Exploring Interactive Experiences to Browse Extensive 360° Video Libraries in Virtual Reality

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Contents

Abstract

The goal of this master's thesis is to investigate the differences in experience and effectiveness among various three-dimensional visualizations of extensive libraries to access 360° videos in virtual reality (VR) with head-mounted displays (HMDs). Currently, 360° video libraries are commonly accessed through a two-dimensional grid of thumbnails with an equirectangular representation of a subset of the library. This approach is inspired by the representation of digital video libraries on flat, two-dimensional screens. However, it fails to take advantage of the opportunities that immersive HMDs provide, such as larger display sizes and the ability to explore three-dimensional visualizations interactively. This study builds on previous work that revealed the advantages of using three-dimensional representations of individual 360° videos instead of the commonly used flat, equirectangular projections in terms of user experience and search performance. This is done by evaluating how these individual representations can best be visualized and explored in a three-dimensional environment with the aim of providing a pleasant and enjoyable browsing experience. Specifically, this study examines two layouts inspired by traditional physical stores (a video store and a record store) and one abstract representation inspired by movies. A comparative study involving nineteen participants revealed that the video store design had the best pragmatic quality, and the record store design had the best hedonic quality. Furthermore, the video store design was better ranked than the record store design. Moreover, participants performed better in the video store design when compared to the abstract store design. Interestingly, no significant differences were found between the three designs regarding perceived performance. These findings underscore the importance of user preference. Depending on whether the user wants an efficient experience or a more immersive experience, the best design shifts between the video store design and abstract store design.

1 Scientific Paper

This section contains the scientific paper presenting the result of the performed study. Supplementary results are discussed in the Appendix.

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Abstract- **Currently, 360° video libraries are commonly accessed through a two-dimensional grid of thumbnails with an equirectangular representation of a subset of the library. This approach is inspired by the representation of digital video libraries on flat, two-dimensional screens. However, it fails to take advantage of the opportunities that immersive HMDs provide, such as larger display sizes and the ability to explore three-dimensional visualizations interactively. This study builds on previous work that revealed the advantages of using three-dimensional representations of individual 360° videos instead of the commonly used flat, equirectangular projections in terms of user experience and search performance. This is done by evaluating how these individual representations can best be visualized and explored in a three-dimensional environment with the aim of providing a pleasant and enjoyable browsing experience. Specifically, this study examines two layouts inspired by traditional physical stores (a video store and a record store) and one abstract representation inspired by movies. A comparative study involving nineteen participants revealed that the video store design had the best pragmatic quality, and the record store design had the best hedonic quality. Furthermore, the video store design was better ranked than the record store design. Moreover, participants performed better in the video store design when compared to the abstract store design. Interestingly, no significant differences were found between the three designs regarding perceived performance. These findings underscore the importance of user preference. Depending on whether the user wants an efficient experience or a more immersive experience, the best design shifts between the video store design and abstract store design.**

1.1 Introduction

The ongoing growth of Virtual Reality (VR) systems with Head Mounted Displays (HMDs) allows ever-easier consumer access to 360° videos and extensive video libraries. Currently, some of the biggest applications that are used for browsing extensive 360° video libraries are Viveport Video [54], Youtube VR [22], and Oculus video [40]. These applications have in common that their interfaces use a form of a two-dimensional grid. This grid consists of thumbnails representing the 360° videos and is placed in the three-dimensional space. Not only is the grid itself two-dimensional, but the thumbnails that represent the 360° videos are two-dimensional as well, containing projections of the 360° videos. Therefore, these applications are not making use of the opportunities provided by immersive HMDs, such as larger display sizes and three-dimensional space.

A study on using three-dimensional thumbnails instead of the omnipresent two-dimensional projections has been conducted by Vermast [53]. This study has demonstrated that using three-dimensional thumbnails leads to the best user experience and performance in detailed search tasks. Whilst the currently used two-dimensional projection has a better performance in high-level search tasks. However, this study primarily focuses on representing a single 360° video instead of an extensive 360° video library. A two-dimensional grid might be the most efficient, as suggested by the results of Vermast, where they showed that the equirectangular (two-dimensional) thumbnails have a better performance in high-level search tasks. However, we expect that using the virtual environments may provide a better user experience and are more suited for situations where the users want to explore available videos in greater detail. This is again motivated by the results of Vermast, where she showed that using three-dimensional thumbnails has a better user experience and better performance in detailed search tasks. Therefore, this paper explores alternative solutions to represent extensive 360° video libraries

in VR that utilize the three-dimensional representations of individual videos proposed by Vermast and take advantage of the opportunities provided by the use of VR with HMDs, such as three-dimensional virtual environments that can be explored more interactively, offering a better user experience.

In the remainder of this paper, first, a brief overview of related work will be given in Section 1.2. Next, the research aim will be explained in Section 1.3. Section 1.4 will delve into a description of our methods. In Section 1.5, the proposed designs will be elaborated upon in detail. Following this, Section 1.6 will show our results, after which we will discuss them in Section 1.7. Next, a short summary will be given in Section 1.8, and finally, in Section 1.9, we will discuss possible future work.

1.2 Related Work

Currently, there are two primary ways for users to access extensive 360° video libraries. The first approach uses a two-dimensional monitor, and the second is by using VR with an HMD. Multiple VR applications are available to users to access these extensive 360° video libraries. These applications can roughly be split into applications that are available to consumers and applications that are used in a more scientific environment.

When looking at VR applications for consumers, we see that, just like in non-VR applications, the grid style to represent the video library is omnipresent. Examples of some prominent VR applications that use this grid style are Viveport Video [54], Youtube VR [22], and Oculus Video [40]. Besides the fact that these applications all use the grid style to represent the library, they also use the same type of thumbnail to represent a single video, a two-dimensional plane. Even though both VR and non-VR applications use the same thumbnail type and style to represent extensive 360° video libraries, there are slight differences between the implementation. In VR applications, the grid itself is placed in a 3D environment and can be manipulated as such. Another difference between VR and non-VR applications can be found in the behavior of the thumbnails. For some of the non-VR applications hovering over the thumbnail starts playing a preview. This is in contrast to VR applications. In VR applications, the thumbnails either use a still frame from the video or an image indicating the file type.

For applications that are used in a more scientific environment, the yearly Video Browser Showdown (VBS)[45] is an excellent source. At the VBS, teams compete for the best retrieval system for extensive video libraries. Although this competition focuses more on the retrieval process of videos from an extensive library, it also showcases many different interfaces to represent these libraries. One often-found design at VBS combines a list style and the previously discussed grid style. This combination emerges due to the task teams need to fulfill at VBS. The task teams are trying to complete at VBS is the execution of search queries inside a video (Temporal queries). Therefore there is a need to display both the video itself and the resulting timestamps. Whilst most teams use normal two-dimensional monitors to display their library, some teams utilize VR. Two projects created by these teams are Vitrivr-VR [51] and Eolas [52].

Vitrivr-VR [51] is an extension to an already existing multi-media retrieval system that was entered at VBS as well. This system is called Vitrivr [43]. Vitrivr-VR uses two manners to display the temporal query result. The first is a grid that wraps around the user, and the second manner of displaying the results is video segments stacked behind each other like a filing cabinet. Figure 1a shows both designs used by Vitrivr-VR.

The other project that uses a VR interface at VBS is Eolas [52]. Where Vitrivr-VR only has a small area in VR, Eolas goes a step further. They group the results based on similarity and display them in these groups in the Virtual Environment (VE), as shown in Figure 1b. Furthermore, they allow users to navigate this virtual environment using the minimap or via teleporting.

Both Vitrivr-VR and Eolas still use two-dimensional thumbnails to display the videos. The reason for this is that there is no need for them to consider other types of implementation as VBS only uses normal videos and not 360° videos. And as stated above, consumer VR applications use the same thumbnails to represent the videos. This thumbnail type is used for both normal and 360° videos, and this poses a challenge when a thumbnail needs to be created from a 360° video. Currently, two methods exist to create a thumbnail of a 360° video. The first method is fitting the entire 360° view into the 2D rectangle via a projection, and the second method is culling away the portion of the video that exists outside of the viewport. The problem with the culling method is that we do not (yet) know how to orient the viewport, resulting in the possibility of removing important content. Therefore, the only viable option is to use a projection to fit the entire view into the 2D rectangle, ensuring that all the content is in said thumbnail. However, using a projection also has a
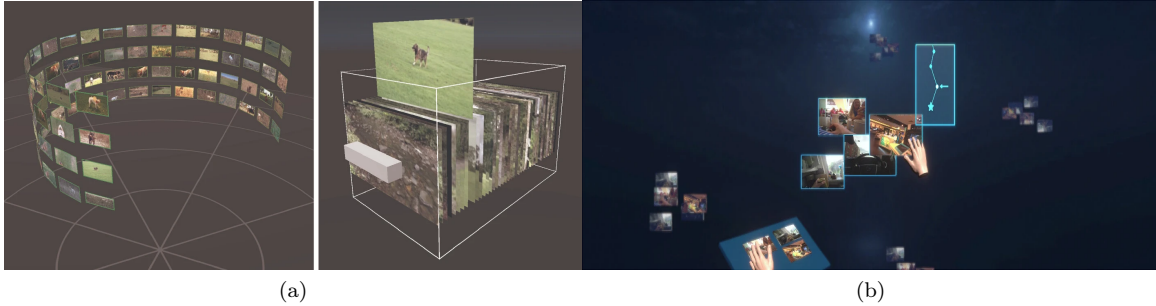
Figure 1: Virtivr-VR [50] interface design (a) and Eolas [52] VE design (b)

downside as we need to distort the image to fit the entire 360° view onto the two-dimensional thumbnail . Besides this, the created two-dimensional thumbnails also do not use the possibilities that VR presents with HMDs.

Figure 2: The spherical Thumbnail as proposed by Vermast [53]

Vermast [53] has addressed this problem, and they propose using spherical thumbnails, an example of which is shown in Figure 2. They have shown that using spherical thumbnails leads to a better user experience than those using the equirectangular projection. However, there is no difference between the use of spherical thumbnails and equirectangular thumbnails when it comes to identifying the high-level subjects of videos. Therefore, they show that using the previously explained 3D opportunities in VR can be favorable for the user experience.

1.3 Research Questions and Approach

As stated in Section 1.2, the current state-of-the-art to represent extensive 360° video libraries predominantly uses a two-dimensional grid with two-dimensional thumbnails. While there might be situations where taking an interface design created

for the two-dimensional monitor to VR is acceptable, we can generally assume that this will not result in the best user experience. This is because it does not take advantage of the opportunities provided by the new type of display, such as its larger display size and the three-dimensional virtual environment. Furthermore, Vermast [53] has shown that using three-dimensional thumbnails can be favorable for the user experience. While they only focused on the representation of a single 360° video, their results suggest that using such three-dimensional thumbnails will also be beneficial when browsing extensive 360° video libraries. The question remains how such libraries should be visualized and designed so users are able to interactively explore them in an engaging yet efficient way.

VR allows the creation of both virtual environments based on reality as well as abstract virtual worlds that do not match any physical setup. Therefore, in our search for better three-dimensional visualization of 360° video libraries, we evaluate three options. Two of these options are inspired by how we traditionally browse media. The other option will be more abstract and does not follow physical constraints. In the pre-digital era, people used to explore large video libraries at video stores, where they could browse a wide selection of videotapes or DVDs before renting them to watch at home. Another way to browse media is in record stores. Here you can flip through vinyl/CDs before deciding to buy them. While having videos and music available instantly via online streaming services is appreciated by all, people old enough to have experienced such video and record stores often express the lack of enjoyment of going to these stores, exploring the available items, and sometimes discovering something unexpected. Thus, why not recreate these experiences in VR for 360° videos by creating virtual environments resembling these stores? The two options we will test that are inspired by how we traditionally browse media will be inspired by the

video store and record store. One of each option focuses on a single store.

For each of the three representations, the implementation details will be explained in Sections 1.5.3.1, 1.5.3.2, and 1.5.3.3 for, respectively, the Video Store, Record Store, and the Abstract Store. These environments will be compared with each other with respect to the following research questions:

- RQ1: Which of these 3D setups creates a better user experience for browsing 360° video libraries?

- RQ2: Which of these 3D setups has a better user performance for browsing 360° video libraries?

As we want to mimic the action of browsing/accessing an extensive 360° video library, the users will perform a single task for each environment. This task is the creation of a "playlist" of ten videos in five minutes. The reason for the creation of the playlist is that we want to force the test subjects to actively browse through the available videos. Furthermore, a time limit is enforced to allow the measurement of the user's performance and perceived performance. For the performance, we look at how many videos the user has added to the playlist once the time is up or, in case the participant finishes early, how much time it took to add ten videos to the playlist. The perceived performance will be measured via self-report.

The user experience will also be measured via a self-report with two questionnaires, the UEQ-S, and the VRSQ. Further details on the questionnaire designs and the performance metrics are explained in Section 1.4

1.4 Methodology

For this study, an application is developed in which three different designs to access 360° video libraries are implemented. Further details on these implementations are discussed in Section 1.5. In the developed application, the participants need to fulfill a browsing task. To complete this task, participants get five minutes to create a playlist of ten videos. To force the user to actively browse the available videos, the user is asked to select ten videos that they are most interested in watching in their entirety.

To be able to compare all three designs, a within-subject design is used due to a lower requirement on the total needed subjects.

1.4.1 User Experience

A commonly used way to measure the user experience is the User Experience Questionnaire (UEQ) by Laugwitz et al. [30, 29]. This questionnaire measures six scales via twenty-six 7-point questions. However, this experiment uses the within-subject design. This means that every participant will test every design. This makes it unfeasible to use the UEQ since it would mean that every participant needs to fill out seventy-eight questions solely for the purpose of measuring the user experience. Leading to a high cognitive strain diminishing the quality of the answers. Therefore, we will use the shorter questionnaire based on the UEQ, the UEQ-S designed by Schrepp et al. [47]. The UEQ-S consists of eight questions that measure the hedonic and pragmatic qualities directly instead of the six scales measured by the UEQ. The UEQ-S will be administered after a participant finishes the browsing task for a single interface.

1.4.2 Cybersickness

As the study takes place inside VR, there is a need to check if the designs are not inducing excessive cybersickness. This will be measured after every design via the participant's self-report, using the Virtual Reality Sickness Questionnaire (VRSQ) by Hyun et al. [28]. The VRSQ consists of nine questions rated on a four-point Likert scale. These points are then changed into the numerical values between zero and one as follows, Not at all = 0, Slightly = 1, Moderately = 2, and Very = 3. Each of the nine questions falls into either the Oculomotor or Disorientation category. To calculate the final score for these, the sum of the values for the Oculomotor is divided by twelve, and the values for the Disorientation are divided by fifteen. After this, both values are multiplied by a hundred. To get a total score, the average of the Oculomotor and Disorientation scores is calculated. The VRSQ was chosen rather than the widely used Simulator Sickness Questionnaire (SSQ) by Kennedy et al. [27], as the SSQ uses sixteen questions, whilst the VRSQ only uses a subset of nine questions. Therefore, using the VRSQ is deemed more appropriate to reduce cognitive strain.

1.4.3 Performance

The performance of a participant will be split into two variants, the quantitative performance and the qualitative performance (or perceived performance). For the quantitative performance, we measure the amount of time it takes until the user

has selected ten videos and the number of videos selected if the time limit is reached.

To measure the qualitative performance, we use a self-report by the user via the following two questions:

- How satisfied are you with the playlist you created?

- Were you able to inspect all the videos you wanted to inspect?

These questions will be asked after each time the participants fill out the UEQ-S (Section 1.4.1) and VRSQ (Section 1.4.2).

1.4.4 Final questions

After the participants have finished the experiment, a short interview is held based on three questions. First, the participants are asked about the reasoning for their ranking of the designs. Based on their answers, a small discussion may be held to make the participants elaborate on their thought processes. After this is finished, the participants are asked if they are able to identify not yet discussed advantages and/or disadvantages of the designs. And finally, the participants are asked if they have any other remarks.

