger the different actions. Internal tests showed that it was confusing when moving around and grabbing objects, since there was not a clear way to swipe between each actions. For example, when moving around it was hard to fire the beam since the right hand was already used to indicate directions. Additionally the cancel option was introduced ,e.g., so the user can fire the beam grab an object and cancel this action when desired. Also by giving more structure to the gestures would bring a better understanding for the users.

For this, two types of gestures concept was introduced: *starting gestures* and *detailed gestures*. The *starting gestures* are those that are based on the place of the hands in the coordinates xyz, while the *detailed gestures* are the ones that are based on the movements that the hands perform, such as fingers closed and pinch with two
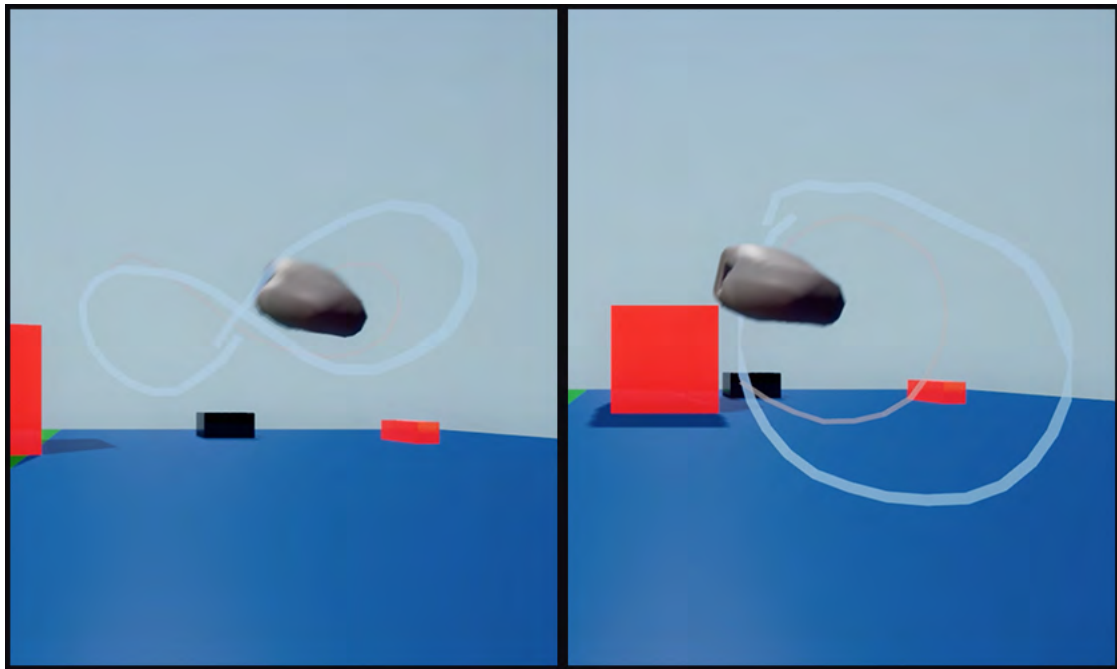
Figure 5.17: Starting gestures. Infinite gesture on the left and circle gesture on the right

fingers. The *detailed gestures* comprised the manipulation of objects and the camera manipulation.

To develop this the gesture tracker plug-in was added, which allowed to track the position of the hands in xyz coordinates. It gets the position of the physical controller and records the position, with that the plug-in draws a white line showing the path that the virtual representation of the controllers are taking, including the error margin. This path can be saved, so gestures based on this information can be created. With this addition the Leap Motion Controller handles the tracking of the hands in the physical coordinates and process the data to process the animation of the hands, the state of the hands, and position; while this new plug-in saves the path that the hands are taking to trigger the general gestures and draw a path line in white color. The architecture didn't change since this plug-in was added to the leap hands pawn, which was very efficient in terms of development time (Figure 5.16).

The paths saved were two: drawing a circle in the air and drawing an infinite loop in the air (Figure 5.17). Those gestures were based on the analysis made previously on gestures in sci-fi movies. It was decided to use those simple gestures since they are easy to remember and to perform.

With these changes the Gestures were redefined as can be seen in these tables 5.2, and 5.3, 5.4.

5.3.1.5.1 Development Update .

Starting Gestures	
Gesture	Action
Close right hand and do a counterclockwise circle then release	Enter object manipulation and laser beam appears
Close right hand and do an horizontal eight (start center to left down) then release	Enter camera manipulation
Start pinch on top left go to down right and release	Cancel all manipulation

Table 5.2: Starting Gestures for Iteration IV

Object Manipulation	
Gesture	Action
Point to object with laser beam and close hand	Grab object
With grabbed object, move fist horizontally	Object moves horizontally
With grabbed object, move fist vertically	Object moves vertically
With grabbed object, close left fist and move left fist away from self	Object moves away (Scroll away)
With grabbed object, close left fist and move left fist towards self	Object moves closer (Scroll closer)
With grabbed object open right hand	Drop object

Table 5.3: Object Manipulation for Iteration IV

Camera Manipulation	
Gesture	Action
Close left hand and move it to the left	Camera turns left
Close left hand and move it to the right	Camera turns right
Close left hand and move it away from self	Camera goes forward
Close left hand and move it towards self	Camera goes backwards

Table 5.4: Camera Manipulation for Iteration IV

To make possible the gestures some specifications were developed in order to make the Leap Motion acquire the data with more precision. The Leap Motion Controller was placed 30 cm ahead of the user in order to give them enough space to perform the movements and to trigger the gestures freely.

Also when developing the prototype some specifications about the hand movements and placement came up. In order to make the big gestures, a figure was recorded with an approximate 60 cm, allowing the user to have enough space to draw in the air the gesture. Also the distance that the hands need to take to trigger the different
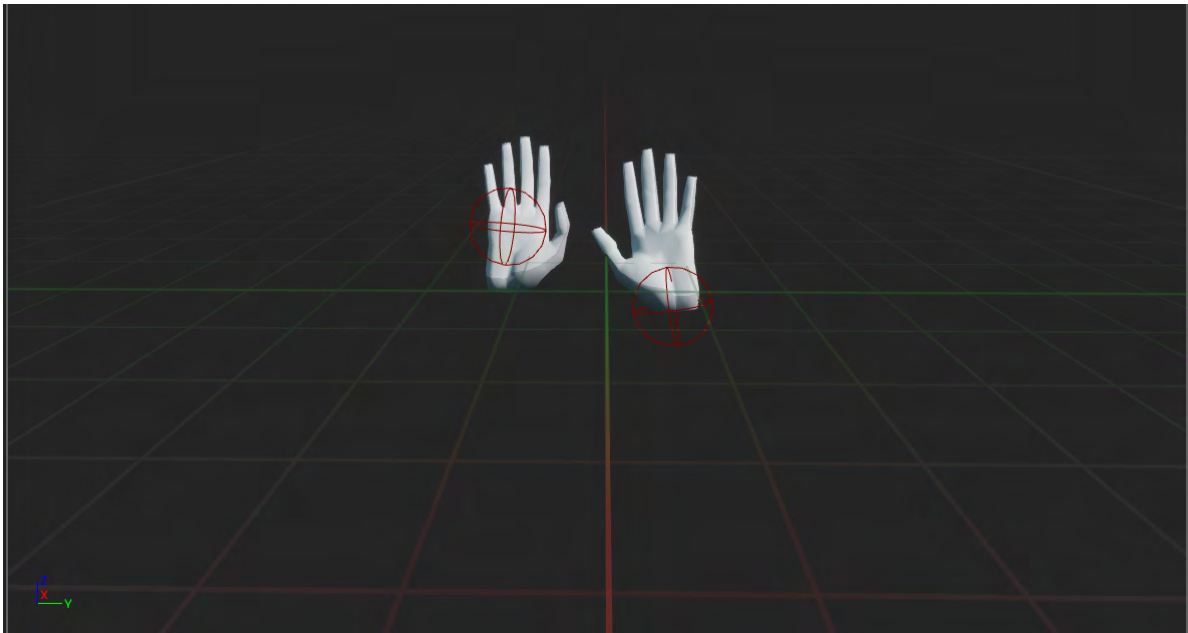
Figure 5.18: Origin point updated. first hand on the left has the origin point updated to the center of the palm, while the other has the original position on the wrist

options was set. Such distance was 10 cm in the second and third iteration, and was changed in the next iteration to 12 cm. As mentioned in the subsubsection 5.3.1.2, the program used to develop this prototype was UE4 with the corresponding plugins, using different blueprints to handle the different gestures.

5.3.1.6 Iteration V

This iterations are concern to the changes after the user studies. Some debugging was performed on the blueprints as they affected the use of the system. The most relevant change on this prototype is the change update of origin point.

For previous iterations the origin point where the hand fires the beam and and the hand tracker plugin is attached was located on the wrist. This was a problem as it caused less accuracy on the gestures and forcing the users to adopt uncomfortable hand position when performing the gestures. This problems arouse when performing the gesture to grab or move, point the beam to the objects, and grabbing them. When performing the gestures to grab or move, the users felt the movement not natural since it didn't match the user's actions. It was the same problem when pointing the beam, while closing the fist to grab an object showed instability. This problems where solved when moving the origin point to the center of the palm 5.18

5.3.2 Setup

In this document, the setup is defined as the set of sensors, a table, the Central Processing Unit (CPU), and other tools needed to capture and process the gestures together with the objects needed to hold those items. The area where the setup is placed is relevant as it defines the person who is going to make the interaction as either the presenter or the pilot.

This step changed through the different iterations as it was adapted to the different necessities. It started having a space for the the HTC Vive, either for the presenter or the pilot and changed to the use of the Leap Motion. Such change brought flexibility to the setup as it now depends of a smaller space that can be adjusted for the presenter or pilot area.

The setup used for the final iteration consisted on a table of $100\,cm \times 55\,cm$, a Leap Motion Controller with the space of $80\,cm$ up the sensor, $80\,cm$ wide on each side (about 150° angle), and $80\,cm$ deep in each angle (120° angle), and a cable to plug the sensor to the closest CPU to process all the information. This setup varied, as it depends on the size of the tables used to perform the tests, but this was the most commonly used. On the Visualization Center it was discussed to change the table to a microphone holder to carry the sensor, reducing the size needed only to the range needed by the LCM to track the hands of the user.