1.4.5 System Data

In addition to the data gathered via questionnaires, we also collect system data. This data can roughly be split into three types: Playlist Data, Interaction Data, and Movement Data. Playlist Data contains all data related to the playlist. The Interaction Data contains the data concerning the interactions the user has with the thumbnails. Lastly, Movement Data comprises all data about movement, both translation and rotation.

1.4.5.1 Playlist Data

For the playlist, we measure the number of times the participants add a video to the playlist. We also measure the number of times a video is deleted from the playlist.

1.4.5.2 Interaction Data

In the application, the participants can interact with the thumbnails in various ways. Further details on this will be given in Section 1.5.2. For each type of interaction, the number of times it occurs and the total and average duration of the interaction are saved.

1.4.5.3 Movement Data

The application contains multiple implementations to move through the virtual environment. For each of these implementations, the total distance traveled is saved. Besides this, we save the amount of rotation the user makes, either physically or via the controls.

1.4.6 Experiment Setup

1.4.6.1 Procedure

Before the experiment begins, participants are given an information sheet and an informed consent sheet that they need to sign. When they have completed this, the VR HMD will be adjusted to their size, after which they will be loaded into the application. Before starting the tasks, the participants are asked to complete a short questionnaire to gather demographic information and the participants' prior experience of using VR with HMDs. The fully used questionnaire can be found in Section B.1.1. To streamline the entire process, all the questionnaires will be administered in the virtual environment; However, the questionnaires will also be available on a separate computer to account for participants who experience severe cybersickness.

Once participants complete the initial questionnaire, they will be loaded into a tutorial scene. In this tutorial scene, each design is presented. Due to the number of controls, the participant will walk through all of them via guidance from the researcher. Participants are then given time to acclimate to the controls and interactions with the different designs. To prevent participants from recognizing videos during the browsing tasks, each set of videos a user can access at a given time will be unique. Once the participant is ready, they can start the actual experiment.

The participant will be loaded into one of the available designs. A balanced Latin square determines the order in which the participants get to see the designs to limit the order effect. This order can be seen in Section B.2.1. After the participants finish the task as described in Section 1.4, they are loaded into the UEQ-S, VRSQ, and perceived performance questionnaire. Once these are filled out, the user will be loaded into the next design until they have completed all three designs. When the participant has completed all three designs, they will be asked to rank the implementations based on their preference. Finally, after this is done, a short interview will be held as described in Section 1.4.4.

1.4.6.2 Environment

Due to the substantial number of controls necessary for this study, the experiments were performed in person. This allows the researcher to guide the users through these controls. Given that the experiments take place in VR, the visual element of the environment is less critical; However, other environmental elements, such as temperature, and background noise, were kept consistent for all participants. Conducting the study in person also provides the opportunity to assist the test subjects in case they run into any questions or unclarities.

The experiment requires a free space of two-by-two meters to ensure that all participants have an equal amount of space to walk around in.

1.4.6.3 Participants

Students between the age of eighteen and thirty were recruited for this study. The reason is that students between this age are generally part of the group that are early adopters of new technology. Twenty participants started the experiment. However, one test subject was unable to complete the experiment for undisclosed reasons. Therefore the partial data gathered from this test subject are omitted.

For the remaining participants, eleven indicated to be male (57.89%), and eight indicated to be female (42.11%). Nine participants fell in the age range of 18-24 years old (47.37%), and ten participants fell in the age range of 25-30 years (52.63%). All participants access extensive video libraries such as YouTube, Netflix, and Disney+ on a daily basis.

Of all the participants, the majority indicated that they either rarely (nine participants or 47.37%) or never (nine participants or 47.37%) use VR with an HMD. Only one participant indicated using VR on a weekly basis (5.26%). As for the 360° videos, eleven participants have indicated to have watched 360° videos before (57.89%). One participant has indicated that they rarely use a laptop/desktop to watch 360° videos (5.26% of the total). Eight participants (42.11% of the total) indicated to have used a mobile phone to watch a 360° video (note when a mobile phone is used with items such as a Google Cardboard, this is seen as a VR headset concerning this question). Of these eight participants, one (5.26% of the total) stated that they used a mobile phone weekly to watch 360° videos, whilst the other seven (36.84% of the total) indicated using a mobile phone rarely. None of the participants have used a tablet to watch 360° videos, and six (31.58% of the total) have used a VR Headset to watch 360° videos. Two participants (10.53% of the total) indicated that they used the VR headset monthly to watch 360° videos, whilst four (21.05% of the total) indicated that they use it rarely.

To watch 360° videos in VR, there are multiple available applications. Two (33.33% of the subgroup) of the participants that have used VR Headsets have indicated that they use YouTubeVR to watch the 360° videos. None of the participants used Viveport Video. Three participants (50% of the subgroup) used Oculus Video, and four participants (66.67% of the subgroup) indicated that they used an application that was not on the list. Unfortunately, the participants were unable to remember the name of the other application they used.

1.5 Implementation

1.5.1 Technical Details

For this study, multiple designs were developed. These designs were created in Unity version 2022.2.9f1. To assist in the development of the designs, four other packages were used, namely Tube Constructor Kit [14], Wooden Floor Materials [9], SteamVR Plugin [11], and the VRQuestionnaire-Toolkit [19].

The Tube Constructor Kit [14] is a unity asset that includes models from tubes. These tubes are used in the abstract store design, discussed in Section 1.5.3.3.

The Wooden Floor Materials [9] is an asset pack containing multiple materials representing wooden floors. These materials are used in all the designs for the floor. Furthermore, the materials in this asset pack are used for the shelves and tables in respectively the video store design and record store design.

The SteamVR Plugin [11] is used to handle all basic interactions between the program and the VR HMD. Using this asset creates the ability to interchange different types of VR HMDs as long as they support using SteamVR.

The VRQuestionnaireToolkit [19] is a toolkit that allows the administering of questionnaires in VR. The use of this creates a smoother experience since participants are not required to remove the VR HMD to fill in the questionnaires.

1.5.2 Thumbnails

For the thumbnails, we used two different implementations: the omnipresent equirectangular form and the spherical thumbnails as proposed by Vermast [53] (Figure 2). All thumbnails start off

as thumbnail images in the equirectangular form. The reason for this is that Vermast has shown that the use of the equirectangular form leads to the fastest performance when it comes to categorizing the video. Another reason to use the equirectangular form for images is that the thumbnail images are already in an equirectangular form. Changing this to a spherical form will deform them due to the projection that needs to be used.

Next, when a user starts interacting with the thumbnail, it will first start playing the video in the equirectangular projection, an example of which can be seen in Figure 4d. As Vermast [53]has shown that the spherical thumbnail is the best thumbnail type for closer inspection of the videos, the thumbnail will change in said spherical thumbnail when the user grabs it. This also allows the user to rotate the thumbnail around in their hand. An example of how this looks can be seen in Figure 3. When releasing the video, the thumbnail will move back to its original position and change back to the equirectangular form as the user is no longer inspecting the video in greater detail.

Figure 3: Transformed Thumbnail

1.5.3 Proposed designs

The designs we propose are two designs that find their origin in real-world applications and an abstract one that was inspired by movies. For real-world applications, the Video Store design and Record Store design were created. As for the design inspired by the movies, we call it the Abstract Store design.

1.5.3.1 Video Store Design

The first design takes inspiration from the video stores that were commonly found in the past. Here, display shelves will be used to display the equirectangular thumbnail of each video. Furthermore, each display shelf will have an assigned category. The implementation of this design is shown in Figure 4. The user has the ability to move freely inside the store to browse the available 360° videos. Interaction with the thumbnails is done via either a laser pointer or touching the actual thumbnail with the controller. When the user interacts with

the thumbnail, the video starts playing, as explained in Section 1.5.2. Furthermore, the user can teleport the thumbnail in front of them via the laser pointer. This is to help with the thumbnails that are placed closer to the ground. If the user wants to inspect the video itself closer, they can grab the thumbnail, transforming it into a sphere.

1.5.3.2 Record Store Design

The second design is based on the layout of a record store and is also partly inspired by the filing cabinet design of vitrivr-VR [51]. In this design, the thumbnails will be somewhat tightly stacked against each other, and the user can flip through them by moving the controller along the group. By doing this, the currently hovered thumbnail will move up, allowing the user to inspect the thumbnail in its equirectangular form closer. Furthermore, this allows the user to see which thumbnail is currently hovered. If the user wants to inspect the video itself closer, they can grab the thumbnail, transforming it into a sphere.

1.5.3.3 Abstract Design

The final design is a more abstract design in the sense that recreating it in the real world would be difficult, if not impossible. The design was partly inspired by movies such as Inside Out and Harry Potter. Here large archives or shelves filled with spheres are used as well. In this design, the videos are transported and selected via a tube. Each tube has a ring around it containing the equirectangular thumbnails. The user can rotate this ring to browse through the available videos for each tube. If the user wants to inspect the video closer, they can select the video by rotating the ring and pulling a lever. Doing this will spawn a sphere that will travel down the tube, finally landing on a pedestal. The user can then pick up the sphere to inspect the video. Releasing the sphere will despawn it. The implementation of the Abstract Store design is shown in Figure 6.

1.5.4 VR HMD

For this study, the first-generation HTC Vive was used. The two base stations were placed on top of two tripods which were placed diagonally of each other.

1.5.4.1 Controls

The different buttons on the controller of the HTC Vive are shown in Figure 7. For the created application, the left and right controllers have different functionalities paired with the buttons. Figure 7a
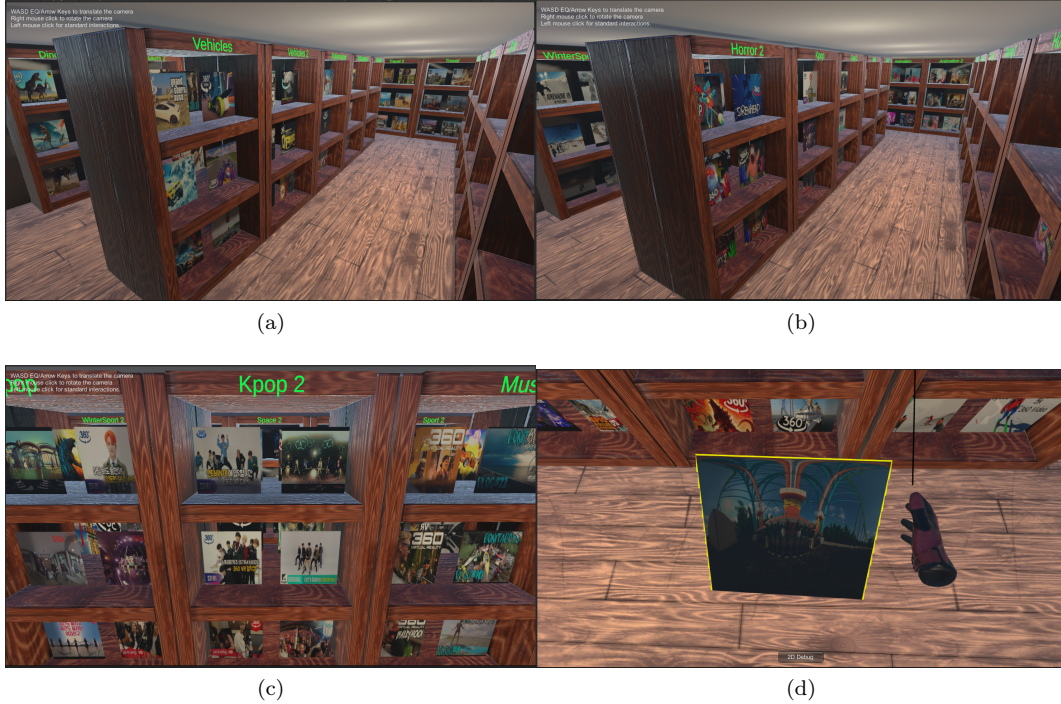
Figure 4: Proposed designs of the Video Store

shows the left controller, and Figure 7c shows the right controller. For both the left and right controllers, the trigger and button on the side have the same functionality (Figure 7b). In the following paragraphs, the text refers to buttons. These buttons are the once that are shown with annotations in Figure 7.

Movement - For the movement, there are two implemented methods. The first implemented method is teleportation. Pressing the teleport button (button A) on the controller will shoot a laser in an arc with a circle showing the current target. Once the circle is green, the teleport button can be released, and the user will be teleported to the target position. The second method for movement is the ability to float through the level. This movement type allows the user to move forward, backward, left, and right (buttons E, G, H, and F, respectively). As for the rotation, the user can rotate their head or press a rotation button that rotates the user 45% left or right (buttons c and b).

Video Interaction - There are multiple ways to interact with videos. The first is via a laser pointer. Pointing the laser pointer at a video starts playing the video in the Video Store and Abstract Store design. Pulling the trigger (button I) in the Video Store design will teleport the video the laser pointer is aimed at in front of the user. Pointing the laser pointer at the teleported video

and pulling the trigger again will teleport it back to its original position. Pulling the trigger in the Abstract Store design allows the user to rotate the videos around the tubes. In the Video Store design and Record Store design, the user is able to pick the video up by touching the video with their hand and pressing and holding the trigger. Furthermore, when touching a video in the Record Store design will teleport it up and slightly tilt the video to allow for a better inspection. In the Abstract Store design, the user first needs to pull the lever, as shown in Figure 6d, to spawn a sphere that the user is able to pick up. Once the video is picked up, it transforms into the sphere proposed by Vermast. When releasing the video, it will teleport back to its original position and form.

Playlist - To add a video to the playlist, it first needs to be in a so-called selected state. For all the designs, one of the selected states is when the user is holding the video. Besides this, all designs have another kind of selected state. For the Video Store design, this is when the user teleports the video in front of them. In the Record Store, it is when the user has touched a video, and it has teleported up. Lastly, for the Abstract Store, it is when the user has pulled the lever and the sphere has come down. To actually add a video to the playlist, the user presses the add to playlist button on the controller (button J). To see what items are currently in the playlist, the user presses the
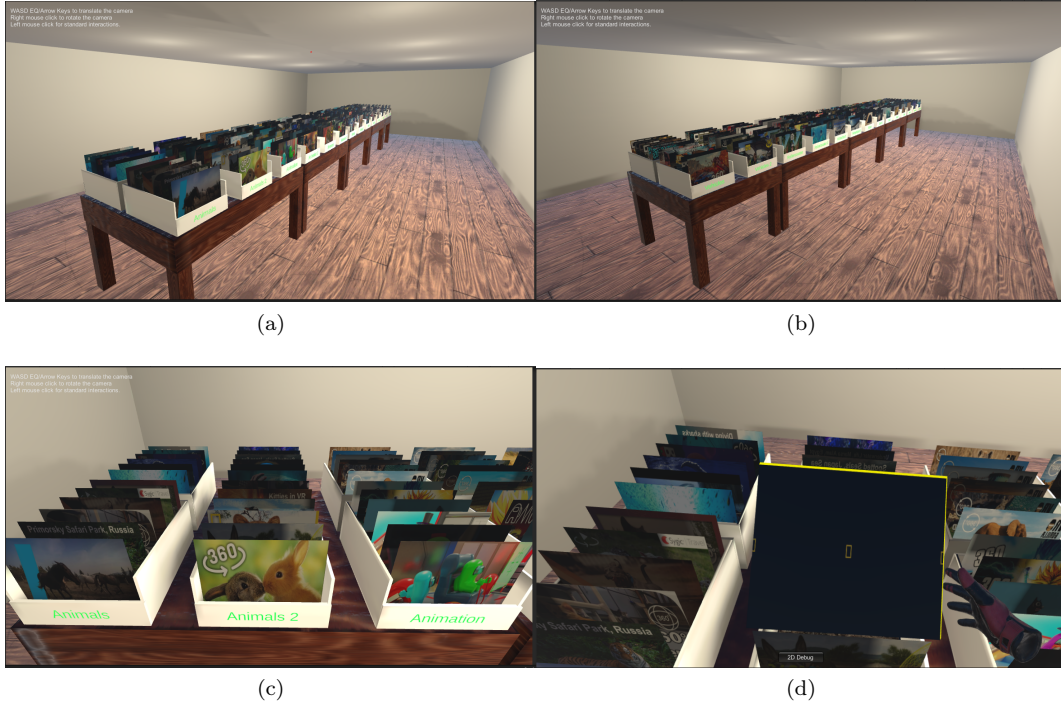
Figure 5: Proposed designs of the Record Store

show playlist button (button J) and the playlist will be teleported in front of them. Pressing this button again will make the playlist invisible. Due to the limited amount of buttons on the controller of the HTC Vive, the show playlist button is the same as the add to playlist button, namely button J. However, the difference is that the button adds to the playlist only when there is a video in the selected state. So if there is no video currently in the selected state, the functionality of the button changes to that of showing/dismissing the playlist. In the case the user wants to remove a video on the playlist, they first need to make the playlist visible. After this is done, they can point the laser pointer at the video they want to remove and press the delete button (button D). Furthermore, the playlist also allows the user to teleport any video that's inside the playlist to them. After they pull up the playlist and point the laser pointer at the video, they need to pull the trigger (button I). This will then teleport the video towards them, allowing them to inspect the videos that are inside the playlist at any given time and everywhere.