This setup is flexible to be used either by the presenter or the pilot as it only depends on the location of the main CPU to connect the sensor and run the program developed. As shown in the figure 5.19, the ideal area for the setup is where the presenter is located, allowing this user to interact directly with the dome without the need of a pilot, but as the location of the main CPU in the Visualization Center is located close to the pilot, the setup might need to be in this location on the future tests.

The setup was tested in two different cities Gothenburg and Norrköping. For the development and some user tests, the location was the Media Lab, a room placed in a building named Kuggen from Chalmers in Lindholmen, Gothenburg. Here a table with the LMC and the main CPU were used to test and develop the prototype, displaying the image in a Mitsubishi XL1550U projector with a 1024×768 pixels resolution (Figure 5.20). Other tests were performed in the Visual Arena, a studio that has one of the largest 4K monitors in Europe [67] with $3.2\,m \times 6\,m$ size, where the setup was calibrated and the interaction with a large-scale screen was tested (Figure 5.21). Finally, the tests performed in the Visualization Center located in the Norrköping in a room called VR-arena, a space with a back-projection system of three separate 2.5K projectors giving a total of $5.5K \times 1.6K$ resolution display and a $6.7\,m \times 2\,m$ size(Figure 5.22. All this locations used a CPU with URE4 installed to run the project and an extension to connect the LMC.
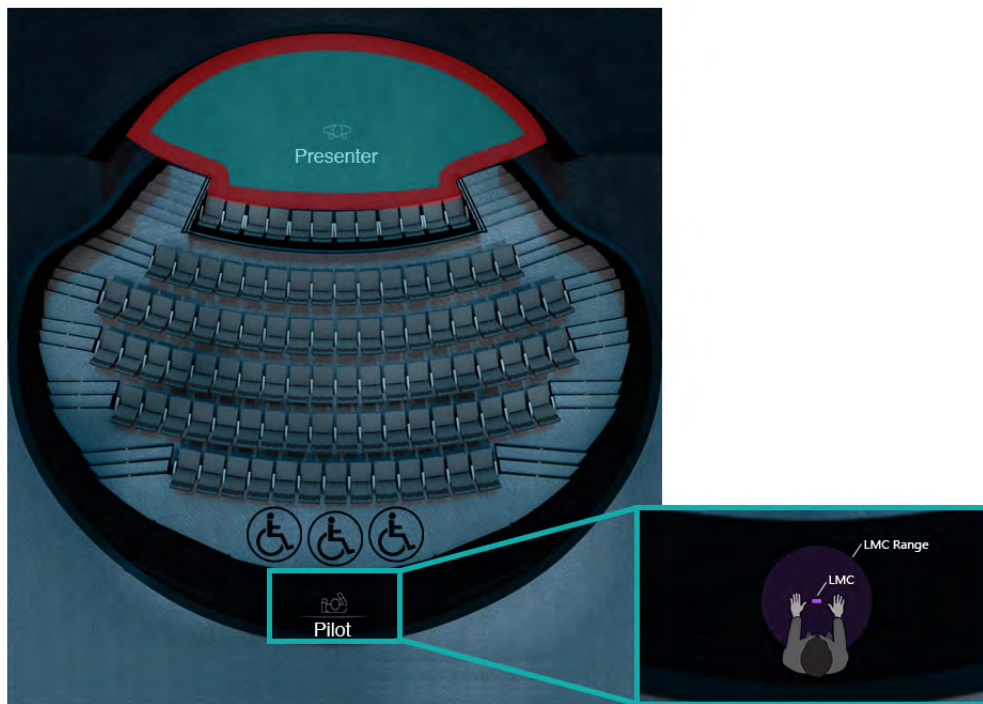
Figure 5.19: Fulldome presenter area and pilot zoom-in

Figure 5.20: Setup used in the Media Lab, Kuggen

Figure 5.21: Setup used in the Visual Arena, Lindholmen Science Park

Figure 5.22: VR-arena, Visualization Center-C

5.3.3 Evaluation

5.3.3.1 User Test

For the user test a usability test plan was created (Appendix A) The duration of a session was in average 30 minutes. To start the session the purpose and the procedure of the testing were stated. Afterwards the gestures were presented in a document (Appendix B) and the participants were given five minutes to explore and get familiar with the gestures. When the time ended, the participants were asked to attempt the tasks given by the tester. For the post-test an UX curve [53] (Appendix C) about the interaction with the system was drawn and then through an unstructured interview the reasoning behind the curve was explored as well as exceptional points in the curve. After this a SUS questionnaire [55] (Appendix D) to evaluate the usability of the gestures hosted in google forms was presented to be completed.

5.3.3.1.1 Participants For the evaluation of the prototype there were two types of participants, the experienced users, and the new users.

The experienced users were recruited at Norrköping Visualization center. This users had presented in the fulldome previously with either one or multiple scenarios. There were two experienced users, and both are researchers within the Visualization center. These tests were held in the VR-arena the 29th of May.

The new user tests were carried out in Gothenburg. These users have never presented in a fulldome. However it was considered relevant to consider this type of users due to the availability of the fulldome to be booked for third party presentations, where the presenters would have no experience presenting in this kind of environment nor the knowledge of how the interface works. There were four new users. All of them had different academic backgrounds and had never been in contact with the leap motion technology. These tests were carried out in Kuggen the 12th, 13th and 15th of July.

5.3.3.1.2 Setting The tests were made in two different locations which lead to two different arrangements.

In the visualization center, the tests were performed in their VR-Arena which consists in a large-scale screen and VR hardware that was easily adapted for the prototype. (Figure 5.23)

In Gothenburg the tests were performed in the media lab (Figure 5.24). The media lab was adapted for the tests moving the furniture and adapting the height of the table to accommodate the different heights of the users.

Figure 5.23: VR-Arena at the Visualization Center-C
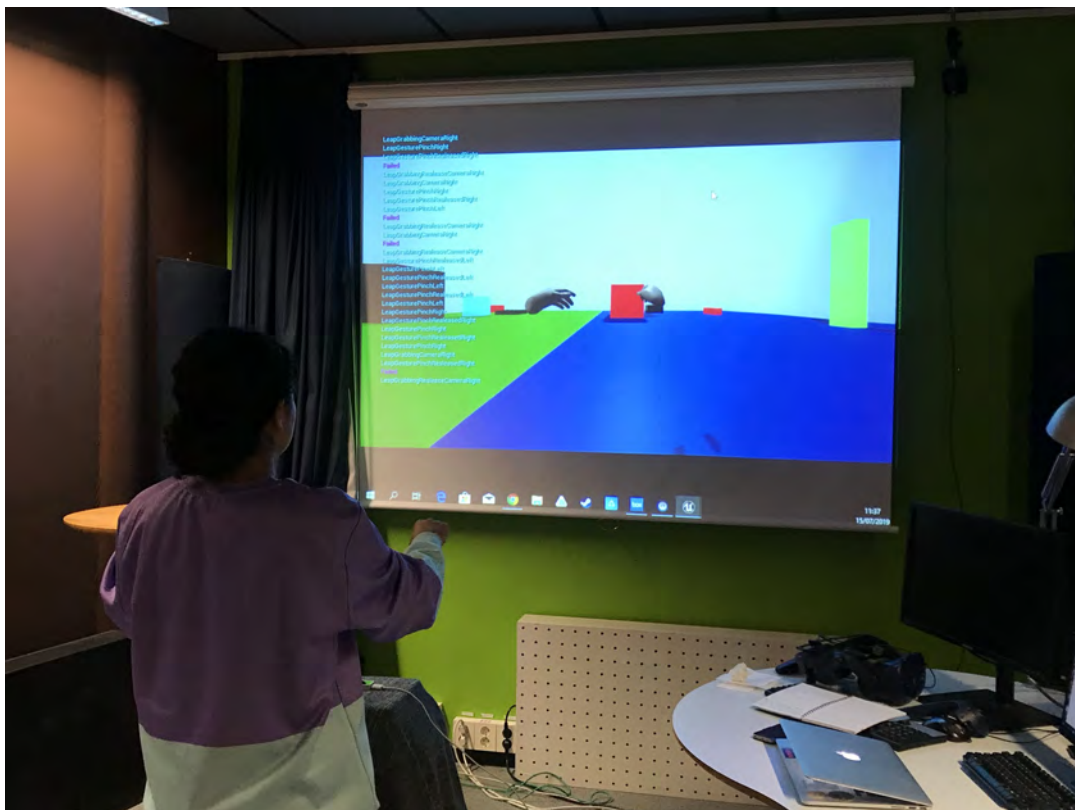
Figure 5.24: Media lab at Lindholmen
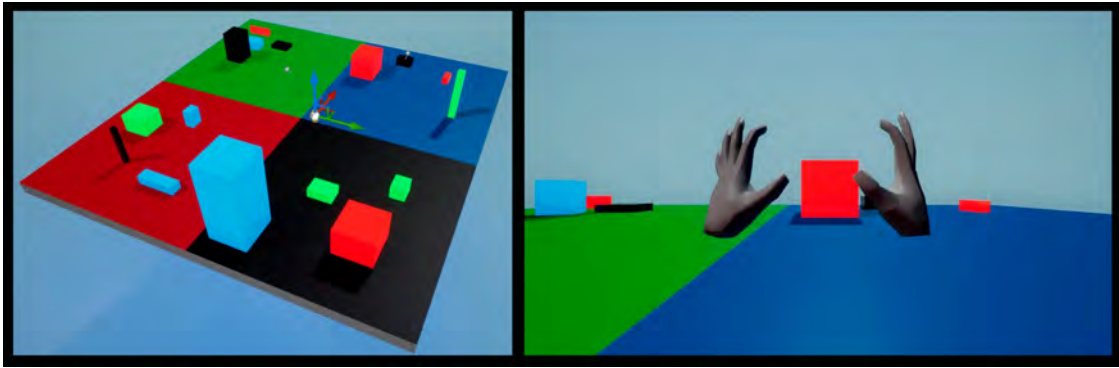
Figure 5.25: Environment where the user performs the tasks

5.3.3.1.3 Tasks When the user was placed in the sensor's range, their hands appeared close to the center of the map (Figure 5.25) on the screen. Then the gestures were presented and some of the times the gestures were demonstrated by the tester if the user asked for it.

There were two tasks in the test. The first task was to move to the black section, the second task was to place a couple of cubes in the correct section according to their color.

It's important to mention that depending on the situation, the tasks were flexible enough to be modified during the test to accommodate the user's activity flow. The relevant part was for the user to understand and try out all the gestures, so as long as they used all the gestures it was not essential for them to perform the tasks perfectly.

5.3.3.2 UX Curve

A UX curve [53] template was produced C so that after the tasks were realized by the user they could draw a curve of their experience. Most of the participants (5 out of 6) hadn't heard of a UX curve before, so one template was drawn by the person administering the test to explain what the curve represented. Through the drawing of the curve the participants were able to express how their emotions changed while using the prototype.

After the curve was drawn the participants were asked about interesting points within the curve and what their reasoning for the changes in the drawn curve meant.

5.3.3.3 SUS Questionnaire

A SUS questionnaire D was presented in a google forms format giving the participants a computer and some space so they wouldn't feel pressured when answering it. The participants were told to write anything they wanted to add or comment upon in the comments section. Alternatively the participants were also told that if

they didn't want to write that much or to expand upon what they wrote they could just talk to any of the people administering the test.

5.4 Deliver

5.4.1 Gesture Specification

The final version of the gestures were defined in subsubsection 5.3.1.5 and were utilized for the user testing. The document used in the user tests can be found in Appendix B.

5.4.2 Guidelines extraction

With the knowledge gathered by developing the prototype, analyzing the user tests, and interviewing the expert developer in fulldome content, several guidelines were found. During this process such information was either recorded in video or audio to be analyzed later in the process. Additionally the relevant information gathered while developing the project was written down in a notebook dedicated only for this purpose. The interview with a fulldome expert with many years in the field was recorded to extract the most relevant information.

Once the results were analyzed it was time to resolve the guidelines. To gather all this information and build up the guidelines, an affinity diagram was done. To do so, three sessions with a 25 minutes duration were performed. In here, the relevant points were written in sticky notes during the first 10 minutes, while the following 15 minutes were taken to discuss the insights written in the sticky notes. For the third session the information was arranged in different categories depending on the topic that each sticky note contained (Figure 5.26), allowing the flow of the discussion and helping to create the different categories for the guidelines. While discussing the information gathered, it was clear that such guidelines had to be divided in three different areas. This with the aim to make them easier to find and understand. Such guidelines are the main considerations that have to be taken when designing in the categories presented in the section 6.2.

Figure 5.26: Groups for the affinity diagram

6

Results

The results of the work done during this thesis are not limited to the evaluation results. They also include the prototype itself, the gestures, and the general guidelines when designing for a fulldome.

6.1 User tests result

The test were focused on the experience of the user as well as the perceived ease of use of the prototype. As such the test were intended to get qualitative data.

6.1.1 Usability

6.1.1.1 Negative Findings

The most common problem for the users was that the prototype had some sensibility issues. It was found out that by using the gesture tracker, requiring one member of the team to record the gestures, the gestures became too personalized. The users had to compensate and adapt their own gestures to what the system had on record. This lead to conflicts when doing a specific gesture. For example when moving the camera backwards a user accidentally cancelled all manipulations because the gestures were the same for the system. Another sensibility issue caused the objects to be dropped unintentionally and due to the lack of physics in the testing environment the objects flew off. This evoked some frustration in the users because they felt a lack of control.

The use of the beam, although some users mentioned it helped to point specific objects, also evoked some frustration. To grab an object it was needed to point with the beam and then close the hand. However this also had the unintended effect of the beam moving a bit from what it was pointing at. This was specially noticeable with far away objects as those needed more precision when pointing.

One user had an issue with the programming of the gestures. The gestures clearly favoured the right hand using it as the dominant hand for all the gestures. The user was left handed and thus had some troubles with the gestures that were lead

with her non-dominant hand. After some practice the gestures were successfully triggered, as she got used to it. However she still had to consciously remember to use the right hand.

The last relevant issue encountered was that the system kept the camera moving even when it didn't register the hands anymore. It presented a problem because the first reaction of most of the users whenever something went wrong was to remove their hands. This situation happened particularly when the user performed gestures related to camera manipulation. In camera manipulation the users found the system more responsive if they used both hands to move forward and thus sometimes they tried to use the same approach when turning left or right. Doing so lead to having the hands overlap and this makes the sensor unable to distinguish the hands correctly.

6.1.1.2   Positive Findings

The users immediately saw the potential of the interface. One user even mentioned that she could see the interface being useful in other areas not only for entertainment. All the users understood the purpose of the design and could see the intention. Most users said that this interface was a good start to achieve an interface usable in the fulldome. However there is still a long way to go in terms of usability, specially regarding the bugs that the software has and the sensibility issues.

In this specific prototype some of the users found the gestures a bit confusing at first. However after trying them for a bit and figuring out the quirks of the motions the gestures presented no problem and the users used them fine.

6.1.1.3   Suggestions

The users also had some ideas for improvement of the prototype while using it. Ideas to make the tasks asked from them easier or faster.

Regarding the gestures, one user suggested to try straight lines instead of curves. They might be easier to remember and to perform. However this might not be the best option as during testing that this kind of gestures were performed accidentally. Which resulted in the system doing unforeseen actions. Another suggestion was about how the grabbing action works. Instead of the beam and the grab motion being done with the same hand, do it with two. Using the dominant hand to get the beam and the non-dominant hand to close the hand to grab might lead to more stability and thus more accuracy when grabbing far away objects.

A user commented on providing a "snap" function so the beam would automatically point to the closest object. Doing so would remove the need to have a perfect accuracy when grabbing an object.

Some users mentioned that the interface would improve if there were more indicators. First for direction so it would be easier to orient oneself when performing the different
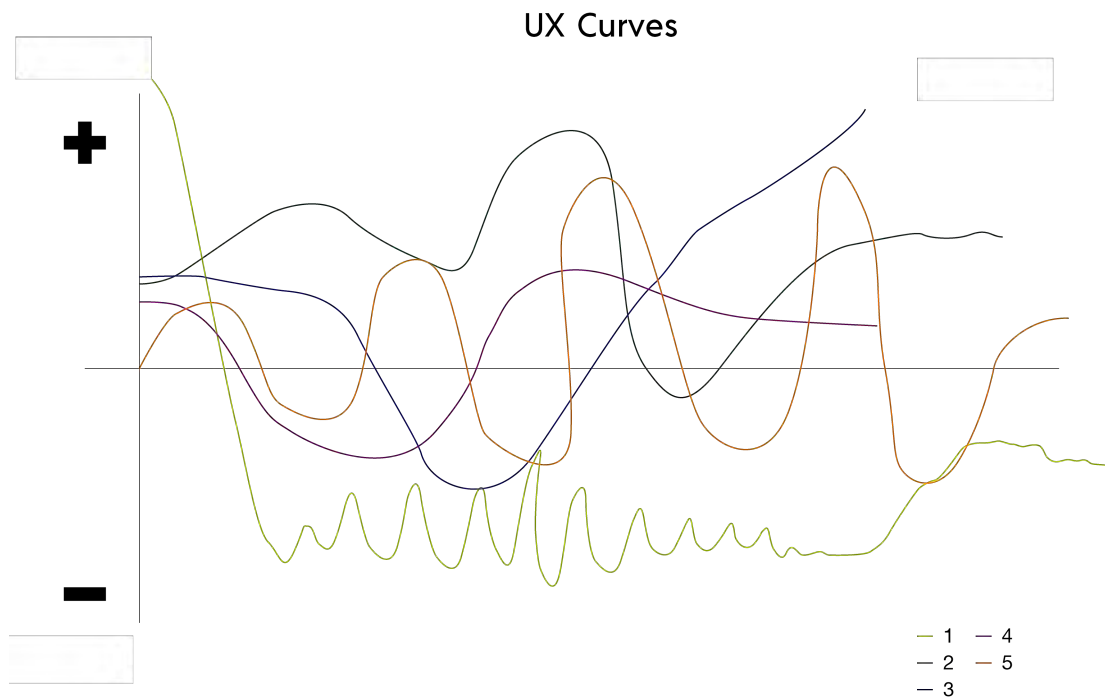
Figure 6.1: The digitalization of the drawn curves.

actions. And second an indicator for the distance between the object and the user. Either by showing the actual distance or having a small window with the top view to have a visualization of how close or far away the object is. This distance was specially important when moving the object closer or further away from the user.

The last suggestion also has to do with this pushing and pulling of the objects or scrolling as it was often referred as. Make the speed of the scrolling actions dynamic. The ratio of the speed should consider the position of the object if it's far away, for example if it's 1 km from the user the speed would be faster than if the object was located 1 meter away. This would reduce the waiting time when trying to get an object closer, which caused stress and impatience in the user during the user test.

6.1.2   UX Curves

The curves are directly dependent on the user's feelings on one interaction with the prototype. As such the results can't be completely relied upon because the UX curve is usually used as a indicator on a long term relationship between the user and a product [53]. As a first time interaction this curves have a significant low point because the user had to learn how to use it. Nevertheless the curves still provided useful feedback to understand what the user thought and felt about the gestures and the experience overall. In the figure 6.1 all the curves drawn during the user testing are shown. It's relevant to mention that there are only five curves out of the six participants as one of them decided not to draw one.

At first glance the curves seem completely different, however a deeper look revealed that in essence they are the same. Most of the curves start high because after presenting the design and the purpose of it the participants were impressed and their expectations were raised. The curve dips down soon after because of two main reasons. The first reason is that the users would feel uncertain on how to start using the prototype and would feel a bit nervous of trying it. This reason is presented in the first two participants where the test approach was to learn the gestures by trying them. This was changed for the next tests because the users asked about a demonstration of the gestures. So for the following user tests a demonstration was performed before the users tried the gestures. Which leads to the second reason on why the curve dips. The users felt there were too many instructions while they were doing nothing. They felt eager to start but had to wait for the "tutorial" to be over.

The other dips in the curves are whenever the prototype presented a bug. Some users encountered more bugs and it's visible in the shape of their curves. These bugs deteriorated the users' experiences making the users feel like they were doing something wrong or making them feel frustrated when the prototype wouldn't do what they wanted.