Miscellaneous - In the case that the user has completed the task before the time is up, they can continue with the study by pressing and holding the continue button (Button D).

1.5.5 Videos

A complete list of the videos used can be found in Section C.2. For this study, a total of 505 videos were used. These videos are separated into different categories and are also displayed grouped by their respective categories. In total, there were fourteen categories, with each category having twelve videos per design. Finally, a single video was used in the tutorial. These categories are shown in Section C.1. And all used videos are shown in Section C.2. According to Hosseini [23] for 360° videos, the functional minimal resolution is 4K, and 8K is desired. However, as Vermast [53] stated, the thumbnails are smaller in size compared to the sphere surrounding users when playing 360° videos. This means that we are not bound to the functional minimal resolution of 4K and can use 360° videos of a lower resolution. A minimum of 720p was deemed sufficient. Therefore all videos were downloaded with a minimum quality of 720p and a maximum quality of 1080p to save storage space and improve performance. Furthermore, all videos were cut to a duration of one minute for the same reasons. Besides the videos, the thumbnails of the videos were also downloaded and displayed when the corresponding video was not playing.
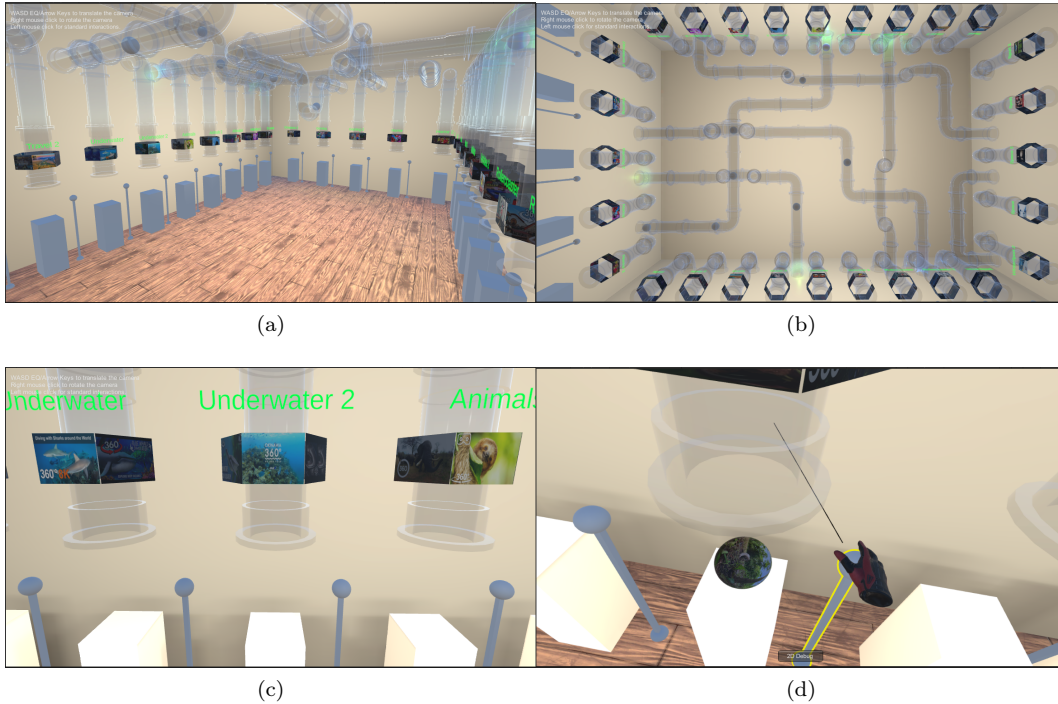
(a) (b)

(c) (d)

Figure 6: Proposed designs of the Abstract Store

1.5.6 Used Tools

For the statistical analysis, SPSS Version 29.0.1.0(171)[24] was used. To analyze the results of the UEQ-S questionnaire, the UEQ-S analysis tool [46] created by one of the authors will be used.

1.6 Results

1.6.1 UEQ-S

To analyze the results of the UEQ-S questionnaire, one of the authors has created an analysis tool [46]. This tool measures the Pragmatic, Hedonic, and overall quality of software. Before calculating these scores, the tool first transposes the results from a 7-point Likert scale with values ranging from 1 to 7, to values ranging from -3 to 3. After this is done, the values for the Pragmatic and Hedonic quality are calculated per person. With this, we are able to calculate the means and standard deviation per design of the pragmatic, hedonic, and overall quality. These are shown in Table 1.

After these values are calculated, it is customary to compare them against a benchmark set. This is shown in Figure 8. This benchmark currently consists only of data gathered from the full UEQ. Looking at Figure 8, we can see that both the Abstract design and Record store design have a bad pragmatic quality. In comparison with that, the Video store has an excellent pragmatic qual-

ity. For the Hedonic quality, both the Video Store design and Record Store design have a Below Average quality. However, the Abstract design has an Excellent Hedonic quality. Due to the fluctuation in the two quality types for the Abstract design and the Video Store design, both their overall qualities are above average. As for the Record Store design, the overall quality falls in the Bad category.
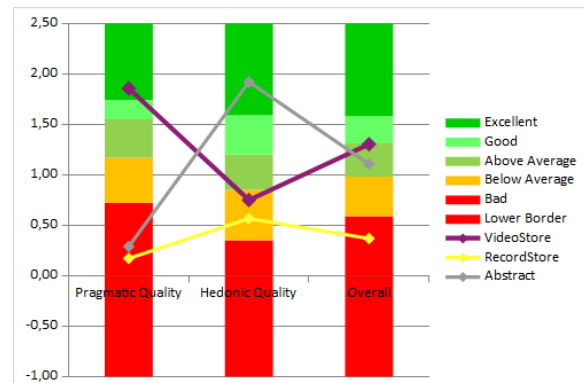

Figure 8: UEQ-S Results of the different designs compared to a benchmarkset

1.6.1.1 Pragmatic Quality

To test if there is a significant difference between the different designs for their quality, we first test for normality with the Shapiro-Wilk test. The
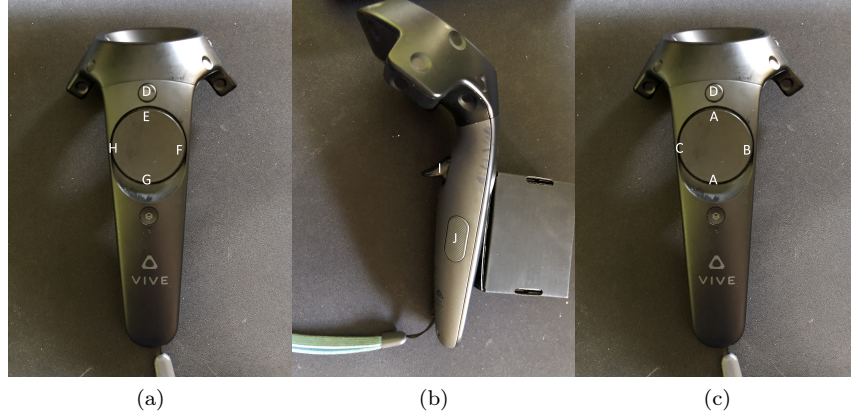
| | (a) | (b) | (c) |

Figure 7: Button assignment Left (a), underside of the controller (b), and Right (c)

	Pragmatic M	Pragmatic SD	Hedonic M	Hedonic SD	Overall M	Overall SD
Video Store	1.855	1.284	0.750	1.247	1.303	0.873
Record Store	0.171	1.179	0.566	1.255	0.368	0.928
Abstract Store	0.289	1.078	1.921	0.618	1.105	0.608

Table 1: UEQ-S Results

Shapiro-Wilk test for the Pragmatic quality of the video store showed a significant departure from normality, $W(19) = 0.779, p =< 0.001$. Both the pragmatic quality of the Record store design and the abstract design did not show a departure from normality. $W(19) = 0.948, p = 0.360$ and $W(19) = 0.952, p = 0.421$ respectively. Without the assumption of normality, we opt for the Friedman test as an omnibus test for significant differences. The Friedman test shows a significant difference in the pragmatic quality, $X^2(2) = 18.270, p =< 0.001$. Post hoc analysis with Wilcoxon signed-rank tests was conducted with a Bonferroni correction. Resulting in a significance level at $p < 0.017$. This indicated that the Video Store design had a statistically significant higher pragmatic quality than the Record Store design, $Z = -3.081, p =< .001$. Furthermore, the Wilcoxon signed-rank test with Bonferroni correction indicated that the Video Store design had a statistically higher pragmatic quality than the Abstract Store design, $Z = -3.227, p =< .001$. There was no indication that there was a significant difference between the pragmatic score of the Record Store design and the Abstract Store design, $Z = -0.356, p = 0.745$.

1.6.1.2 Hedonic Quality

For the Hedonic Quality, we also first applied the Shapiro-Wilk test to test for normality. This indicated that none of the Hedonic qualities have a significant departure from normality, $W(19) =$ 0.927, $p = 0.153$, $W(19) = 0.909, p = 0.072$, and $W(19) = 0.935, p = 0.211$ for respectively the Hedonic quality of the Video Store design, Record Store design, and the Abstract Store design. With the assumption of normality, we continue with the one-way repeated-measures ANOVA. Mauchly's test indicated that the assumption of sphericity had not been violated, $X^2(2) = 0.371, p = 0.831$. The one-way repeated-measures ANOVA determined that there is a significant difference across the three designs, $(F(2, 36) = 15.475, p =< 0.001)$. A post hoc pairwise comparison using the Bonferroni correction showed a significantly higher Hedonic Quality for the Abstract design as compared to both the Video Store design $(p = 0.002)$ and Record Store design $(p =< 0.001)$. There was no significant difference between the Hedonic quality between the Video Store design and the Record Store design, $p = 1.00$.

1.6.1.3 Overall Quality

Lastly, we test the Overall Quality for significant differences. The Shapiro-Wilk test indicated that none of the Overall Qualities have a significant departure from normality, $W(19) = 0.977, p = 0.909$, $W(19) = 0.977, p = 0.899$, and $W(19) = 0.959, p = 0.546$ for respectively the Video Store design, Record Store design, and the Abstract Store design. We continue with a one-way repeated-measures ANOVA. Mauchly's test indicated that there is no violation of the sphericity, $X^2(2) = 1.149, p = 0.563$. The one-way

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repeated-measures ANOVA determined that the Overall Quality differed significantly across the designs, $F(2,36) = 14.057, p =< 0.001$. The post hoc pairwise comparison using the Bonferroni correction showed a significantly higher overall Quality of the Video Store design compared to the Record Store design ($p =< 0.001$). The Overall quality was also higher for the Abstract Store design when compared to the Record Store design ($p = 0.007$).

1.6.2 VRSQ

To calculate the VRSQ values, the answers given by the participants are first converted to numerical values as described in Section 1.4.2. Then the mean and standard deviation are calculated and are shown in Tables 2, 3, and 4

1.6.2.1 Oculomotor

The Shapiro-Wilk test for the Oculomotor scores indicates that there is a significant departure from normality for both the Video Store design and the Record Store design, $W(19) = 0.789, p =< 0.001$, and $W(19) = 0.841, p = 0.005$ respectively. The Oculomotor scores for the Abstract Store design did not show a significant departure from normality, $W(19) = 0.925, p = 0.142$. Following this, we conducted the Friedman test as an omnibus test. The Friedman test did not indicate a significant difference between Oculomotor scores for the three designs, $X^2(2) = 3.294, p = 0.198$.

	Oculomotor M	Oculomotor SD
Video Store	14.47	14.39
Record Store	20.18	21.21
Abstract Store	21.49	17.42

Table 2: VRSQ Oculomotor Results

1.6.2.2 Disorientation

For the Disorientation score, all of the designs depart from normality according to the Shapiro-Wilk test, $W(19) = 0.833, p = 0.004$, $W(19) = 0.771, p =< 0.001$, and $W(19) = 0.874, p = 0.017$ for respectively the Video Store design, Record Store design, and the Abstract Store design. The following Friedman test did not show the presence of a statistically significant difference between the three designs in the Disorientation score, $X^2(2) = 0.042, p = 0.996$.

	Disorientation M	Disorientation SD
Video Store	14.74	11.46
Record Store	15.09	13.30
Abstract Store	15.09	10.62

Table 3: VRSQ Disorientation Results

1.6.2.3 Total

When combining the Oculomotor and Disorientation scores into the Total scores, the Shapiro-Wilk test indicated that both the Video Store design and Record Store design Total scores departed from normality, $W(19) = 0.828, p = 0.003$, and $W(19) = 0.809, p = 0.002$ respectively. For the Abstract Store design, the Shapiro-Wilk test did not indicate a departure from normality, $W(19) = 0.924, p = 0.132$. Due to the lack of normality for two of the three levels, we opt for the Friedman test. The Friedman test did not indicate a significant difference between the Total scores of the three designs, $X^2(2) = 2.351, p = 0.317$.

	Total M	Total SD
Video Store	14.61	11.58
Record Store	17.63	16.46
Abstract Store	18.29	12.94

Table 4: VRSQ Total Results

1.6.3 Ranking

At the end of the experiment, the participants were asked to rank the different designs based on their personal preferences and the experience they had during the experiment. As the participants are ranking the designs from one to three, the lower the score, the better the participants rank the design. The distribution of the answers given for each design is shown in Figure 9. Table 5 shows the mean and standard deviation. As we are dealing with ranking data, we opt for the Friedman test to detect if there is a significant difference present. This test indicates the presence of a significant difference, $X^2(2) = 15.158, p =< 0.001$. Post hoc analysis was done with a Wilcoxon signed-rank test with a Bonferroni correction resulting in a significance level of $p < 0.017$. This test indicates a significantly better ranking for the Video Store in comparison to the Record Store, $Z = -3.482, p =< 0.001$. This same test, however, did not find a statistically significant difference between the ranking of the Video Store and the Abstract Store, $Z = -1.427, p = 0.184$. It also did not detect a significant difference between the Record Store and the Abstract Store, $Z = -2.032, p = 0.053$.
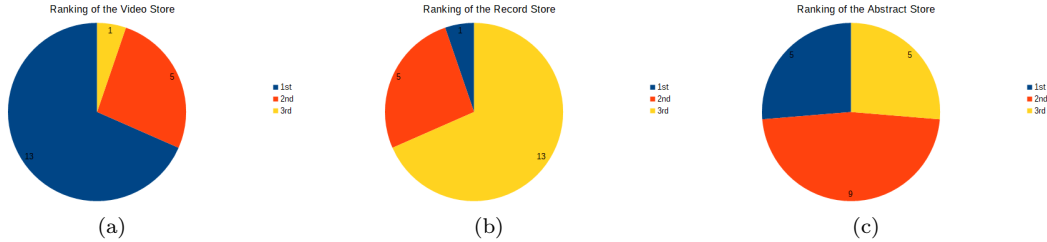
Figure 9: Distribution of the ranking for the Video Store (a), Record Store (b), and Abstract Store (c) design

	Total M	Total SD
Video Store	1.37	0.60
Record Store	2.63	0.60
Abstract Store	2.00	0.75

Table 5: Ranking Results

1.6.4 Performance

1.6.4.1 Measured Performance

For the measured performance, we look at both the time it took for a participant to complete the browsing task described in Section 1.4 and the number of thumbnails that were present in the created playlist at the end of the task. The time taken is measured in milliseconds and capped at 300000 (5 minutes). The mean and standard deviation per design is shown in Table 6. For the time taken, the Shapiro-Wilk test showed that all three designs departed from normality, $W(19) = 0.596, p =< 0.001$, $W(19) = 0.373, p =< 0.001$, and $W(19) = 0.244, p =< 0.001$ for respectively the Video Store design, Record Store design, and the Abstract design. Because of the lack of the assumption that the data is normally distributed, we use the Friedman test. This test does not indicate that there is a significant difference between the three designs, $X^2(2) = 2.500, p = 0.317$.