The high points in the curve happened when the system correctly performed an action that the user prompted. This also led to the user thinking of new possibilities and combinations of the gestures to execute the tasks asked for in the user test.

Some users felt that the cognitive load asked of them was higher than needed. Which is directly related to this being the users' first time using the interface and learning a new language. The cognitive load is high at the beginning however as seen in the figure 6.1 most curves stabilized or ended in the positive side by the end of the test. Which is mostly due to the user learning and understanding the language as well as the quirks of the system. However more testing from a larger sample is needed to confirm this.

6.1.3 SUS Questionnaire

The System Usability Scale (SUS) is a popular measure of perceived usability. The 10-item questionnaire is scored on a 101-point scale and provides a measure of a user's perception of the usability of a system. The SUS has the benefit of 30 years of usage and data from over 10,000 responses and hundreds of products so the scores can be interpreted in at least five ways [68]. In this thesis it has been decided to use 2 ways: acceptability, and promoters and detractors. These categories were chosen because they show if the user would advocate for the system, and if it's good enough to be used multiple times.
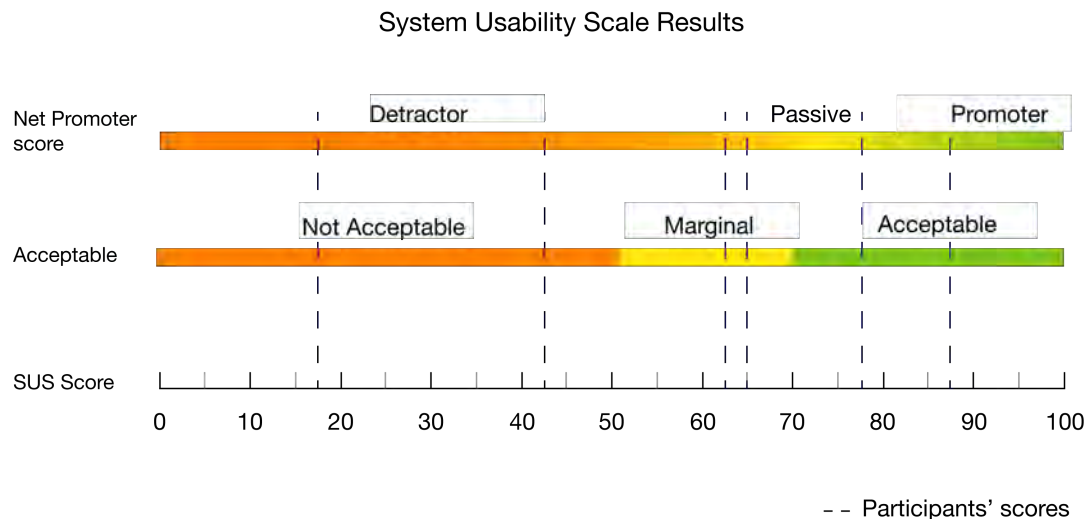
Figure 6.2: Acceptability and NPS categories associated with the SUS scores received.

6.1.3.1 Net Promoter Score

The net promoter score (NPS) is a metric used in customer experience programs. NPS measures the loyalty to a system by basing the measurement in the question "How likely is it that you would recommend this system to a friend or colleague?" [69].

There has always been a strong correlation between the SUS and the NPS. On average, the SUS explains between 30 and 50% of the variation in users' likelihood to recommend [68]. In the NPS there are three classes of users: the Promoters who are most likely to recommend the system to a friend, the Detractors who are more likely to discourage other users, and the Passives that will use the system but won't recommend it.

To achieve a Promoter classification, the SUS score needs to be at least 81 on average. Detractors have an average SUS score of 53 and below and Passives are the scores in between [68].

The SUS scores received in the user tests (Figure 6.2) demonstrate that only one user is a promoter of the system as it is, while two users are detractors and would speak against the use of the system. Finally three users think the usability is fair enough to not talk against it but they wouldn't praise it either.

6.1.3.2 Acceptability

One variation of the SUS scores is to put them in terms of what's acceptable or not acceptable. Bangor et al. [70] determined that "acceptable" corresponds to roughly above 70 and "unacceptable" to below 50. They designated the range between 50-70

as "marginally acceptable," which encompasses a range for a fair usability but that could be improved.

In the figure 6.2 the results from the testing can be seen. In this category the results are equally divided having two in each term. For two users the usability is unacceptable, one close enough to the marginal level. The next two are in the upper part of the marginal level. And the last two found the usability in an acceptable level.

Overall the participants that were specialists in an interaction field were harsher and had higher standards for what they look for in a system than the users that do not delve in this field. It's worth considering that the latter were impressed by the novelty of the interaction to care more about the context and what the everyday use of the interface implicates.

6.2 Guidelines

Using the knowledge gathered by developing this prototype, working with the LP sensor, the results of the user tests, and the interviews made, several guidelines were found. Since the work done was extensive and included different areas, the guidelines found were divided into three main categories: Fulldome Guidelines, Gestural Interaction Guidelines, and Leap Motion Guidelines.

This guidelines are important considerations found when designing for the previous groups. They are presented in this chapter, divided in the three different areas, and explained taking examples on how they were relevant in this project or how they were introduced. They are not sorted in an specific order and they cover the work described in this report.

6.2.1 Fulldome Guidelines

The guidelines in this section are a set of data collected from the analysis of user tests and an interview we had with a current developer of content for dome environments. All of them are relevant points to consider when designing for a fulldome environment.

6.2.1.1 Consider the availability

As the fulldome is a complex space usually with the purpose to entertain, the access to such facility is very limited. It's relevant to consider this as it could delay the design process. It's recommended to take advantage of the space when it's available, understand the technology used and its dimensions. It could also be very useful to use a virtual model of the fulldome for testing.

6.2.1.2 Consider the blind spots

Because of the nature of the dome, there are some blind spots for the audience that could be used efficiently for the users, in this case the presenters. For example the section that is in front of the presenters, in the back part of the audience, can be used to place some helpful information for the presenter, since the audience don't really focus on this part. This also depends of the type of presentation that is being given in the dome.

6.2.1.3 Design for an immersive experience

When designing any type of content for a dome environment, do not forget that there is audience involved waiting for an immersive experience. For this, it's important to create an immersive design that takes advantage of the size and shape of the dome and the type of view that it provides. The space and planet exploration is the most common example of this immersive environment, but not the only one.

Also it's important to understand the projectors used and the quality of them. This is relevant, since it could help the design content with a better feeling of immersion. Which draws the line between good or bad content according to the dome expert.

6.2.1.4 Consider the scale of the content

Immersion is very important when designing content for a fulldome. To achieve this, is relevant to consider the scale of content presented, since this would create the feeling of immersion. In the interview with the dome expert it was mentioned that if the scale is not the adequate, the audience might feel that something is off, not real for which the immersion might not be achieved. As an example of this, a video was presented where different objects with different sizes were placed on a table. Starting from a cup of coffee, the camera starts zooming-in to a coffee bean while changing the scale and demonstrating the size of the coffee bean related to the size of the cup, then it goes from the coffee bean to a salt crystal making the same comparison and showing the scale, but now from the point of view of the salt crystal. The video keeps going showing the different scales going to a HIV Virus, an antibody, DNA, and finishing with the scale of the atom with always, or at least when possible, the cup of coffee on the background showing always the comparison of sizes. This was a good exercise to understand the importance of the scale and how it can affect the immersion.

6.2.1.5 Use slow and precise movements

When designing content that moves in the xyz axis, it's important to not forget the audience. Rough and spontaneous movements can provoke an unpleasant experience

for the audience when looking at the screen, and not only that but it also can provoke motion sickness. To avoid this, it's important to design slow and precise movements to move from point A to B. If the distance between this two points is too long, it's important to add a way to jump between them with a smooth visual representation.

6.2.1.6 Consider the setup of the technology

When designing a new type of technology for a dome environment, it's important to take in consideration the setup. Depending on the fulldome space, computers might not be accessible on the spot desired to make connections, the space required for the setup could be limited, or the light might not be good enough. All these need to be consider, so the custom technology designed for a fulldome works as desired.

6.2.1.7 Use the rest zone

When designing any type of content for a fulldome technology, it's crucial to design around the zone where it's not hard to see by the audience. The audience are going to be looking at the content in an immerse dome that covers their vision in approximately 180 °, giving the possibility to look at more things in their surroundings. According to the interview with the expert in dome content, a safe zone is the area located in front of the audience in the middle-down spot.

It was explained by the expert that this is where relevant content should be placed to get the attention or where objects should be used as point of reference. It was also explained that this area could work as a point where the user looks at to avoid motion sickness or to have a sense of direction.

When the content includes movements,a good practice is to place in this spot an object as a point of reference to help the audience understand the spatial coordinates. For example, in the underwater expedition named *Below The Surface* [18], content shown in the Visualization Center that explores the bottom of the Baltic Sea, the rest zone is were the small submarine used to explore the surroundings is located, described in subsection 2.5.7.

6.2.2 Gestural Interaction Guidelines

The guidelines in this section came out from the knowledge gathered from programming and testing the gestures on this thesis work. The guidelines presented are recommended for when designing gestural interfaces independently of the sensor used to capture the movements.

6.2.2.1 Simplify the gesture

Consider simple to execute and remember gestures. Design them with few steps to trigger the different actions, easier to remember and also more efficient when trying to achieve the main goal.

6.2.2.2 Take in consideration two layers of gestures

Consider the combination finger position and hand-arm location when creating custom gestures. This combination could be used to create many different types of gestures, either to create simple gestures for simple actions, or to create more complicated gestures that represent more difficult tasks. For example, this was used when making the gesture to trigger the beam based on the position of the arm, and then closing the fist to grab an object.

6.2.2.3 Consider the distance between hands as triggers

The distance between the hands can be used to trigger different actions, and together with the direction can be used to differentiate the types of actions. For example in this project, the distance used to trigger the push and pull action is about $12\,cm$, while the direction was in charge to define whether an object should be pushed or pulled.