As for the number of videos in the playlist at the end of the task, the Shapiro-Wil test showed a departure of normality for the Video Store design, $W(19) = 0.787, p =< 0.001$. The Shapiro-Wilk test did not show that the number of videos in the playlist at the end of the task for the Record Store design and the Abstract Store design departed from normality, $W(19) = 0.933, p = 0.196$, and $W(19) = 0.926, p = 0.144$. The following Friedman test indicates that there is a significant difference over the three designs, $X^2(2) = 11,460, p = 0.003$. A post hoc analysis was conducted with the Wilcoxon signed-rank test with a Bonferroni correction. This correction resulted in an adjusted significance level of $p < 0.017$. The Wilcoxon

signed-rank test indicates a significantly higher number of items in the list at the end when using the Video Store design when compared to the Abstract Store design ($Z = -2.959, p = 0.002$). There was no significant difference between the Video Store design and the Record Store design ($Z = -2.246, p = 0.028$) and between the Record Store design and the Abstract Store design ($Z = -2.116, p = 0.037$).

1.6.4.2 Perceived Performance

To measure the perceived performance, the users self-reported this via two questions in the questionnaire on a 7-point Likert scale as described in Section 1.4.3. For the satisfaction with the created playlist, the mean and standard deviation for each design are denoted in Table 7. The Shapiro-Wilk indicates that for all three designs, the satisfaction for the created playlist data departs from normality, $W(19) = 0.776, p =< 0.001$, $W(19) = 0.867, p = 0.013$, and $W(19) = 0.876, p = 0.018$ for respectively the Video Store design, Record Store design, and the Abstract Store design. Due to the lack of normality, we conduct the Friedman test to test for a significant difference. The Friedman test did not show a significant difference for the three designs, $X^2(2) = 1.600, p = 0.479$.

	Satisfaction M	Satisfaction SD
Video Store	5.63	1.16
Record Store	5.11	1.59
Abstract Store	5.00	1.70

Table 7: Created Playlist Satisfaction Results

The means and standard deviation for each of the designs for the opportunity to allow inspection for all videos in given in Table 8. According to the Shapiro-Wilk test, the Video Store design, Record Store design, and the Abstract Store design depart from normality, with $W(19) = 0.861, p = 0.010$, $W(19) = 0.855, p = 0.008$, and

	Time Taken M	Time Taken SD	Videos In playlist M	Videos In playlist SD
Video Store	274296.74	44764.24	7.95	2.20
Record Store	287597.95	37442.52	7.00	2.29
Abstract Store	298981.63	4438.9	5.89	2.71

Table 6: Measured Performance Results

$W(19) = 0.897, p = 0.043$ respectively. The following Friedman test did not show that there is a significant difference between the designs, $X^2(2) = 1.607, p = 0.473$.

	Ability M	Ability SD
Video Store	5.11	1.79
Record Store	4.21	2.18
Abstract Store	4.37	2.06

Table 8: Perceived ability to inspect videos Results

1.6.5 Qualitative Data

At the end of the experiment, participants were asked to rank the designs based on their preferences. When they had done this, a short interview was held in which the participants could elaborate on their decisions. The transcripts of the interviews can be found in Section A.3. Section A.3.1 gives a short overview of the remarks that participants gave on the advantages and disadvantages of the different designs.

1.6.5.1 Video Store

For the video store a slight majority of the participants indicated that the Video Store had a clear overview. Furthermore, four participants remarked that the design was easy to use. Two of the participants remarked that they found it fun to walk and look around; However, two participants also remarked that this was not an advantage but rather a disadvantage of the design. Another remark made by a participant is that it is a bit complicated to get to the videos that are located on the bottom shelf.

1.6.5.2 Record Store

During the interviews, only one participant remarked that they found the interaction fun, whilst five participants remarked that they had difficulty with the interaction. Furthermore, five participants remarked that they had difficulty seeing which video they were currently interacting with. But the most often disadvantage mentioned by the participants (twelve) is the occlusion of the thumbnails that are stacked behind each other.

1.6.5.3 Abstract Store

As for the Abstract store, there are four participants who mentioned that the design had a good overview. Five participants found the interaction fun. Furthermore, five participants remarked that the design was fun. However, there were also five participants who remarked that the actions necessary to watch the video were a disadvantage. Three participants noted that they found that the need to rotate the thumbnails to be able to see all available thumbnails for a single category was a disadvantage. Two participants remarked that the design was confusing. Furthermore, two participants remarked that turning the thumbnails was somewhat difficult.

1.7 Discussion

This study aims to answer two research questions about accessing extensive 360° video libraries in VR. The first research question is aimed at the user experience. Therefore to answer this question, we look at the results of the UEQ-S Questionnaire in Section 1.6.1, VRSQ in Section 1.6.2, and the ranking data in Section 1.6.3. Furthermore, the qualitative data in Section 1.6.5 will also be used to try and help explain the results. The second research question is aimed at the performance of the user. This is split into both measurable performance and perceived performance. To answer this question, we look at both the results of the Measured Performance (Section 1.6.4.1) and the Perceived Performance (Section 1.6.4.2).

1.7.1 RQ1: User Experience

The results of the UEQ-S show that participants found that both the Video Store and Abstract Store significantly have an overall better user experience than the Record Store. Furthermore, the Video Store provided a statistically significantly better user experience in terms of pragmatic quality as compared to both the Record Store and Abstract Store. Suggesting that the users found the Video Store design more efficient and functional. In contrast, the Abstract Store had a statistically higher hedonic quality. Indicating that users found this design more enjoyable and stimulating.

The participants also indicated these points during the interviews. The participants called the interaction fun (five participants) and the design fun (four participants). In comparison, only a single participant called the interaction fun for the record store, and two participants called to possibility to walk around in the Video Store fun. The same can be seen for the pragmatic quality. Ten participants mentioned the overview of the Video Store as an advantage, whilst none mentioned it for the Record Store, and four participants mentioned it for the Abstract Store. Furthermore, ten participants mentioned that they had difficulties when interacting with the videos in the Record Store, either in general or by not being able to see the entire thumbnail of the videos placed more in the back. Which explains the low pragmatic quality of the Record Store.

The results of the rankings also reflect the results of the UEQ-S. In the ranking data, the Video Store was statistically significantly higher ranked than the Record Store. And, although not statistically significant, the video store was ranked first more often than the Abstract Store. Showing signals that participants found the Video Store the best overall. However, further research is necessary to conclusively verify this assumption. Comparing both the Video Store and Abstract Store to the benchmark data of the UEQ (Figure 8), we see that they both have an above-average overall quality. Notable is that the Video Store has a better pragmatic quality, and the Abstract Store has a better hedonic quality. Looking at the Record Store, we see that it has a bad score for the Pragmatic and Overall quality and a below-average Hedonic quality.

During the experiment, the cybersickness level of the participants was measured after completing the browsing task for a single design via the VRSQ. The scores calculated from the VRSQ did not show any statistical difference. Each design had a low average score, 14.61, 17.63, and 18.29 out of 100 for respectively the Video Store, Record Store, and Abstract Store.

With all this, the answer to RQ 1 (Which 3D setup creates a better user experience for accessing 360° video libraries?) depends on what the user would prefer to use. If the user wants a more efficient and functional design, the Video Store would be best. However, if the user prefers a more enjoyable and stimulating experience, the Abstract Store would be better. Looking at the ranking results, there are signs that the users would prefer an efficient system to browse an extensive 360° library more; however, this needs more research to be confirmed.

1.7.2 RQ2: Performance

To measure the perceived performance, two questions were asked after each design. The first question was aimed at how satisfied the participants were with the created playlist, and the second question was aimed at if the participants felt they had enough time to inspect all the videos they wanted to inspect. When looking at the data, we see that there is no statistically significant difference between the three designs for both questions. However, there was a statistically significant difference in the measured performance. In the measured performance, the participant had statistically more videos in the playlist when the time ran out for the Video Store when compared to the Abstract Store. This indicates that there is a potentially higher efficiency when compared to the Abstract Store. This difference is also highlighted by the results of the UEQ-S, where the Video Store had a significantly higher pragmatic quality. Even though there are clear signs that the Video Store is more efficient than the other designs, the perceived performance, as reported by the participants, did not show a significant difference.

To answer RQ2, we look at both the perceived and the measured performance. As stated above, there was no statistically significant difference in the perceived performance. However, there is a statistically significant difference in the measured performance (the number of videos in the playlist at the end of the task). With this, we can conclude that the Video Store achieves better objective performance, even if there appears to be no impact on the subjective performance experienced by the user.

1.7.3 Limitations

This study has several limitations that should be considered when interpreting the results. The first is the sample size. This study only had nineteen participants. With this number of participants, the results might not be generalizable.

Another significant constraint of this study is the absence of a comparison against the current state-of-the-art (grid design). As a result, it remains unclear how the proposed designs stand relative to the leading solutions in the field.

Finally, feedback from participants indicated difficulties with the interaction of the Record Store design. Running a smaller preliminary test or pilot study could have highlighted these challenges. This would have allowed for time to explore and implement alternative solutions. Another solution could be to give the participants a longer time period to get accustomed to the controls. In this

study, they only had a short tutorial and only experienced each design once. Giving the participants more time could have alleviated the struggles they experienced. The difficulties faced by the participants may have affected their engagement or performance in the study, thereby potentially skewing the results.

1.8 Conclusions

The goal of this study was to create and explore new designs to access extensive 360° video libraries in VR with HMDs. This was done with three proposed designs: Video Store, Record Store, and Abstract Store. These designs were tested against each other on the user experience and performance. The user experience was tested via the UEQ-S, VRSQ, and the ranking by the participants. The performance was split into measured performance and perceived performance. The measured performance was tested via the amount of time the participants needed to perform a browsing task and how far they were able to complete this browsing task. Whilst the perceived performance was measured with the participant's self-report via two questions.

The results have shown that in terms of pragmatic quality, the Video Store design was superior, whereas the Abstract Store design was perceived to have higher hedonic quality. Furthermore, both these designs had a better overall quality when compared with the Record Store design. These results were also reflected by the ranking data where the Video Store was better ranked than the Record Store.

With respect to the performance, there was no difference found between the three designs when it came to the perceived performance. However, the measured performance showed that the users performed better in the Video Store design than in the Abstract Store design.

Furthermore, these findings emphasize the importance of user preferences and the individualized nature of design experiences. There is no one-size-fits-all solution; the "best" design may vary depending on whether the user seeks an efficient, streamlined experience or a more immersive VR exploration.

1.9 Future Work

In light of the limitations mentioned in Section 1.7.3, future research needs to be done where a comparison is made against the state-of-the-art. Furthermore, future research could either improve the Record Store interaction to ensure a more seamless user experience or allow the user more time to get accustomed to the controls.

Besides this, there are other directions available for future research. First, this study has only tested three designs and shown that a more abstract design is not worse than designs based on real-life experience. Therefore, future research could look at completely other ways to represent and access extensive 360° video libraries. Another direction is further completing the system. Looking at current state-of-the-art video libraries, such as YouTube, allow the user to perform search queries. Future research could be conducted to examine the best possible way to facilitate this in VR.

A   Additional Results

A.1   Questionnaire Results

A.1.1   Demographic Information

This section shows the demographic information of the participants of this study. There were a total of twenty participants that started the study, however, one was unable to complete the study. Therefore this participant's data has been omitted as it was incomplete. Of the remaining nineteen participants, eleven indicated to be male, and eight were female (Figure 10a). Nine of the participants fell in the age range of 18-24, and ten fell in the age range of 25-30 (Figure 10b).
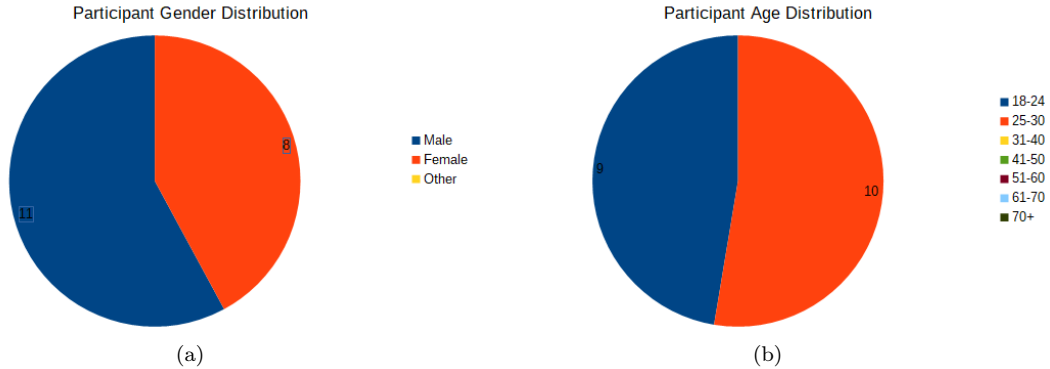
Figure 10: Distribution of the participant's gender (a), and age (b)

All of the participants indicated that they access existing large video libraries such as YouTube, Netflix, and Disney+ on a daily basis (Figure 11a). Furthermore, nine participants indicated to have used VR before but used it rarely, whilst one participant indicated to use VR on a weekly basis (Figure 11b).
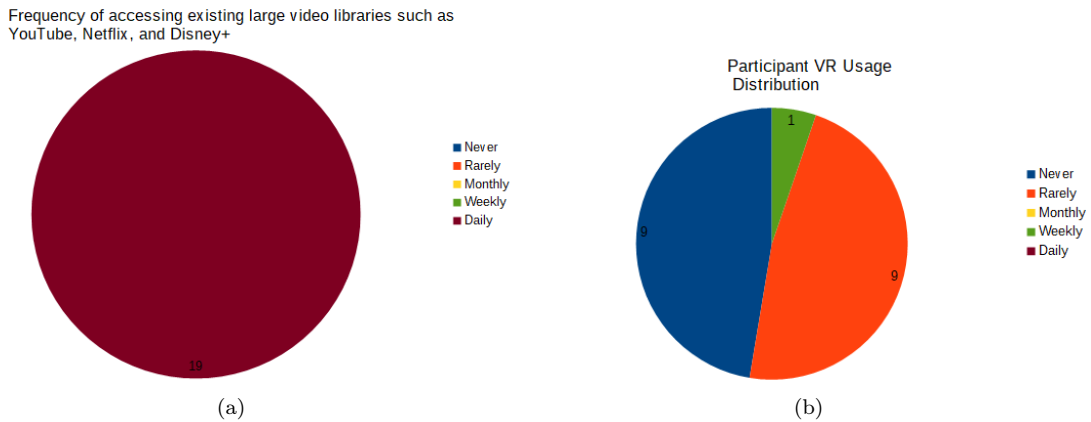

Figure 11: Distribution of the participant's access to large video libraries (a), and VR usage (b)

Eleven of the participants indicated that they had watched 360° videos before (Figure 12). One participant indicates to watch the 360° video on a laptop (Figure 13a). Eight participants stated using mobile phones to watch 360° videos, of which one weekly and the other seven rarely (Figure 13b). As for the use of tablets to watch 360° videos, none of the participants indicated using them (Figure 13c). However, four participants indicated to use a VR headset rarely to watch 360° videos, and two indicated that they use a VR headset monthly to watch 360° videos (Figure 13d).