6.2.2.4 Consider the dominant hand of the user

Designing for the dominant hand of the user is relevant, this would define the user experience making an impact on the efficient use of the system. This was observed during the user tests, where users that were left handed had a harder time drawing the gestures, since the design favoured the right hand. This also affected the use of directions, for example when testing the prototype, some users felt that they couldn't perform the gestures because they had a hard time drawing the different shapes to trigger the different actions.

6.2.2.5 Consider the dead reckoning

Technique used in navigation, is the correlation between how far are two objects, the distance between them, and the velocity. With this technique a determined position is calculated by a previous one, advancing in that position based upon known or estimated speeds over elapsed time and course [71]. Consider this technique to determine how and when an object should move, and how fast it should do it. In this project a similar concept was used when doing the gestures to move around and pull and push objects. To pull and push the held object, the position of the hand

and the direction was used to perform this actions, the farther the object was located the faster it moves. When moving around the virtual world, the initial distance of the hand compared to the current position and direction is what gives the indication whether to move left or right.

6.2.2.6 Allow the user to easily cancel the different actions

Provide an option to easily cancel actions. This will create an easy way to exit when the user feels frustrated or overwhelmed, or just when they want to change between actions. For example when performing the user tests some users wanted to change from grabbing an object to move around. By providing a simple gesture to cancel they were able to end any action with the same command, either when they were grabbing objects, pushing or pulling objects, or moving around.

6.2.2.7 Consider a simple gesture to reset or clean the screen

When designing gestural interfaces, consider to design a way to clean the screen or reset everything that is shown. It was found that when some users feel overwhelmed, some of them put their hands behind their backs waiting for the system to reset. Also it was found that users assumed that when the hands stopped being tracked by the sensor, the actions that they were performing previously where going be canceled.

6.2.3 Leap Motion Controller Guidelines

The guidelines at this section are designed for cases when the Leap Motion Controller is used to develop customized gestures. This was possible because of the work done using this sensor during this project. The guidelines presented are not in any specific order, and they should be considered when designing or developing gestures as the case may be.

6.2.3.1 Consider the index fingers and thumbs

The index fingers and thumbs can be used to develop gestures since they have good accuracy when there being tracked by the sensor. Even though the other fingers were tracked very accurately they showed problems when tracking them individually, if not much, enough to not be reliable to design a gesture with them. It's worth to mention that the tracking accuracy also depends on the position of the sensor.

Interaction Area
2 feet above the controller, by 2 feet wide on each side
(150° angle), by 2 feet deep on each side (120° angle)
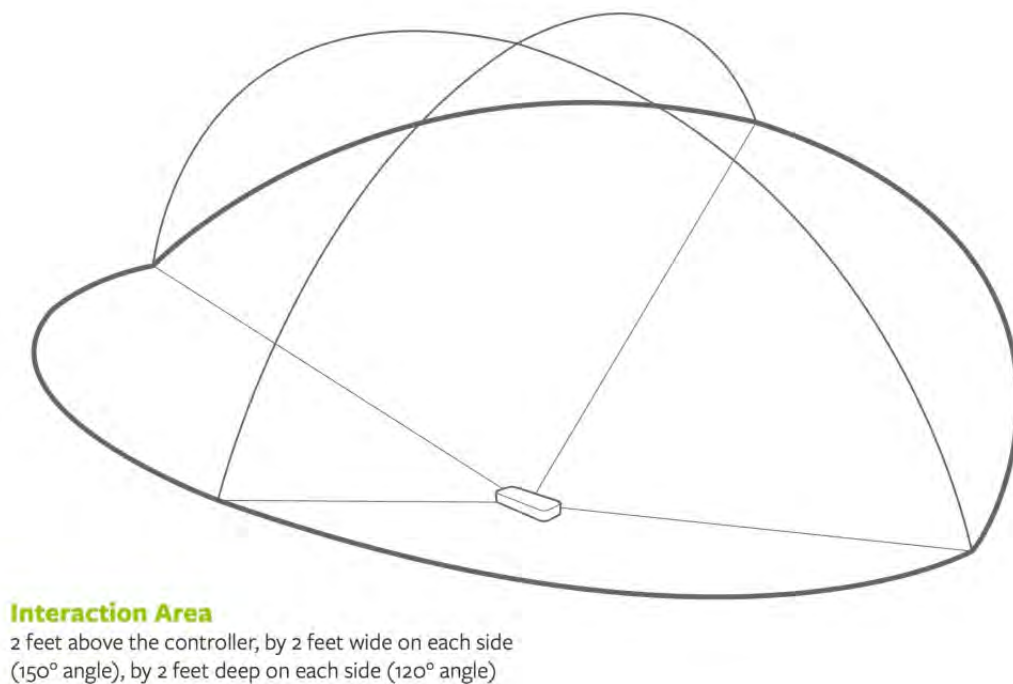
Figure 6.3: Leap Motion Controller sensor area.

6.2.3.2 Avoid gestures that require overlapping hands

When developing the prototype with the Leap Motion, overlapping hands proved to be a problem. The tracking system has a considerably accuracy when tracking the hands, but this fails when the hands are overlapping. Usually when this happens the hand that is more visible or closer to the sensor is the one that keeps being tracked, while the other one gets lost.

6.2.3.3 Consider the space of the LMC for the interaction

As it's described in its website [72], the area that the sensor works with is approximately 80 cm up the sensor, 80 cm wide on each side (about 150° angle), and 80 cm deep in each angle (120° angle) 6.3. Is important that this space is considered for both the setup and the development of the custom gestures since it could affect the interaction.

6.2.3.4 Consider the placement of the sensor

When using the Leap Motion Controller as a Desktop application place the sensor in a considerable distance, where it can track the gestures without making the user having to do an extra effort. The placement of the sensor can affect the efficiency of the space where the user performs the different gestures.

For example in this project, the sensor was located at the user's stomach level and 20 cm away from them, so the user feels comfortable. Other placements where tested, but this resulted the most efficient.

6.2.3.5   Use a flat surface

When placing the sensor, be sure that is in a flat surface to avoid problems when tracking the hands. The location of the sensor is the origin the xyz coordinates giving the coordinate to the virtual hands. Thus if the sensor is tilted, the hands will also be a little tilted which might affect the designed interaction. It's worth to remember that the sensor can be used as a desktop application, by placing the sensor in a flat surface without moving it, and as a VR application by attaching the sensor to the HMD, allowing the sensor to track the hands depending on the head position.

6.2.3.6   Consider the origin point when attaching objects

When designing the interaction with this technology, consider its origin point, so it doesn't affect the interaction or the tracking performance. The plugin required for the Leap Motion Controller has the origin on the wrist of the virtual hand, thus if an object is attached to the pawn it would have the same origin 5.18. In this project not considering the origin point caused less accuracy on the gestures and uncomfortable hand position, explained in subsubsection 5.3.1.6.

6.2.3.7   Consider the distance between the sensor and the hands

When using the LMC, it was found out that the sensor does not work properly when the hands are to close to each other. When this happens, the tracking starts to glitch and sometimes it even stops tracking. For this, it's relevant to consider the distance between the hands and the sensor. In this project, the distance between the hands and the sensor depended on the user's height, but usually it was around 20 cm.

7

Discussion

In this chapter we discuss the analysis the work done with the prototype, the setup, and the implications that designing a technology for a fulldome environment has, together with the future work.

7.1   Limitations

When working with a fulldome environment there are many implications that need to be considered to have a successful result. First the technology needs to be analyzed, so a proper solution can be designed. Then it's important to have a clear understanding of the software used, what is its purpose?, is it a static video to entertain the audience or is it an interactive tool to explore and amaze the audience?. Finally it's crucial to include the audience for any design either content design or technology for the dome, since they are the final users.

This considerations reflected in limitations when developing the work described in this document. Regarding the technology used, the dome had an important update when the work was in process, which caused a limitation on the design. After updating the fulldome, the resolution of the dome was updated to 8k, leaving the content designed outdated since it was only 4k. Additionally, it wasn't considered the use of nDisplay to display the content on the different projectors. This was a big limitation as the nDisplay needs to be initialized on the Unreal project before developing the content. It is also possible to update the files, but since it is a large size file and this knowledge was acquired late in the process, it was decided to give priority on the user tests and the development of the gestures.

An other limitation founded regarding the fulldome environment was the setup of the sensor. Because the prototype was designed for users that will have a presentation on this environment, the setup was planned to be in the front where the presenter is visible. This was not possible since the Leap Motion requires to be plugged to a central processing unit (CPU).

When working with big-scale screens, in this case the dome, it's important to consider the accuracy of the technology used. This is due to that big scale details can be appreciated better, when this is not considered, limitation can arise. In this project,
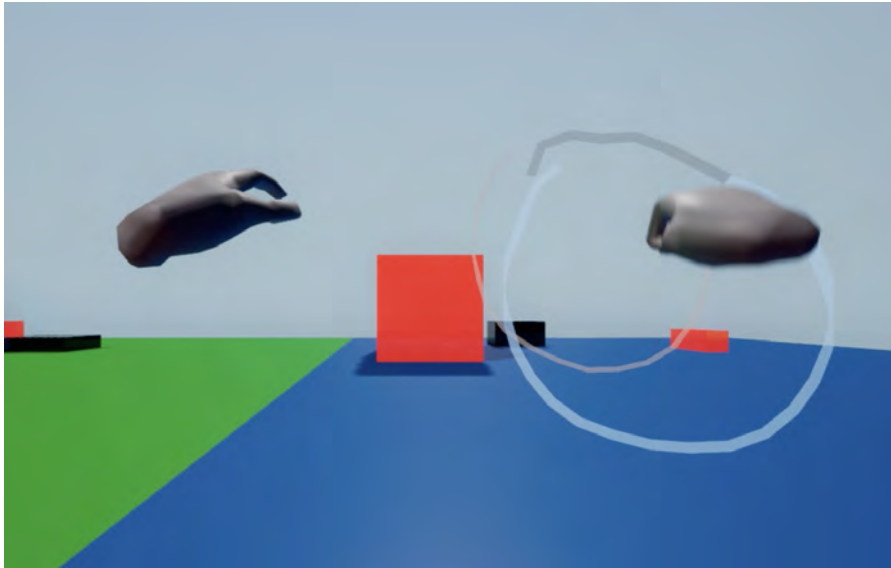
Figure 7.1: Gesture path.

the use of the sensor was not that precise, causing some weird jumps in the virtual hands an other imperfections. Those imperfections might not be visible on regular screens, but on a big-scale screens, they are evident. This opens the discussion whether to use physical controllers or not.

Additionally, the limitations about the prototype were found. The lack of visual feedback was pointed out by the users in the test. This is an interesting topic since the final users are the audience and they don't need to see this feedback. The question here is how to properly present this information when actions, or in this case gestures, are done successfully or not. Another problem found is about the use of the LMC and the location of the user. When using this sensor it was thought that the user could be placed on any side of the sensor and then walk around the sensor keeping the position of the hands related to the position of the user always pointing forward. Unfortunately the LMC automatically rotates the position of the hands, for which when the user walks around the sensor, the hands would always rotate to match the original position. Also it would have been relevant to give a way for the user to not have to stand in only one place to interact with the sensor, but to do so, another sensor would have to be added.

The way that the gestures are performed by the user, which determines if an action is triggered or not, is another limitation as the input depends very much on how the person records the gesture and how the users can follow that exact path (Figure7.1). For example a simple gesture, like the circle made to start the beam, was sometimes a difficult task as it depends on the user. Sometimes they made circle from left to right, others from right to left, or another times they just didn't feel natural when performing the gesture as it was recorded.

The amount of users available to perform the tests where the information was gathered was another limitation. Initially it was planned to have different iterations with

expert users, people that are familiar with the dome and that have presentations or expositions very often, but this was not possible as there are a limited amount of people with this profile and their schedule didn't match to the times where this user test took place at the Visualization Center located in Norrköping. Still some tests were performed, but more user tests with these people would have been very useful to gather more relevant data and to understand better either if this is a useful tool for them or not. Additionally, the results of the user test may have been biased as the tests were performed once with the users and it requires to understand the gestures, since most of the time used in the test was to teach to the people how to use the technology and not performing all the tasks designed. This could have caused a different experience, giving different results.

7.2   Improvements

The most pressing problem in the interface is the overtraining of gestures. So a way to avoid the problems that the overtraining causes would be to give the user a training session before a presentation with an audience. In this training sessions two paths could be taken. First option can be that the users try out the gestures already recorded by a third part to learn the nuances of those specific gestures. The second option is that during this training session the user would be allowed to record their own gestures so that the nuances are intrinsically tied to the user that is going to have the presentation. This would reduce the risk of forgetting gestures or of them not working because of unintentional personal movements. The second option would probably require a set of predefined rules, such as add a stop or cancel gesture. For both options a tutorial would be needed. Either with someone that knows the system or a digital tutorial added to the system.

To significantly improve the usability of the interface a visual representation of the commands is needed. By having even a simple indicator that a certain type of manipulation is on the user would be able to know if their attempt to initiate a gesture was successful or not. In the current prototype the user doesn't know when the system has failed to understand a gesture. A visual indicator would reduce the confusion in the user and know if they have to repeat the gesture right away. Furthermore the indicator would serve the user as a reminder to cancel or stop the command being used before moving on to another one.

A much talked about improvement is to make the scrolling speed dynamic. This would improve the experience because it reduces the waiting time for the user which is specially notorious when getting an object from really far away. The ratio of the speed should consider the position of the object relative to the position of the user. In doing so the speed can change to suit the distance.

7.3   Future Work

As the user tests were limited, there is a clear need to perform more tests with the expert users. For this, the next studies must be updated, so the users focus more on the actions and gestures with the intention to reduce the learning curve. Additionally it would be relevant to test the final design including the audience to gather more information about the feelings that the gestural interaction evoke.

To perform the tests the prototype has to be updated. First nDisplay has to be setup in the UE4 project, so the image can be fragmented and displayed by the projectors that conform the dome in the Visualization Center. With this update, the user tests would be able to be performed in the fulldome, the proper environment. Additionally the purpose of this update is to understand how the sensor would work with the dome, and how the users handle the different movements in this immersive environment. Next step is to add the capability to run the project in a virtual dome environment, where the users can also explore the technology on the fulldome environment without the need to be there physically. This will also give more advantages as the Leap Motion would be attached to the HMD giving the user to freely use the hands to perform the different gestures. Additionally the users will be able to move around the virtual dome, opening the possibility to understand better the performance of this gestural interaction.

After performing more user tests, enhance the prototype with the feedback retrieved is the next step to take. Moreover exploring more options using a gestural interaction with the dome is the next priority. As mentioned by the users, the need of feedback and more information about the actions performed is required. This is a hard task as the audience is involved and they might not require to see this information. For this, the option to fragment the projection in two screens would need to be added. With this change, the presenter would be able to see more information and feedback about the actions taken without showing such information to the audience.

Updating the setup to give the possibility to the presenter to have more freedom by not forcing them to be in an specific place to perform the gestures, is the next priority. For this, it would be very interesting to explore a different setup where the user has the LMC attached on a helmet that they can use while presenting, as it's done when developing content for VR and attaching the sensor to the HMD. With this, the sensor would track the hands, but only when the hands are in range, in other words, only when the user look at the hands which could represent a possible problem.

To solve these issues, it would be very interesting to explore the North Star project recommended in the LMC website. This is an open source project based on a 3D printed helmet where the LMC can be attached allowing the interaction in a mixed reality environment [73]. The idea by introducing this new setup is that the user has a separate screen where it has more options to interact, while using the hands combined with gestures to trigger the different actions. In this way the user would have full control of the dome and more information about the actions taken, such as

feedback, without showing unnecessary information to the audience. Moreover the use of this setup will give more freedom to the user, and since the information would be placed in the helmet's lenses, it won't be a problem for the tracking system as the objects have to be be manipulated in the area designated. The concern with this updates is to enhance feeling of immersion and the interaction with the fulldome, either for the audience and the presenter.

8

Conclusion

With this work the research questions were answered:

How to design an interface with a gestural interaction to control and explore 3D content displayed in a fulldome?

In order to answer this questions, a double diamond process (Figure 5.1) was used to create a prototype of an interface. This prototype includes the software developed in Unreal Engine 4, and the hardware compiled primarily of a Leap Motion. The definition of hand gestures to control objects 5.3 and the direction of the camera 5.4 was also realized as well as tested.

The prototype used the Leap Motion Controller to track the hand gestures that together with the plug-ins Motion Tracker and the Leap Motion plugin, and a visual scripting language called blueprints offered by UE4 Controller, was used to create the gestural interaction presented in this document. Such interactions had two main gesture divisions: Starting an action and object/camera manipulation.

The prototype provides a first approach of how hand gesture based interaction can be used to control 3D digital content and create an engaging experience within a big-scale screen to manipulate different objects and move around the virtual space.

Sub-question 1: How can existing gestural tracking technology be mapped to make an interface suitable for immersive interaction?

Using the leap motion technology as main hardware for the prototype allowed the team enough freedom to map a wide range of hand gestures to control 3D content. As explained in this document, the gestural interactions were created to interact with objects in an immersive environment, such as grab objects at a distance and manipulate them. Even though it has a positive opinion towards the manipulation, there is still not enough data to conclude that using this technology is appropriate using the current setup for the presenter, being more suitable for the pilot user. On the other hand the LMC does not require additional controllers or sensors for tracking the hands, and it provides a good tracking system using a small size sensor, which is good to create an immersive interaction. This technology has a big potential, but still needs to be explored with a different setup. The gestures mapped in the Leap Motion can be found in the subsubsection 5.3.1.4.

Sub-question 2: What could be a suitable setup design guidelines for free spacial exploration when designing an interaction for a fulldome?

The setup explored in this work described in subsection 5.3.2, was not the adequate to work in the fulldome environment, but through the interview with the expert, theory research, the design process, and the user tests conducted in this thesis, guidelines were defined in section 6.2. Such guidelines are for three different areas designing for the fulldome, Leap Motion as a controller, and gestural interaction, giving the best practices to design for this environment using such technology. Additionally a proper setup was discussed in the section 7.3, where a second screen is presented and where the user can have more information, such as feedback of the actions taken, and have more control without bothering the audience.

Bibliography

[1] Elke Reinhuber, Ross Williams, and Benjamin Seide. The scale of immersion: different audio-visual experiences exemplified by the 360° video secret detours. In *Proceedings of the Conference on Electronic Visualisation and the Arts*, pages 236–243. BCS Learning & Development Ltd., 2018.

[2] Intolight. iland - an interactive fulldome installation, mar 2010.

[3] Leap Motion. Project north star.

[4] Sophia Li, Yazhou Huang, Vinh-Sang Tri, Johan Elvek, Samuel Wan, Jan Kjallstrom, Nils Andersson, Mats Johansson, and Dan Lejerskar. Interactive theatersized dome design for edutainment and immersive training. In *Proceedings of the 2014 Virtual Reality International Conference*, VRIC '14, pages 8:1–8:5, New York, NY, USA, 2014. ACM.

[5] Heba Gamal, Hatem Abd elkader, and Elsayed Sallam. A performance evaluation of feature extraction techniques for hand gesture recognition. 03 2019.

[6] Daniel Bachmann, Frank Weichert, and Gerhard Rinkenauer. Review of three-dimensional human-computer interaction with focus on the leap motion controller. *Sensors*, 18(7), 2018.

[7] Giulio Marin, Fabio Dominio, and Pietro Zanuttigh. Hand gesture recognition with jointly calibrated leap motion and depth sensor. *Multimedia Tools and Applications*, 75(22):14991–15015, Nov 2016.

[8] William Goddard, Alexander Muscat, James Manning, and Jussi Holopainen. Interactive dome experiences: Designing astrosurf. In *Proceedings of the 20th International Academic Mindtrek Conference*, pages 393–402. ACM, 2016.

[9] Wisdome. https://wisdomeproject.se/english/.

[10] Thomas Clifford. Welcome to wisdome.

[11] Visualiseringscenter C. About c.

[12] Simone Schnall, Craig Hedge, and Ruth Weaver. The immersive virtual environment of the digital fulldome: Considerations of relevant psychological processes. *International Journal of Human-Computer Studies*, 70(8):561–575, 2012.

[13] J. Rico, A. Crossan, and S. Brewster. Gesture-based interfaces: Practical applications of gestures in real world mobile settings. In *Whole Body Interaction*, Human-Computer Interaction Series, pages 173–186. Springer, London, UK, 2011.