As for the applications that participants used to watch the 360° videos in VR, two indicated using YoutubeVR, none used Viveport Video, three used Oculus Video, and four indicated that they used
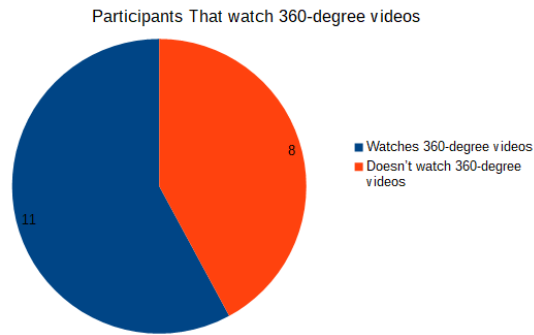
Figure 12: Distribution of participants that have watched 360° videos
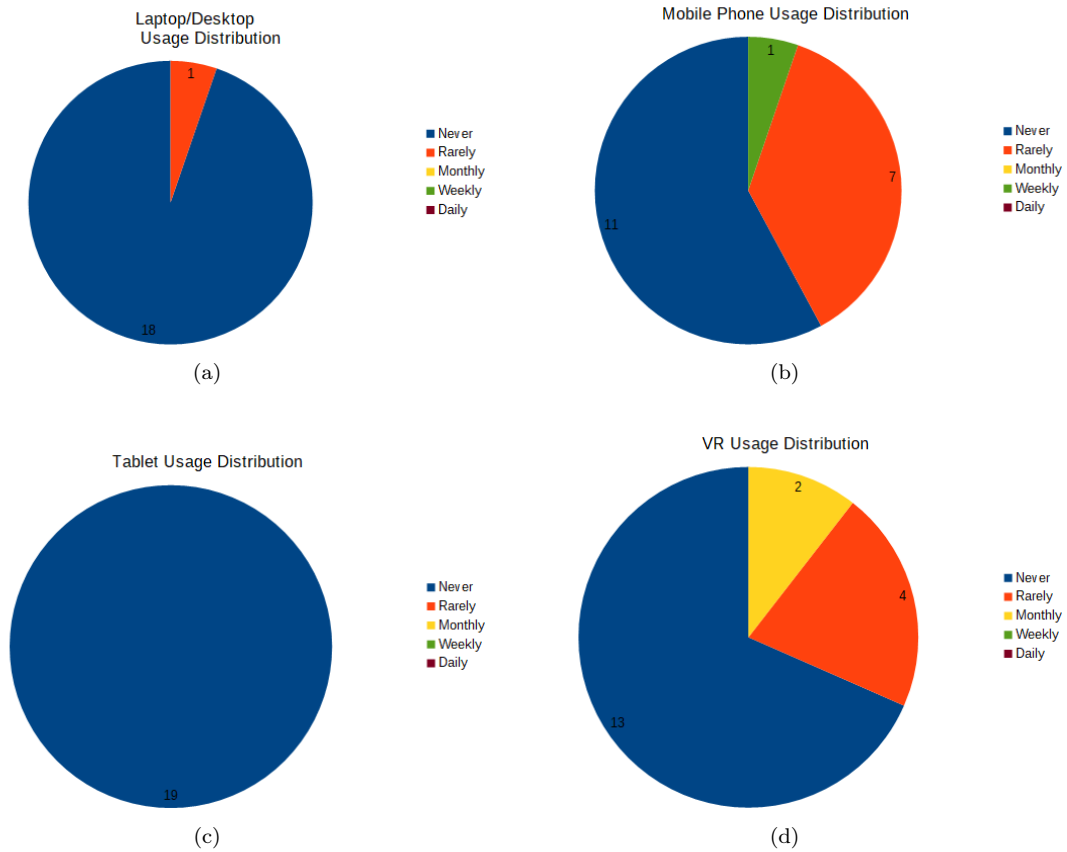

Figure 13: Distribution per devices how often participants use it to watch 360° videos. Laptop/Desktop (a), Mobile Phone (b), Tablet (c), and VR usage (d)

other applications that were not in this list (Figure 14). Participants were asked to check every application they used. Therefore the numbers do not add up to the total amount of participants that indicated using VR headsets to watch 360° video.
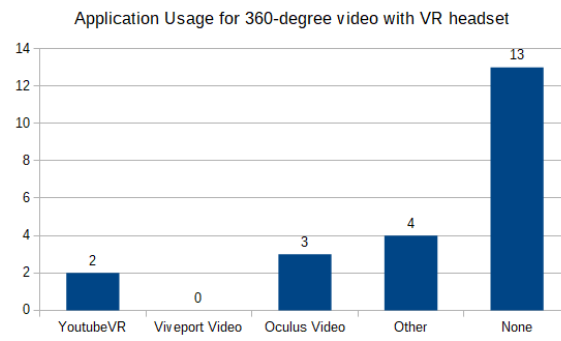
Figure 14: Used applications to watch 360° videos in VR

A.1.2 UEQ-S

The analysis of the UEQ-S was done with the help of the tool created by Martin Schrepp [46]. The questions in the UEQ-S are shown in Section B.1.2. This section contains the result of this analysis. Note that participants did not go through the study in the same order, and this is not reflected in this section.

A.1.2.1 Video Store

Table 9 shows the answers given by the participants to the UEQ-S for the Video Store design. To calculate the quality scores, the scores are translated to fall in the range of -3 to +3. Questions 1 to 4 measure the pragmatic quality, and questions 5 to 8 the hedonic quality

	Q1	Q2	Q3	Q4	Q5	Q6	Q7	Q8
ID 1	7	7	7	7	7	7	7	5
ID 2	7	7	6	7	5	5	6	6
ID 3	5	5	5	6	5	5	5	5
ID 4	6	6	6	7	5	7	5	5
ID 5	6	7	6	7	2	2	3	2
ID 6	2	4	1	2	5	5	5	6
ID 7	7	7	5	6	5	6	6	4
ID 8	6	6	6	6	5	5	3	3
ID 9	6	6	6	6	5	5	5	5
ID 10	4	3	2	3	6	5	6	4
ID 11	6	7	7	7	2	6	2	2
ID 12	7	7	7	7	5	4	6	3
ID 13	6	5	5	6	7	6	5	3
ID 14	6	7	7	7	7	7	7	7
ID 15	7	7	7	7	2	6	3	6
ID 16	6	6	4	6	3	3	2	2
ID 17	5	6	6	6	5	5	2	2
ID 18	6	7	6	7	4	5	6	7
ID 19	5	6	4	6	5	5	6	5

Table 9: Participant answers to the UEQ-S for the Video Store design

Combining these answers results in Table 10, which shows the mean value of each question and its corresponding standard deviation. Furthermore, Table 11 shows the mean and standard deviation for the combined scores.

Question	Mean	Std
1	1.8	1.2
2	2.1	1.1
3	1.4	1.7
4	2.1	1.4
5	0.7	1.6
6	1.2	1.3
7	0.7	1.7
8	0.3	1.7

Table 10: UEQ-S Score per question for the Video Store design

Finally, the results of the UEQ-S are compared to the benchmark data of the UEQ. This is shown in Figure 15 with corresponding 95% error bars.

	Mean	Std
Combined Pragmatic Quality	1.855	1.284
Combined Hedonic Quality	0.750	1.247
Combined Overall Quality	1.303	0.873

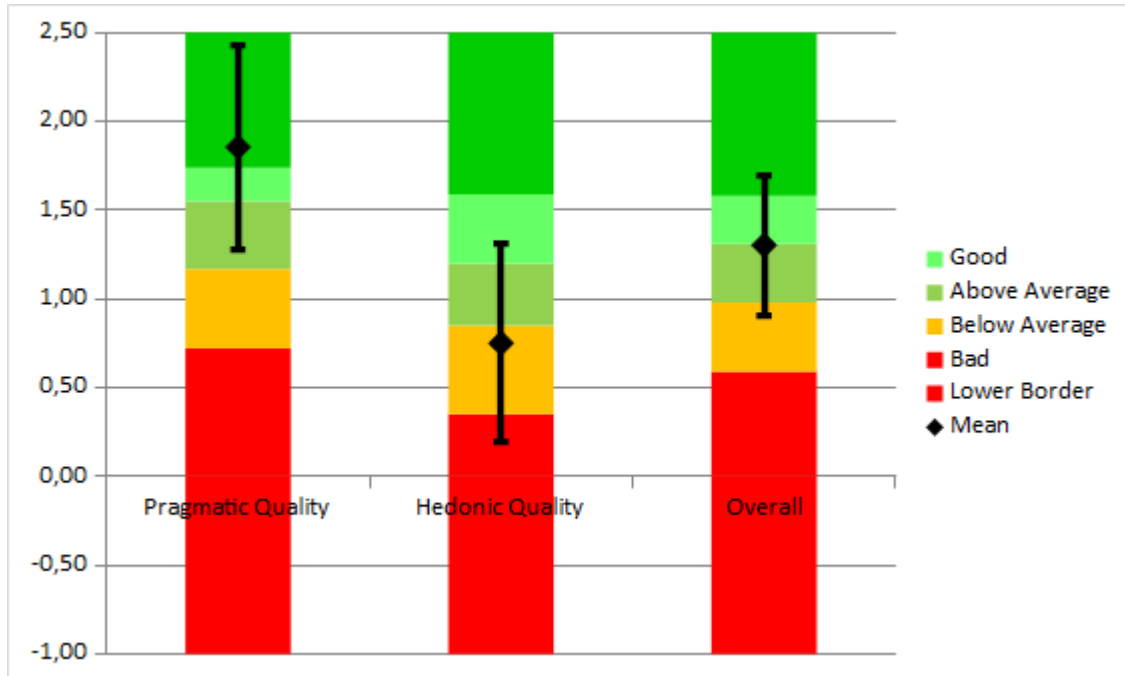Table 11: Combine UEQ-S scores for the Video Store design

Figure 15: Video Store design UEQ-S results compared to the UEQ benchmark data with 95% error bars

A.1.2.2   Record Store

The same process that has been done for the Video Store in Section A.1.2.1 is done here. First Table 12 shows the answers of each participant to the questions of the UEQ-S. Next Table 13 calculates the translated (to a range of -3 and +3) mean score for each question. Table 14 combines this in an average pragmatic, hedonic, and overall score. And the comparison against the UEQ benchmark is shown in Figure 16.

	Q1	Q2	Q3	Q4	Q5	Q6	Q7	Q8
ID 1	6	5	4	6	6	7	6	5
ID 2	6	5	5	4	6	5	7	7
ID 3	5	4	5	4	6	5	5	5
ID 4	5	5	6	4	5	6	5	4
ID 5	1	2	1	6	3	3	3	3
ID 6	2	4	2	5	5	5	5	5
ID 7	2	6	5	7	4	3	3	4
ID 8	3	5	3	5	6	6	6	5
ID 9	2	6	3	3	5	6	7	6
ID 10	5	6	6	6	3	2	3	3
ID 11	3	1	1	1	3	3	2	6
ID 12	3	3	3	7	5	6	5	5
ID 13	5	3	5	3	5	3	3	3
ID 14	4	7	6	6	7	7	6	6
ID 15	6	7	2	5	4	3	2	3
ID 16	3	5	2	5	3	3	3	3
ID 17	5	6	5	6	5	5	2	3
ID 18	3	2	2	5	4	5	5	5
ID 19	2	3	2	5	5	5	5	5

Table 12: Participant answers to the UEQ-S for the Record Store design

Question	Mean	Std
1	-0.3	1.6
2	0.5	1.7
3	-0.4	1.7
4	0.9	1.5
5	0.7	1.2
6	0.6	1.5
7	0.4	1.7
8	0.5	1.3

Table 13: UEQ-S Score per question for the Record Store design

	Mean	Std
Combined Pragmatic Quality	0.171	1.179
Combined Hedonic Quality	0.566	1.255
Combined Overall Quality	0.368	0.928

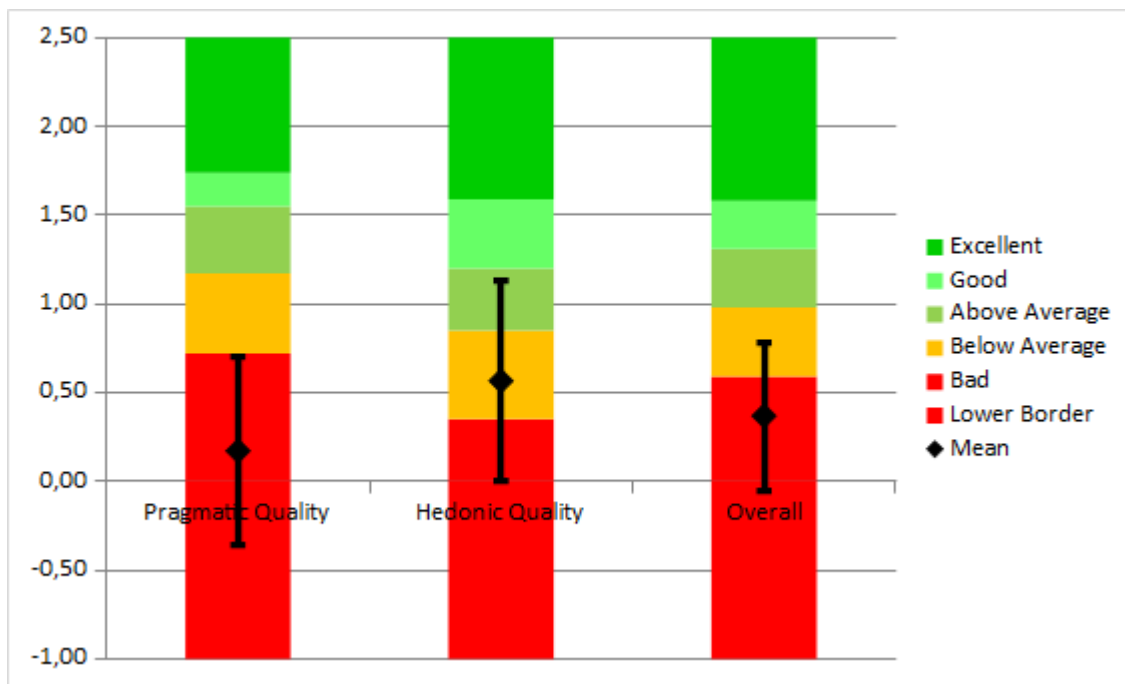Table 14: Combine UEQ-S scores for the Record Store design

Figure 16: Record Store design UEQ-S results compared to the UEQ benchmark data with 95% error bars

A.1.2.3 Abstract Store

Just like for the Record Store and the Video Store, Table 15 shows the answers of each participant for the UEQ-S. Table 16 calculates the mean and standard deviation of each question, and Table 17 combines it into the pragmatic, hedonic, and overall quality scores. Finally, Figure 17 shows the scores compared to the UEQ benchmark data with 95% error bars.