[14] Roger Dannenberg and D. Amon. A gesture based user interface prototyping system. pages 127–132, 01 1989.

[15] Maurice H. P. H. van Beurden, Wijnand A. Ijsselsteijn, and Yvonne A. W. de Kort. User experience of gesture based interfaces: A comparison with traditional interaction methods on pragmatic and hedonic qualities. In Eleni Efthimiou, Georgios Kouroupetroglou, and Stavroula-Evita Fotinea, editors, *Gesture and Sign Language in Human-Computer Interaction and Embodied Communication*, pages 36–47, Berlin, Heidelberg, 2012. Springer Berlin Heidelberg.

[16] Archive Dreaming. http://refikanadol.com/works/archive-dreaming.

[17] Event horizon, feb 2019.

[18] Visualiseringscenter C. Below the surface.

[19] Visualiseringscenter C. Cosmos 3d.

[20] Tian-Shu Wang, Heung-Yeung Shum, Ying-Qing Xu, and Nan-Ning Zheng. Unsupervised analysis of human gestures. In *Pacific-Rim Conference on Multimedia*, pages 174–181. Springer, 2001.

[21] Juan Pablo Wachs, Mathias Kölsch, Helman Stern, and Yael Edan. Vision-based hand-gesture applications. *Communications of the ACM*, 54(2):60–71, 2011.

[22] S Schechter. What is gesture recognition? gesture recognition defined. *Gesture Recognition:< https://www.marxentlabs.com/what-is-gesture-recognition-defined*, 2014.

[23] Kohei Arai and Ronny Mardiyanto. Camera as mouse and keyboard for handicap person with troubleshooting ability, recovery, and complete mouse events. *International Journal of Human Computer Interaction (IJHCI)*, 1(3):46, 2010.

[24] JM Gray, WL Fraser, and I Leudar. Recognition of emotion from facial expression in mental handicap. *The British Journal of Psychiatry*, 142(6):566–571, 1983.

[25] Rakhi A Kalantri and DK Chitre. Automatic wheelchair using gesture recognition. *International Journal of Engineering and Advanced Technology (IJEAT)*, 2(6), 2013.

[26] Consuelo Valdes, Diana Eastman, Casey Grote, Shantanu Thatte, Orit Shaer, Ali Mazalek, Brygg Ullmer, and Miriam K Konkel. Exploring the design space

of gestural interaction with active tokens through user-defined gestures. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems*, pages 4107–4116. ACM, 2014.

[27] Ekaterina Olshannikova, Aleksandr Ometov, Yevgeni Koucheryavy, and Thomas Olsson. Visualizing big data with augmented and virtual reality: challenges and research agenda. *Journal of Big Data*, 2(1):22, 2015.

[28] Pramod Kumar Pisharady and Martin Saerbeck. Recent methods and databases in vision-based hand gesture recognition: A review. *Computer Vision and Image Understanding*, 141:152–165, 2015.

[29] Leigh Ellen Potter, Jake Araullo, and Lewis Carter. The leap motion controller: A view on sign language. In *Proceedings of the 25th Australian Computer-Human Interaction Conference: Augmentation, Application, Innovation, Collaboration*, OzCHI '13, pages 175–178, New York, NY, USA, 2013. ACM.

[30] Ka Chun Yu, Matthew Brownell, Joslyn Schoemer, Daniel Neafus, Thomas Lucas, and Zachary Zager. Live action film footage for an astronomy fulldome show. *Planetarian*, 36(1):6–17, 2007.

[31] Paul David Bourke and Dalai Quintanilha Felinto. Blender and immersive gaming in a hemispherical dome. *Computer Games & Allied Technology*, 10:280–284, 2010.

[32] Inc. Epic Games. Rendering to multiple displays with ndisplay, 2019.

[33] Pixela Labs LLC. Pixela labs vr products and services, 2019.

[34] UnrealEngine. Childish gambino creates a fantasy world for pharos | project spotlight | unreal engine, mar 2019.

[35] Jo Szczepanska. Astrosurf in 360 at design and play, may 2016.

[36] Danwei Tran Luciani and Jonas Lundberg. Enabling designers to sketch immersive fulldome presentations. In *Proceedings of the 2016 CHI Conference Extended Abstracts on Human Factors in Computing Systems*, pages 1490–1496. ACM, 2016.

[37] Brian Badillo, Doug A Bowman, William McConnel, Tao Ni, and Mara G da Silva. Literature survey on interaction techniques for large displays, 2006.

[38] Epic Games. Unreal engine 4 documentation.

[39] Epic Games. Actors.

[40] Epic Games. Camera.

[41] Epic Games. Pawn.

[42] Epic Games. Character.

[43] Epic Games. Mesh.

[44] Inc. Epic Games. Blueprints visual scripting, 2019.

[45] Viktor Farcic. Software development models: Iterative and incremental development. *Technology Conversations:< https://technologyconversations.com/2014/01/21/software-development-models-iterative-and-incremental-development/*, Development Models, 2014.

[46] Barry W Boehm. A spiral model of software development and enhancement. *Computer*, 21(5):61–72, 1988.

[47] Design Council. The design process: What is the double diamond. *Saatavana osoitteessa:< http://www. designcouncil. org. uk/news-opinion/design-process-whatdouble-diamond>. Luettu*, 26:2017, 2015.

[48] Bruce Hanington and Bella Martin. *Universal methods of design: 100 ways to research complex problems, develop innovative ideas, and design effective solutions.* Rockport Publishers, 2012.

[49] Han Dorussen, Hartmut Lenz, and Spyros Blavoukos. Assessing the reliability and validity of expert interviews. *European Union Politics*, 6(3):315–337, 2005.

[50] Neil Turner. A guide to sketch storming – a design game for ideation. *UX for the Masses:< http://www.uxforthemasses.com/sketch-storming/*, 2017.

[51] Rikke Dam and Teo Siang. How to select the best idea by the end of an ideation session. *Interaction Design Foundation:< https://www.interaction-design.org/literature/article/how-to-select-the-best-idea-by-the-end-of-an-ideation-session*, 2018.

[52] Carolyn Snyder. Using paper prototypes to manage risk. *User Interface Engineering:< www.articles.uie.com/prototyping_risk*, 1996.

[53] Sari Kujala, Virpi Roto, Kaisa Väänänen-Vainio-Mattila, Evangelos Karapanos, and Arto Sinnelä. Ux curve: A method for evaluating long-term user experience. *Interacting with Computers*, 23(5):473–483, 2011.

[54] Jeff Sauro. Measuring usability with the system usability scale (sus). *MeasuringU:< https://measuringu.com/sus/*, 2011.

[55] John Brooke et al. Sus-a quick and dirty usability scale. *Usability evaluation in industry*, 189(194):4–7, 1996.

[56] William Gaver. What should we expect from research through design? In *Proceedings of the SIGCHI conference on human factors in computing systems*, pages 937–946. ACM, 2012.

[57] Carmelo Ardito, Paolo Buono, Maria Francesca Costabile, and Giuseppe Desolda. Interaction with large displays: A survey. *ACM Computing Surveys (CSUR)*, 47(3):46, 2015.

[58] Hrvoje Benko and Andrew D Wilson. Multi-point interactions with immersive omnidirectional visualizations in a dome. In *ACM International Conference on Interactive Tabletops and Surfaces*, pages 19–28. ACM, 2010.

[59] Sophie Stellmach and Raimund Dachselt. Look & touch: gaze-supported target acquisition. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems*, pages 2981–2990. ACM, 2012.

[60] Jonathan Lukens and Carl DiSalvo. Speculative design and technological fluency. *International Journal of Learning and Media*, 3(4), 2011.

[61] Bruce Sterling. Cover story: Design fiction. *Interactions*, 16(3):20–24, May 2009.

[62] Peter Kotecki. Here are 15 wild sci-fi predictions about future technology that actually came true. *Science Alert:< https://www.sciencealert.com/these-15-wild-sci-fi-predictions-about-future-tech-actually-came-true*, 2019.

[63] Cable News Network. Sci-fi inventions that became reality. *CNN Health:< https://edition.cnn.com/2018/03/21/health/gallery/sci-fi-inventions-that-became-reality/index.html*, 2018.

[64] British Broadcasting Corporation. Science fact: Sci-fi inventions that became reality. *BBC News:< https://www.bbc.com/news/health-38026393*, 2016.

[65] Lucas S Figueiredo, Mariana GM Gonçalves Maciel Pinheiro, Edvar XC Vilar Neto, and Veronica Teichrieb. An open catalog of hand gestures from sci-fi movies. In *Proceedings of the 33rd Annual ACM Conference Extended Abstracts on Human Factors in Computing Systems*, pages 1319–1324. ACM, 2015.

[66] Inc. Leap Motion. User experience guidelines.

[67] Visual Arena. Venue.

[68] Jeff Sauro. 5 ways to interpret a sus score. *MeasuringU:< https://measuringu.com/interpret-sus-score/*, 2018.

[69] Qualtrics. What is net promoter score? *https://www.qualtrics.com/uk/experience-management/customer/net-promoter-score/*, 2019.

[70] Aaron Bangor, Philip Kortum, and James Miller. Determining what individual sus scores mean: Adding an adjective rating scale. *Journal of Usability Studies*, 4(3):114–123, 2009.

[71] Curtiss Murphy. *Believable Dead Reckoning for Networked Games*, pages 307–328. 02 2011.

[72] Alex Colgan. How does the leap motion controller work?

[73] David Holz. Unveiling project north star.

Bibliography

A

User Test Plan Appendix

GAMMA LZT
Usability Test Plan

**Erick Hernández and
Mariana Manrique**

10/05/2019

Table of Contents

Welcome and Purpose

Thank you so much for coming in today. I wanted to give you a little information about what you will be using and give you time to ask any questions you might have before we get started.

Today we are asking you to serve as an evaluator of an interface prototype for the fulldome and to complete a set of tasks. Our goal is to see how easy or difficult you find the prototype to use.

About the recording

Erick will record your reactions and comments of the prototype you will use. This video will be later used by us to observe the interaction to analyze and will only be used for academic purposes.