	Q1	Q2	Q3	Q4	Q5	Q6	Q7	Q8
ID 1	5	4	4	6	7	7	7	7
ID 2	4	4	5	5	7	6	6	6
ID 3	5	5	5	5	6	5	5	5
ID 4	5	5	6	4	6	5	6	4
ID 5	3	6	2	5	6	6	6	6
ID 6	5	5	3	4	4	4	7	7
ID 7	1	2	1	6	7	7	7	6
ID 8	6	3	5	6	7	6	7	5
ID 9	2	2	2	3	6	6	7	7
ID 10	3	2	1	5	6	3	7	6
ID 11	5	2	5	5	5	5	6	7
ID 12	3	5	3	7	7	7	7	7
ID 13	5	3	5	5	6	5	5	5
ID 14	5	6	6	6	6	5	6	6
ID 15	2	5	2	3	6	6	6	5
ID 16	3	3	3	5	5	5	5	5
ID 17	5	5	2	6	5	6	5	5
ID 18	6	5	5	5	6	6	7	6
ID 19	6	6	7	6	7	5	7	6

Table 15: Participant answers to the UEQ-S for the Abstract Store design

Question	Mean	Std
1	0.2	1.5
2	0.1	1.4
3	-0.2	1.8
4	1.1	1.0
5	2.1	0.8
6	1.5	1.0
7	2.3	0.8
8	1.8	0.9

Table 16: UEQ-S Score per question for the Abstract Store design

	Mean	Std
Combined Pragmatic Quality	0.289	1.078
Combined Hedonic Quality	1.921	0.618
Combined Overall Quality	1.105	0.608

Table 17: Combine UEQ-S scores for the Abstract Store design
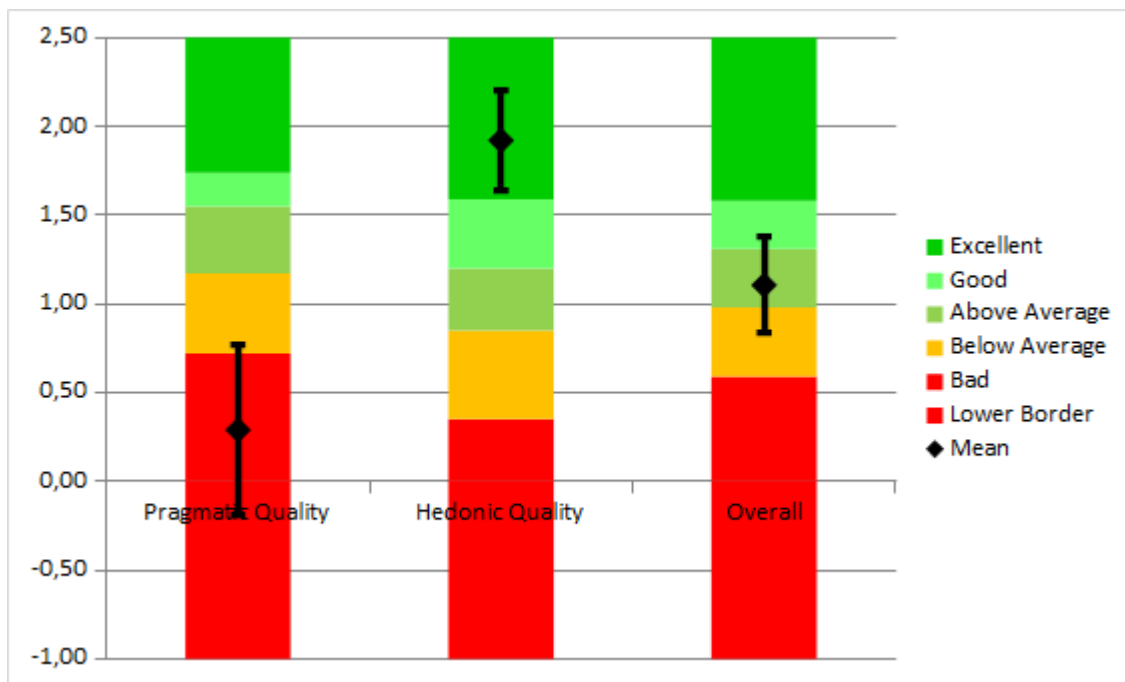
Figure 17: Abstract Store design UEQ-S results compared to the UEQ benchmark data with 95% error bars

A.1.3 VRSQ

To measure the cybersickness experienced by the participants, the VRSQ by Hyun et al. [28] was used after each design. This section will show the distribution of symptoms experienced by the participants. Most notable here is that the majority of the participants indicated that they have some kind of difficulty with focusing (Figure 22) and have some level of blurred vision (Figure 24) for all three of the designs. An explanation for this could be the fact that during the period that the study was done, the environmental temperatures were relatively high, causing sweating and fogging of the VR HMD. Furthermore, Figure 20 shows that more participants indicated that they have some level of fatigue after using the Abstract Store design. This can be explained by the fact that in this design, the participants must physically make the motion to pull a lever when inspecting the videos.
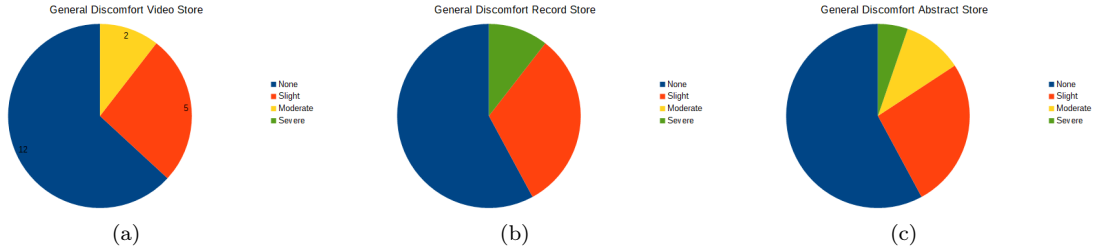
Figure 18: Distribution of the participant's General Discomfort level for the Video Store (a), Record Store (b), and Abstract Store (c) design
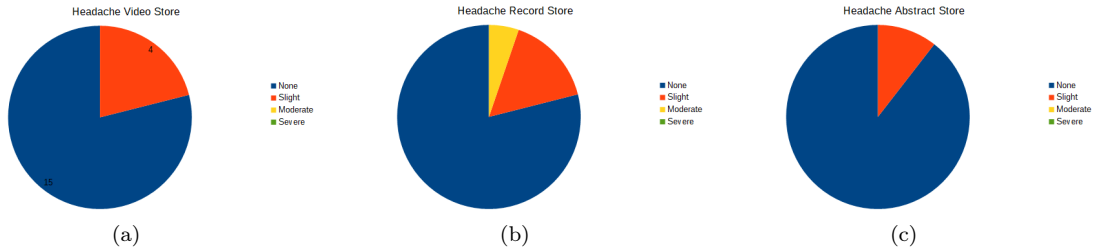
Figure 19: Distribution of the participant's Headache level for the Video Store (a), Record Store (b), and Abstract Store (c) design
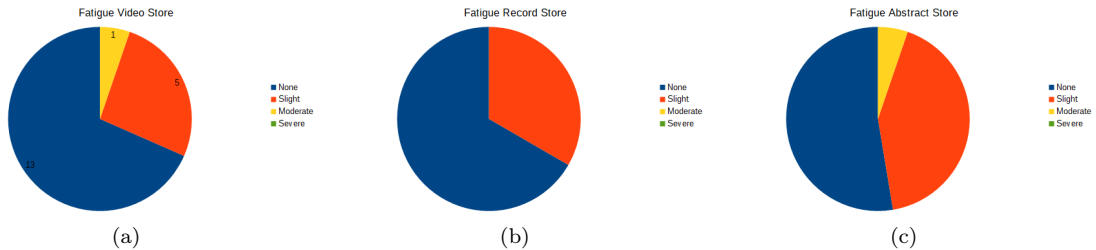
Figure 20: Distribution of the participant's Fatigue level for the Video Store (a), Record Store (b), and Abstract Store (c) design
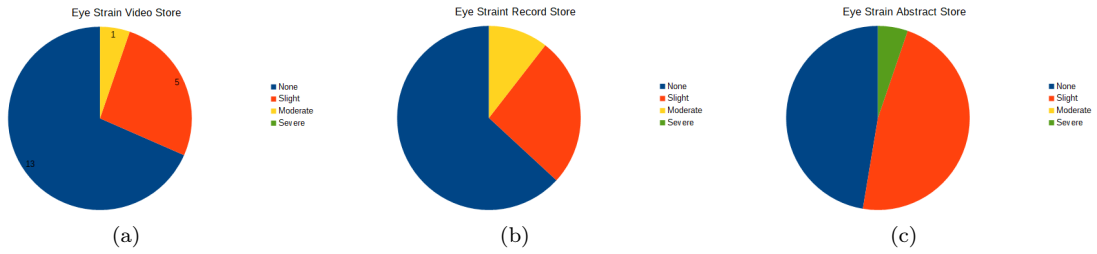
Figure 21: Distribution of the participant's Eye Strain level for the Video Store (a), Record Store (b), and Abstract Store (c) design
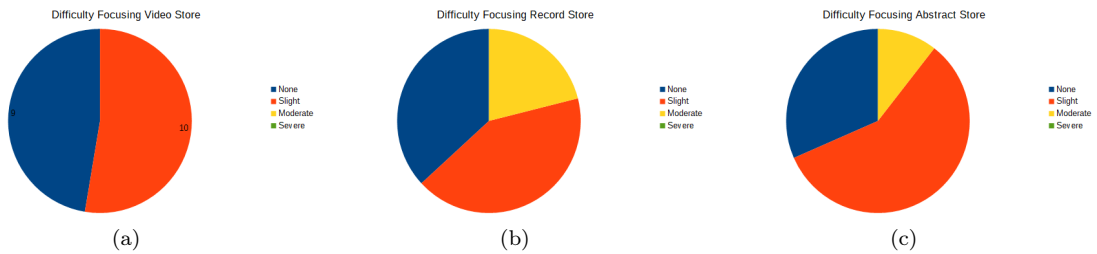
Figure 22: Distribution of the participant's Difficulty of Focusing for the Video Store (a), Record Store (b), and Abstract Store (c) design
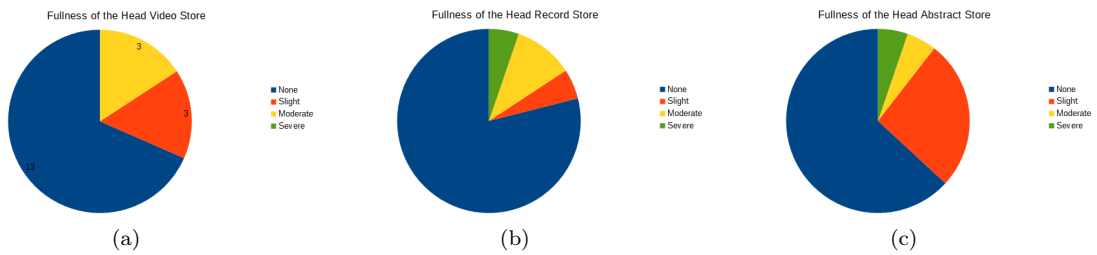

Figure 23: Distribution of the participant's Fullness of the Head level for the Video Store (a), Record Store (b), and Abstract Store (c) design
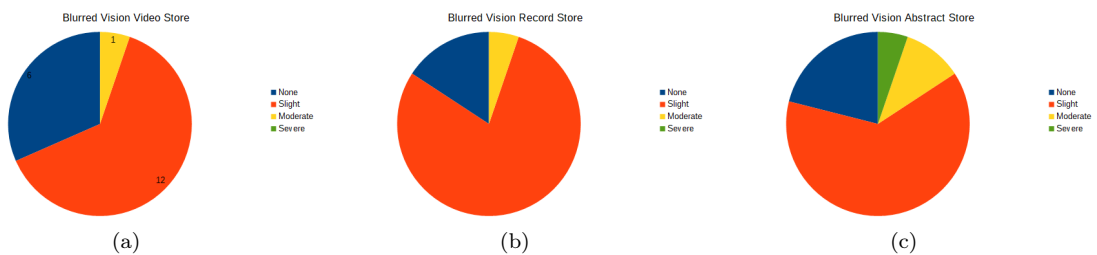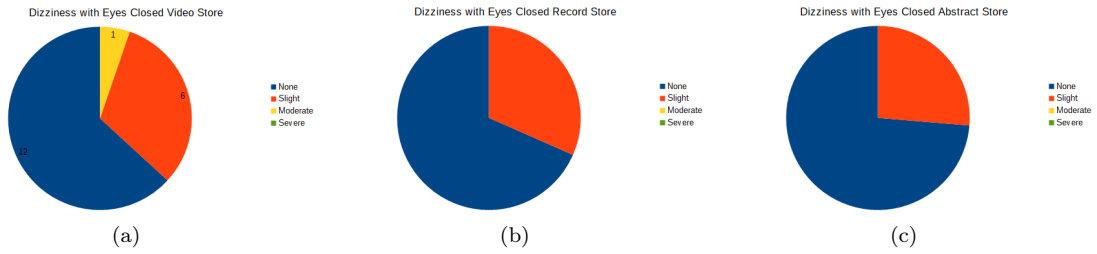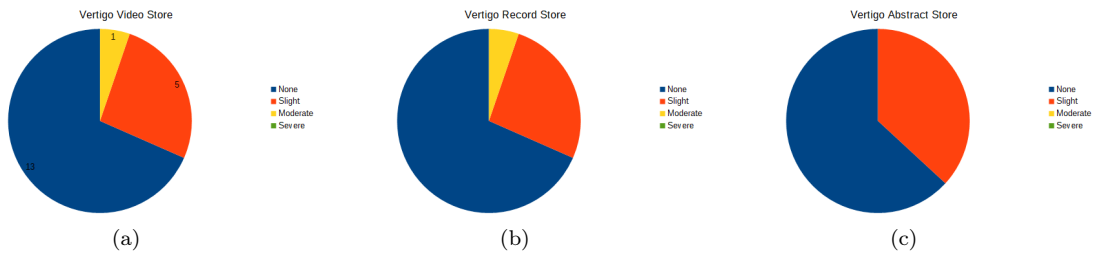

Figure 24: Distribution of the participant's Blurred Vision level for the Video Store (a), Record Store (b), and Abstract Store (c) design

Figure 25: Distribution of the participant's Dizziness with Eyes Closed level for the Video Store (a), Record Store (b), and Abstract Store (c) design

Figure 26: Distribution of the participant's Vertigo level for the Video Store (a), Record Store (b), and Abstract Store (c) design

A.1.4 Performance

The performance can be split into perceived performance and measured performance. Section A.1.4.1 will contain the perceived performance, and Section A.1.4.2 will contain the measured performance.

A.1.4.1 Perceived Performance

To measure the perceived performance, the participants were asked two questions (Section B.1.4). Figure 27 shows the distribution of answers given by the participants for each design for the satisfaction of the created playlist. Figure 28 contains the distribution to the question about the ability to inspect all the videos that the participant wanted.
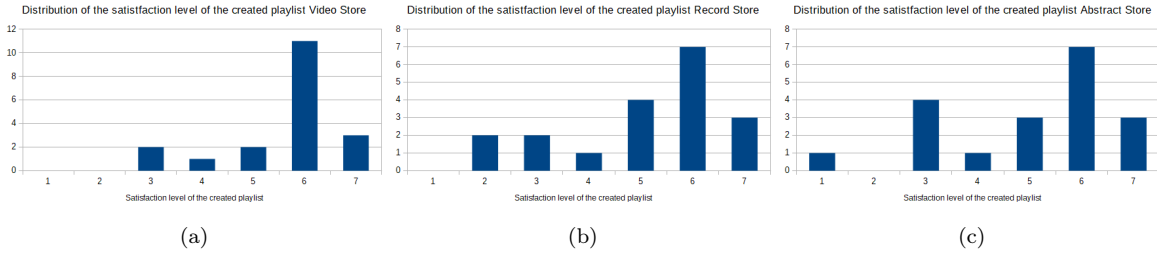
Figure 27: Distribution of the participant's Satisfaction level of the created playlist for the Video Store (a), Record Store (b), and Abstract Store (c) design
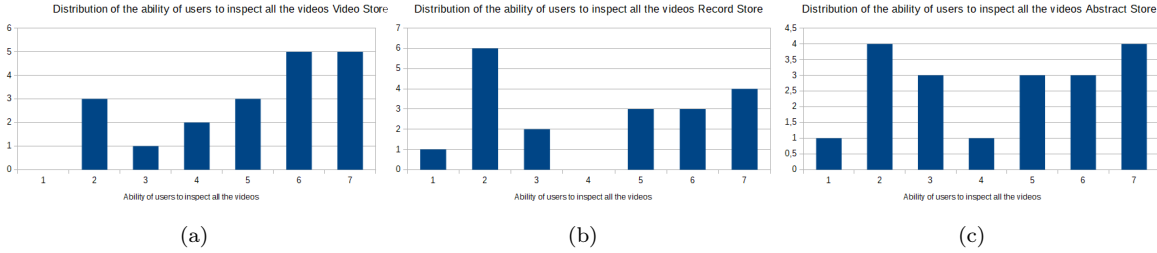

Figure 28: Distribution of the participant's Perceived ability to inspect all videos for the Video Store (a), Record Store (b), and Abstract Store (c) design

A.1.4.2 Measuered Performance

For the measured performance, the time the participants needed to complete the task was measured. The time was capped at five minutes per design. For this reason, the amount of videos that the participants added when the time was over was also recorded. Figure 29 shows the distribution of how long each participant did over the task. The bins are of a 30-second size (or 30000 ms). Figure 30 shows the distribution of how many videos the participants added to the playlist at the end of the task.