During this session, I would like you to think aloud as you work to complete the tasks. I will not be able to offer any suggestions or hints, but from time to time, I may ask you to clarify what you have said or ask you for information on what you were looking for or what you expect to have happen.

About the participant's role

- Today I am going to be asking you to perform some actions in an environment using the prototype and tell me how easy or difficult it was to perform the actions. These activities are all about how intuitive and easy we have made it for people to use the interface.

- There is no right or wrong answer. If you have any questions, comments or areas of confusion while you are working, please let me know.

- As you use the prototype, please do so as you would in a fulldome presentation. I would ask that you to try work through the tasks based on the instructions given, but if you reach a point where you are not sure how to do something, I will ask you what you might do in a real-world setting and then please feel free to try whatever gesture makes sense to you.

- We will be recording this session for reference if needed. We are capturing your gestures (full-body), your voice and what you see on the screen. Your name will not be associated or reported with data or findings from this evaluation.

- I may ask you other questions as we go and we will have some questions at the end of the test to wrap up.

Do you have any questions before we begin?

Test

Part 1- Tasks

[Appendix 1] This is a document with the gestures that can be used. You can try them out and get familiarized with them by exploring the surroundings.
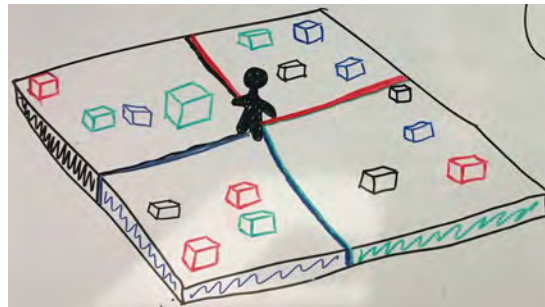
Sketch of set-up. On screen it's in 1st POV

- *Task 1*: Move to the black section

- *Task 2*: The environment is divided in four colors, the task is for you to place all the cubes in the correct section according to their color.

[During process remind the participant to think aloud as well as to mention if they consider a specific motion or gesture would be more intuitive and try it out].

Part 2- UX Curve and Questionnaire

UX Curve

Participant ID:

Draw a UX curve *[Appendix 2]* of your experience during the test

[Explain the UX curve if necessary and afterwards talk about relevant points that can be seen in the curve]

SUS Questionnaire

Lastly we would like you to fill this short questionnaire *[Appendix 3]*
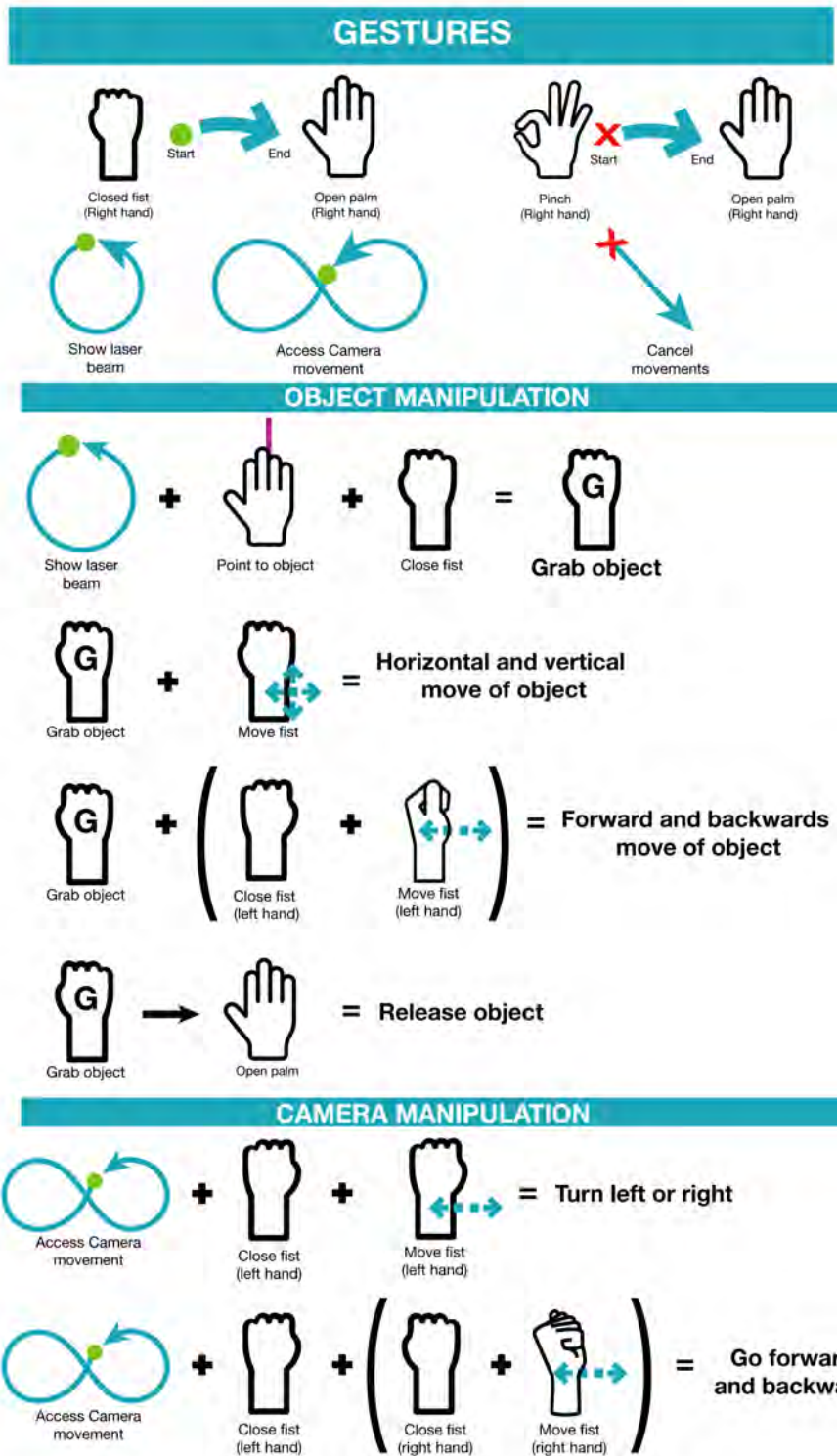
https://forms.gle/x2jz8k6ZaVwQErzRA

Wrap-up

That's all, we thank you for participating in our user testing and you're welcome to have some fika.
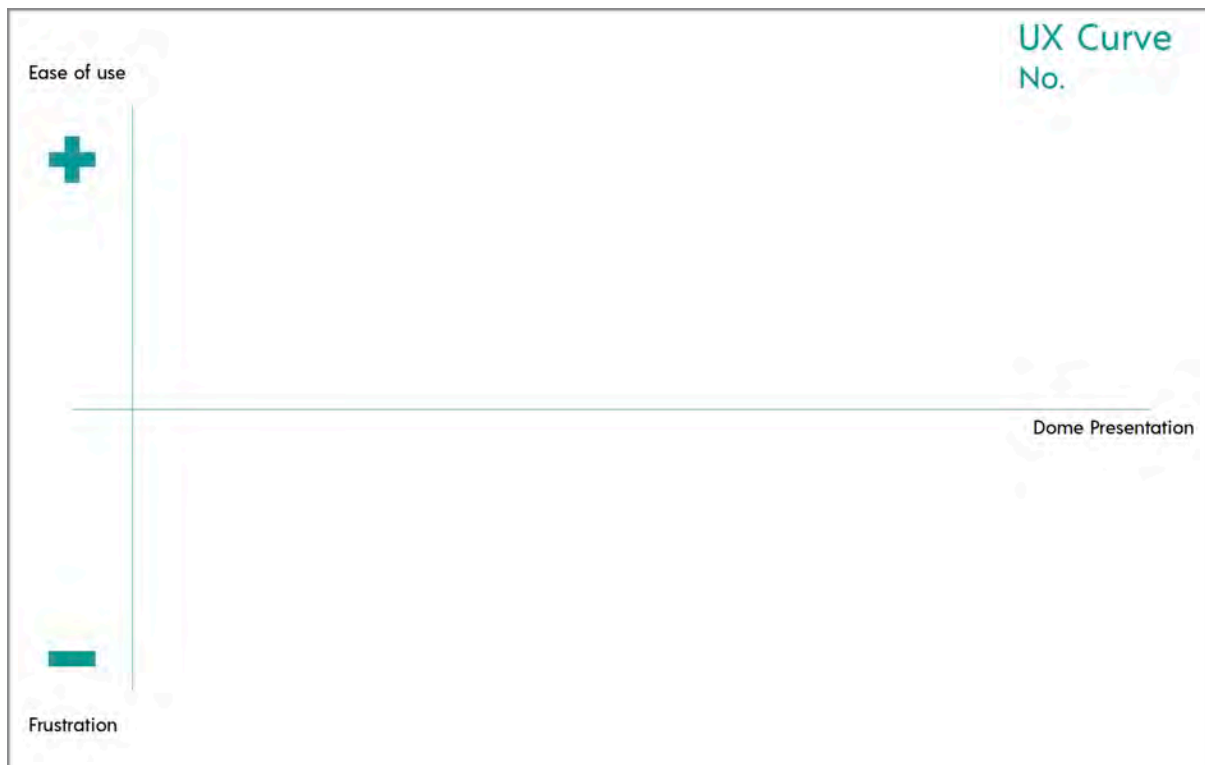
B

Gestures Appendix

C

UX Curve Appendix

UX Curve

D

SUS Questionnaire Appendix

Master Thesis Interactive Fulldome project

SUS Questionnaire

The questions use are taken from the SUS (System Usability Scale). This questionnaire has 10 required questions plus an added optional comment section.

1. I think that I would like to use this system frequently.

2. I found the system unnecessarily complex.

3. I thought the system was easy to use.

4. I think that I would need the support of a technical person to be able to use this system.

5. I found the various functions in this system were well integrated.

6. I thought there was too much inconsistency in this system.

7. I would imagine that most people would learn to use this system very quickly.

8. I found the system very cumbersome to use.

9. I felt very confident using the system.

10. I needed to learn a lot of things before I could get going with this system.

Please provide any further opinion or comments of the system here: _____

All of the questions (except the comment section) uses the following response format:

	1	2	3	4	5	
Strongly disagree	○	○	○	○	○	Strongly agree