Comparing these tables, we see that for the video store, the majority of participants had added eight or more videos to the playlist before the end of the task, whereas for the Record Store this was at seven and the abstract store at six. As for the time taken, almost all participants were not able to finish the task within 5 minutes. Furthermore, in the interviews (Section A.3), ten participants indicated some kind of difficulty with interacting with the Record Store. However, when looking at the distributions with the number of videos in the playlist at the end for the Record Store and Abstract Store (Figures 30b and 30c) we can see signals, though not significant, that despite these difficulties the record store could be more efficient.
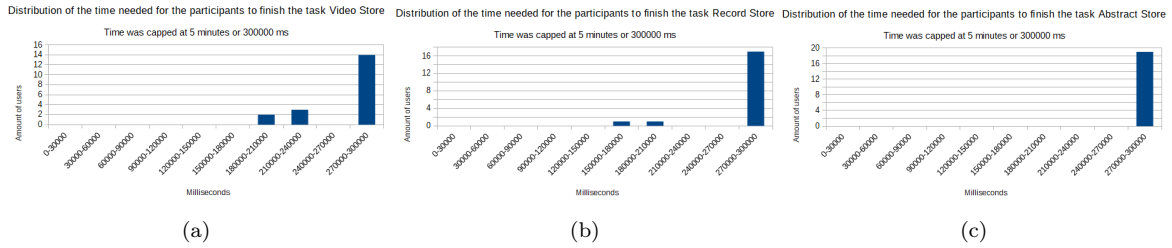
Figure 29: Distribution of the time needed by the participant to complete the task for the Video Store (a), Record Store (b), and Abstract Store (c) design
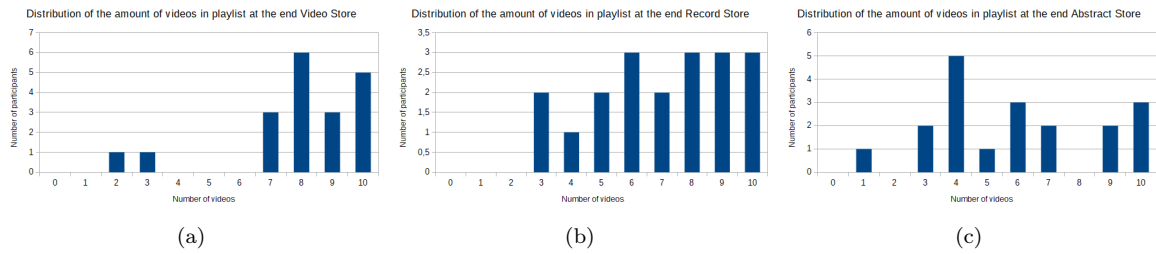

Figure 30: Distribution of the number of videos in the playlist at the end of the task for the Video Store (a), Record Store (b), and Abstract Store (c) design

A.1.5 Ranking

This section contains an overview of the ranking data. Table 18 contains all the ranking data submitted by the participants. 1 equals first place, 2 second place, and 3 third place. Figure 31 shows the distribution of the rankings per design. This shows that the Video Store is ranked higher than the Record Store, which was also shown by the Wilcoxon signed-ranked test in Section 1.6.3. This same section shows that there is no statistically significant difference between the Video Store and Abstract Store and the Abstract Store and Record Store. However, looking at Figure 31, we can see that the Record Store is predominantly ranked third in comparison to the Abstract Store, which is ranked second most of the time. Though the difference is not significant, this does show that there are signals that the Abstract Store is better than the Record Store.

	Video Store	Record Store	Abstract Store
ID 1	1	3	2
ID 2	3	2	1
ID 3	2	3	1
ID 4	1	3	2
ID 5	1	3	2
ID 6	2	3	1
ID 7	1	2	3
ID 8	1	3	2
ID 9	1	2	3
ID 10	2	1	3
ID 11	1	3	2
ID 12	1	3	2
ID 13	2	3	1
ID 14	1	3	2
ID 15	1	2	3
ID 16	1	3	2
ID 17	1	2	3
ID 18	1	3	2
ID 19	2	3	1

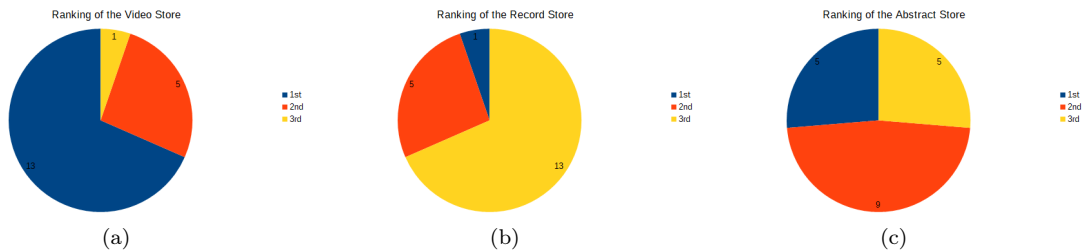Table 18: Participant ranking of the three designs

Figure 31: Distribution of the ranking for the Video Store (a), Record Store (b), and Abstract Store (c) design

A.2 System Data

During the Experiment, there were three ways for the participant to navigate through the virtual environment. They could teleport, float (via the controller), or walk in the real environment. Figure 32 shows the mean values with a 95% confidence interval of the three navigation types and a total.
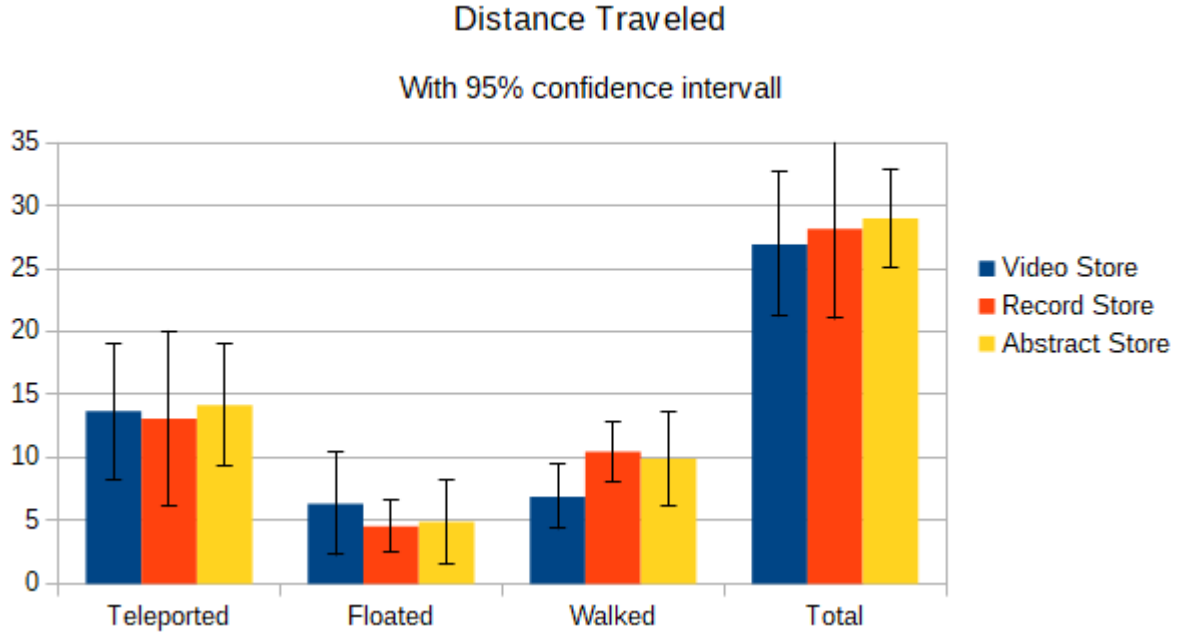

Figure 32: Distance Traveled in meters per design with 95% confidence intervall

In Figure 32, it appears that there might be a difference between the Distance walked for the Video Store and the Record Store. Running the Shapiro-Wilk test shows a departure of normality from the Distance walked for the Video Store, $W(19) = 0.883, p = 0.024$. The other two designs did not depart from normality, $W(19) = 0.959, p = 0.549$ and $W(19) = 0.921, p = 0.116$ for respectively the Record Store and Abstract Store. Following this, the Friedman test was used to detect if there was a statistically significant difference. This test indicated that there indeed was a statistically significant difference $X^2(2) = 13.053, p = 0.001$. This was followed by the Wilcoxon Signed-Ranked test with Bonferroni correction resulting in a significance level of $p < 0.017$. This test indicated that there was a statistically significant lower distance walked for the Video Store than the Record Store, $Z = -2.897, p = 0.002$. There was no significant difference between the Video Store and Abstract Store ($Z = -1.811, p = 0.073$) and the Record Store and Abstract Store ($Z = -0.684, p = 0.515$). A reason for the difference between the Video Store design and the Record Store design could be the fact that in the Video Store design, the user can use laser pointers to interact with far-away videos. Whilst for the Record Store, they need to actually touch them. Furthermore, in the Record Store, the Display containers are closer together when compared to both the Video Store and Abstract Store design. This might have the effect of inviting the participants to walk a short distance instead of teleporting and floating. This signal can also be seen when comparing Teleportation and Floating. In Figure 32, we see that the mean of these two movement methods is lowest for the Record Store.

A.3 Interviews

In this section, the transcripts of the interviews that were conducted at the end can be found. Note, that in the interview, "Tubes" is often used to describe the Abstract Store Design. Furthermore, text in italics are comments by the author to make some things clearer. These were not present in the audio files. Below in Section A.3.1 an overview of some common remarks that participants made are given. These remarks are split into advantages and disadvantages for each design.

A.3.1 Interview Overview

Advantages of the Video Store	Mentions
Clear overview	10
Easy	4
Fun to be able to walk and look around	2
Looks like an old Video Store	1

Table 19: Advantages of the Video Store design as mentioned by the participants during the interviews

Disadvantages of the Video Store	Mentions
You have to walk through the store to see everything	2
Items on the bottom shelve are a bit complicated to get	1

Table 20: Disadvantages of the Video Store design as mentioned by the participants during the interviews

Advantages of the Record Store	Mentions
The interaction is fun	1

Table 21: Advantages of the Record Store design as mentioned by the participants during the interviews

Disadvantages of the Record Store	Mentions
You are not able to see the entire thumbnail when they are in their container	12
Difficult to see which video you're interacting with	5
Difficulty interacting with the video	5

Table 22: Disadvantages of the Record Store design as mentioned by the participants during the interviews

Advantages of the Abstract Store	Mentions
Good overview	4
The interaction is fun	5
The design is fun	4

Table 23: Advantages of the Abstract Store design as mentioned by the participants during the interviews

Disadvantages of the Abstract Store	Mentions
Turning the thumbnails around the tube was somewhat difficult	2
Confusing	2
An extra action is necessary to watch a video	5
You have to rotate the videos to see all of them	3

Table 24: Disadvantages of the Abstract Store design as mentioned by the participants during the interviews

A.3.2 Id1

RESEARCHER: I didn't catch your rankings. However, are you able to explain them?

NOTE: Ranking was as follows: Video Store = 1, Record Store = 3, Tubes = 2

PARTICIPANT: I found the video, the first one, I found it very easy, the library. I found it very easy because the overview was a bit clearer. You were able to immediately see what you had. The Record store was a bit more unclear because you were only able to see the first image completely and the others were a bit obscured. The tubes, I found it clear as well, however, I struggled a bit with the turning of the images. So had that one as two, the Video Store as one and the second one as three.

RESEARCHER: So the reason that the Tubes are second and not first is that the interaction with the tubes to select a video and see what is available is more difficult than with the Video Store.

PARTICIPANT: Yes, yes correct.

RESEARCHER: If you are able to change something about the Record Store what would you change?

PARTICIPANT: Maybe you could change the height of each video. Place them like a stair. That way you are maybe able to create a clearer picture.

RESEARCHER: Any other pros or cons?

PARTICIPANT: no not really.

RESEARCHER: Any other general remarks?

PARTICIPANT: No, I found it fun to do.

RESEARCHER: Alright, thank you for your time.

A.3.3 Id2

RESEARCHER: You had the Tubes on one, the Record Store on two, and the Video Store on three. Can you explain to me why you chose this ranking?

PARTICIPANT: I found the Video Store very easy, it had a clear overview. You just pointed and you already had it. With the Record Store and the Tubes, I found it really fun that you were able to swipe and pull a lever or that you can literally move your hand through the container with the videos.

RESEARCHER: So it is more that you are actually doing something instead of simply browsing through.

PARTICIPANT: I had with the Video Store that I found a video that looked fun but when the image was there I thought oh never mind. Because it goes a lot faster. And with the Record Store, you really need to move to the containers to see if you really liked it.

RESEARCHER: But if you needed to select the design that works best when you need to create a playlist the fastest you would pick the video store?

PARTICIPANT: Yes, that is correct.

RESEARCHER: Any other pros and cons.

PARTICIPANT: Not really. I did like the tubes. But it was also confusing. When I stopped swiping the videos continued rotating a bit, I didn't know if it was in the system. But that was something that I thought was a bit confusing.

RESEARCHER: Both when rotating via touch and via the laser pointer?

PARTICIPANT: Only when touching.

RESEARCHER: Any other remarks?

PARTICIPANT: Not really.

RESEARCHER: Alright, thank you for your time.

A.3.4 Id3

RESEARCHER: What was the ranking you chose? If I remember correctly, it was first the tubes, then the video store, then the record store, right?

PARTICIPANT: No, first the record, then the tubes, and then the bookcase. I had to go through the...

RESEARCHER: No, no, not your order, the ranking you chose.

PARTICIPANT: Oh, yes, sorry, then it is correct.

RESEARCHER: Why?

PARTICIPANT: The Tubes were the most fun and the easiest.

RESEARCHER: Can you explain why that was the easiest?

PARTICIPANT: Yes, you could just move your hand like this, back and forth. Instead of clicking and...

RESEARCHER: Am I correct to say that it is the interaction possibility you have with the Tubes?

PARTICIPANT: Yes.

RESEARCHER: Why did you rank the Tubes higher then the Record Store?

PARTICIPANT: Because the Tubes were more clear. With the Record Store I went through the videos, and I couldn't see which video I was currently interacting with.

RESEARCHER: Any other pros and/or cons?

PARTICIPANT: With both the Video Store and Tubes you are able to see the images. But with the Record Store they are placed behind each other.

RESEARCHER: Anything else?

PARTICIPANT: The advantage of the Video Store is that it is really clear which video you are going to watch. And the Tubes are just fun.

RESEARCHER: So the Video Store gives the best overview, and the Tubes are the most fun?

PARTICIPANT: Yes.

RESEARCHER: Any other general remarks?

PARTICIPANT: No.

RESEARCHER: Alright, in that case, thank you for your time.

A.3.5   Id4

RESEARCHER: I saw that you ranked the Video Store as one, the Record Store last, and the tubes as second. Is that correct?

PARTICIPANT: Yes.

RESEARCHER: Why?

PARTICIPANT: I like that you are able to walk around in the Video Store, and for the tubes I liked that you pulled a lever. As for the Record Store, I found it difficult to flip through the videos. Because you suddenly see a lot passing by. I found that annoying. It was more that you are overstimulated because of that.

RESEARCHER: Is the difficulty in flipping through the videos the defining reason to put in last or are the other reasons?

PARTICIPANT: Ehh... no, not at all. I just find it the least fun. I liked that you could really walk through the video store and that you are actually doing something in the Tubes design.

RESEARCHER: Are there any other pros or cons?

PARTICIPANT: You have a better overview of what is available in the Video Store and Tubes. You are able to see faster which videos there are in comparison to when you are flipping through the videos as you can't see the entire image.

RESEARCHER: Anything else?

PARTICIPANT: No those are the biggest things. Especially walking around and being busy, that's fun.

RESEARCHER: Alright, thank you for your time.

A.3.6   Id5

RESEARCHER: I saw that you the video store as the first one, and the Tubes as the second one, and the record store as last. Why?

PARTICIPANT: What I found easiest with the video store is that I could already see the thumbnail at a distance. And with the Record Store, it was all in a row, so I couldn't see it well. And with the tubes, it was all around the tube. So I found it very nice that I could already see it on a distance what the thumbnails are. And I could easily check what was happening in the video. And if I wanted to watch it again, I would grab it. While with the other store, I had to do an action to be able to check the thumbnail.

RESEARCHER: So the biggest advantage is overview?

PARTICIPANT: Yes, I can see all the thumbnails the fastest.

RESEARCHER: Okay, other things that stood out?

PARTICIPANT: I didn't like going through the Record store. That's partly because I'm used to using two hands. I don't know when I touch one record or the other because I don't have tactile feedback besides that. What I also found annoying was that it was all in the middle. And what I liked about the Tubes and Video Store is that it is placed around me. What I didn't like about the Video Store was that I still had to walk through it. But it was in such a way that I didn't mind. Because there wasn't much that I couldn't see. Here I really had to walk around it (*Record Store*). And I didn't like that.

RESEARCHER: Any advantages?

PARTICIPANT: The Tubes are funny. I don't think it's very useful for daily use. But if it's in a video game setting or something. I think that's very nice for the immersion. In general, I thought the immersion was good with everything. The youth of today don't know it but it is like you are actually back standing in a Video Store. And it's fun to browse. It's more fun than, for example, a YouTube interface. On YouTube, you just scroll to see which movie you want to watch. Here it was a bit like, let's see what's there. That was a bit more fun. It can also be a bit of a novelty because it's new to me. But it felt more fun, anyway. I thought it was funny. First, I scanned which thumbnail looked good. Then which video looked good? And then I grabbed it and looked more closely. It became like a mini-game. It is more fun but less efficient.

RESEARCHER: Any other General remarks?

PARTICIPANT: No.

RESEARCHER: Alright, thank you for your time.

A.3.7 Id6

RESEARCHER: You had the tubes on one, the Video Store on two, and the Record Store on three, right?

PARTICIPANT: Yes

RESEARCHER: Why?

PARTICIPANT: I had the tubes as one because I liked the design the most. And it had a clear overview. When looking around you could see which categories were available. I had the Video Store on two because I found it a bit less clear. But I like how it was done. Like you were standing in an old Video Store. But moving through the aisle was a bit difficult with the glasses. (*VR Headset*) At last, I had the Record Store. It was clear as you were able to see the image but it wasn't efficient to pick a video.

RESEARCHER: So the interaction itself was difficult?

PARTICIPANT: Yes. And the space was bare. In the Video Store, you had the closets against the walls and the same for the tubes. But with the Record Store, you had the containers and the rest was empty.

RESEARCHER: With respect to overview. Do you find it more important that you have an overview of the available categories or the videos inside the categories?

PARTICIPANT: Initially you are thinking about what kind of video do I want to watch, and within a category, you will eventually find a video you want to watch.

RESEARCHER: Are there any other pros or cons that you can think of?

PARTICIPANT: An advantage is that it is partially new. But maybe I haven't used a VR Headset before. But it also has a bit of nostalgia. Like you are choosing videos, even with the tubes, in a kind of Video Store. Another advantage is that you might pick a video more consciously in comparison to simply scrolling on your phone. And the immersion, that you are really standing somewhere. As a con, I think that it is a bit less efficient when I compare it to scrolling on my phone.

RESEARCHER: Anything else?

PARTICIPANT: No.

RESEARCHER: In that case, thank you for your time.

A.3.8   Id7

RESEARCHER: You had Video Store 1, Record Store 2, and Tubes 3, right?

PARTICIPANT: Yes.

RESEARCHER: Why?

PARTICIPANT: For the Video store, the overview was clear, you could easily see the videos that were present and it was easy to pick one out.

RESEARCHER: And how about the Tubes?

PARTICIPANT: With Tubes, the problem was that as soon as I scrolled it went to the preview and I could see the thumbnail. And that made it very difficult. And you couldn't see them at the same time.

RESEARCHER: And how about selecting a video?

PARTICIPANT: In the Video Store it was really clear, I want that one, click, pick up. But with Tubes it was first looking around, which one do I want, and then taking the handle and grabbing the ball. And that was a lot more confusing.

RESEARCHER: You also said something about not liking that the thumbnails switched to the preview. Furthermore, I noticed during the experiment that you predominantly looked at the thumbnail images and not at the videos. Would you say that if the preview started playing 3 or 4 seconds later that would be sufficient or would you like to have total control over when the video starts playing?

PARTICIPANT: Yeah, I think that would be more chill.

RESEARCHER: The last option.

PARTICIPANT: Yes.

RESEARCHER: How about the record store?

PARTICIPANT: In the record store you could see the thumbnail images and they started playing when you grabbed them right?

RESEARCHER: It starts playing when the video teleports up.

PARTICIPANT: Yes, but that's the thing. There is an active moment when the thumbnail moves up and the video starts playing.

RESEARCHER: Did you find any difficulty with looking at the thumbnails that were placed more at the back of the container?

PARTICIPANT: Not as much, but that was because I just stood inside the tables.

RESEARCHER: Any other pros or cons of the designs?

PARTICIPANT: The Video Store was clean. I would use that one. The Record Store, yeah, the way to select is less chill. With the tubes, the videos were too small, you could see less of them at the same time. The scrolling and changing to the preview make it difficult to use. Making it so I wouldn't use it. Pulling the lever is cool, however, I don't know if it actually adds something.

RESEARCHER: Any other general remarks?

PARTICIPANT: No.

RESEARCHER: Alright, thank you for your time.

A.3.9 Id8

RESEARCHER: If I'm correct, I saw you put the video store in first place, the Tubes in second and the Record Store in third.

PARTICIPANT: Yes, that's right.

RESEARCHER: Why?

PARTICIPANT: Mainly in terms of what I found easiest to work with. What was easiest to operate and most clear. For the Record Store, if you take one video, you sometimes get another. And it was difficult to see the entire image. Of the middle one you were only able to see the top edge. So it would be nice if you could scroll through it, that if you go over it with your hand, it will flap forward. What you would also do with DVDs. You would move them forward and then you can see behind it.

RESEARCHER: So if I understand you correctly, instead of shooting up and playing the video you would say, for example, zoom up and show the thumbnail.

PARTICIPANT: Yes exactly.

RESEARCHER: And then start the video playing after, for example, five seconds or allow the user to define the moment the video starts playing.

PARTICIPANT: Yes, that you can scroll through it and that they come up and then you can choose the pick that one.

RESEARCHER: That's the reason why the Record Store is ranked last?

PARTICIPANT: Yes.

RESEARCHER: Why did you rate the Video Store above the Tubes?

PARTICIPANT: I found that Video Store was very clear. If you stood in front of it, you could see exactly what everything was and then you could easily choose one. And I liked the tubes more, because it's really fun that you pull the lever and video falls down the tube. But it was just a bit more difficult to operate. Maybe also because it was still a search with the VR, but then you had to do a lot more.

RESEARCHER: So the main point is the overview?

PARTICIPANT: Yes, and also the number of steps you have to do. Also, I noticed that scrolling with the tubes was a bit difficult. With the other one you could grab it easily. So I thought that Video Store was very clear and easy to work with.

RESEARCHER: Any other pros and/or cons we haven't discussed yet?

PARTICIPANT: The only thing with the Video Store was that when you went somewhere you suddenly stood halfway in the closet because it was a smaller space. Furthermore, I noticed with the tubes, when you are touching the thumbnails that there is no yellow edge that is visible in the other two.

RESEARCHER: alright, any other remarks?

PARTICIPANT: No.

RESEARCHER: In that case, thank you for your time.

A.3.10 Id9

RESEARCHER: You had Video Store one, Record Store two, Tubes three, right?

PARTICIPANT: Yes, that's correct.

RESEARCHER: Why?

PARTICIPANT: In VideoStore you have a very good overview. You can also just bring a video to you from a very far distance. I think I was able to watch most of the videos there. And it also felt the least clunky in terms of controls.

RESEARCHER: And why the Record Store on two and the Tubes on three?

PARTICIPANT: Yes, with Record Store it was very annoying to go through the videos, it gets a bit awkward and it is very difficult to get the right video. But it did feel more pleasant to use than that you first have to pull a lever and then pick up the ball to select it, and then add it to the playlist. It felt as a lot more effort.

RESEARCHER: So if I understand you correctly, your priority is overview. And also the efficiency to complete your goal.

PARTICIPANT: Yes, exactly.

RESEARCHER: Any other pros and/or cons?

PARTICIPANT: Because you have to walk around a lot and it's a small space, you still have to use the buttons often, so you have to teleport often. So maybe you don't quite get the VR feeling.

RESEARCHER: Any other general remarks?

PARTICIPANT: No.

RESEARCHER: Alright, thank you for your time.

A.3.11 Id10

RESEARCHER: You had the Record Store on one, the Video Store on two, the Tubes on three, right?

PARTICIPANT: Yes.

RESEARCHER: Why?

PARTICIPANT: The tubes just sucked. I like it when it's all easy. I want to be able to do something immediately.

RESEARCHER: Alright, and why is the Video Store second?

PARTICIPANT: I think the Record Store is nicer because I have the idea that I have more overview. You have one category, and you can get an idea of what they look like. At the bookstore, you have to walk through it, and you have a little less overview. But the Video Store and Record Store are close. I was doubting, you could almost flip those two. You could also see that in the ratings. If I'm correct, I rated those two more boring-esque. And the tube is of course a bit more exciting. And that is exactly the opposite of what I would be interested in if I were to work with that.

RESEARCHER: Any other pros and/or cons we haven't discussed yet.

PARTICIPANT: In the Video Store you are able to see everything clearly in comparison to the Record Store where the thumbnails are placed closely behind each other.

RESEARCHER: Any other general remarks?

PARTICIPANT: Yes, I just thought that it was very nice to be able to pick the video up and look inside it.

RESEARCHER: Alright, thank you for time.

A.3.12 Id11

RESEARCHER: Let's see, you had the video store on one, the tubes on two and...

PARTICIPANT: No, I had the tubes on one.

RESEARCHER: The tubes on one?

PARTICIPANT: Yes.

RESEARCHER: Okay, you had the Tubes on one, the Video Store on two, and the Record Store on three. Correct?

PARTICIPANT: Yes.

RESEARCHER: Why? What is the reason that you put the Tubes first instead of the Video Store?

PARTICIPANT: No, that's not true. I did have the Video Store on 1.

RESEARCHER: Alright, but why?

PARTICIPANT: Because I could see everything at once in the Video Store. I had a very good overview of which videos there were.

RESEARCHER: Is it about the overview that you have per category or the total overview?

PARTICIPANT: I think the total overview. When I walked around, I saw all the videos at once.

RESEARCHER: And how about the overview of Record Store?

PARTICIPANT: I think it's too compact. Because then you still have to scroll through it to be able to see the pictures, so to speak.

RESEARCHER: Other advantages or disadvantages that we have not talked about yet?

PARTICIPANT: I think with the tubes the space was very large. So it took me a lot of time, I could not put ten videos into the playlist, to go from part to part. And then scroll through it.

RESEARCHER: Any other remarks?

PARTICIPANT: No.

RESEARCHER: Alright, thank you for your time.

A.3.13   Id12

RESEARCHER: Let's see, you had the Video Store on one, the Tubes on two, and the Record Store on three?

PARTICIPANT: I had the Video Store on one, the Tubes on two, and the Record Store on three.

RESEARCHER: Why?

PARTICIPANT: The video Store was clear, the tubes were fun, and the third was inconvenient, the Record Store.

RESEARCHER: The inconvenience, was that caused by the interaction?

PARTICIPANT: Yes, exactly. I think if it would be less sensitive, it would be better.

RESEARCHER: You were also talking about an overview of the Video Store. Is important for you that you have an overview of everything that was available or an overview of the videos within the categories?

PARTICIPANT: More of the videos themselves.

RESEARCHER: What do you look at when selecting videos for the playlist?

PARTICIPANT: I look... I can see pretty quickly if I find something interesting or not. Thumbnail I also find interesting, but if you have seen the first ten seconds, you can already feel whether you find it interesting or not.

RESEARCHER: So it's a combination. You look at both the thumbnail and the video itself.

PARTICIPANT: Yes, indeed.

RESEARCHER: Any other remarks?

PARTICIPANT: No.

RESEARCHER: Alright, thank you for your time.

A.3.14   Id13

RESEARCHER: Let's see, you had the tubes on 1, the VideoStore on 2, and the RacketStore on 3, right?

PARTICIPANT: Yes.

RESEARCHER: Why?

PARTICIPANT: Because in the tubes it was easier to search. You're faster through because give it a sweep and you can see the videos coming by. Then you have the Video Store, which has a great overview. The videos are just there and you can simply look at them. As for the Record store, you need to search through them. But if you get too close with your hand to another it already switches to another. That's why I have chosen that order.

RESEARCHER: Did you need to perform too many actions in the Tube design?

PARTICIPANT: No, you rotate it a bit. You release it. You do this and then that. *Partipant shows the action off pulling the lever* You pick it up, and at the moment you pick it up you immediately press the button to add it to the playlist. You release the video and you move on to the next.

RESEARCHER: Let's see. You talked about the overview you have in the Video Store. How is the overview in the Record Store?

PARTICIPANT: You have less. You can see the image of the few videos at the front but not of those at the back. So you either need to hover over it, or you need to flip through them. But if you hold your hand slightly wrong you immediately jump to another video.

RESEARCHER: So the overview is less?

PARTICIPANT: Yes

RESEARCHER: Other pros and/or cons that we haven't discussed?

PARTICIPANT: No.

RESEARCHER: In that case, thank you for your time.

A.3.15   Id14

RESEARCHER: You had the Video Store on one, the Tubes on two and the Record Store on three, right?

PARTICIPANT: Yes.

RESEARCHER: Why?

PARTICIPANT: I just thought the Video Store was easier to use. You can see everything in one place. You have everything under each other. And Nicely indicated at the top. That's the main thing. And with the Record Store it was sometimes difficult to pick out the records I wanted. And with the Tubes, you have to turn them around first before I can see them all. With the Video Store it's all under each other. Nice and handy.

RESEARCHER: So it is correct that overview and the interaction are important?

PARTICIPANT: Yes. The tubes are also easy to use. The most difficult to use was the Record Store.

RESEARCHER: Other pros and/or cons we haven't discussed?

PARTICIPANT: The advantage was that it went pretty fast. The disadvantage was that I had to get used to it. And I think I got used to it pretty quickly. So I wonder how it is with people who don't have that. But for the rest, I don't feel sick or anything. It all works pretty intuitively. So that's a big advantage for me.

RESEARCHER: Any other remarks?

PARTICIPANT: No.

RESEARCHER: Alright, great, thank you for your time.

A.3.16 Id15

PARTICIPANT: Number one was the libraries...

RESEARCHER: The Video Store?

PARTICIPANT: Yes the video store, number two was the record store, and number three was the tubes.

RESEARCHER: Why?

PARTICIPANT: The video store is simple, the videos are all on a row that is relaxed. They are easy to get out of the closet which really helped.

The disadvantage of the Record store is that they were difficult to pick up from the container. That really took some effort.

As for the tubes, I found it annoying that you had to constantly rotate them. I found it bad that I needed to pull the lever to watch the videos.

RESEARCHER: So if my understanding is correct, the overview is the primary reason for the Video Store ranking, and for the Record Store, the interaction is difficult.

PARTICIPANT: Yes, however, I find the overview for the Record Store good.

RESEARCHER: About the tubes, is it just the additional actions you need to perform that are working against you or are the other things as well?

PARTICIPANT: No, just the additional actions. Because in terms of design, I find it the most fun. The most interesting. It is predominantly the actions. You need to make extra actions. If you click on a video you simply want to watch the video.

RESEARCHER: Did you find any difficulties with the videos starting to play to quickly?

PARTICIPANT: No, I didn't. I actually liked that.

RESEARCHER: Also with the tubes?

PARTICIPANT: I found it fine. The only thing that was difficult is that some videos had a long introduction. So if they started playing I forgot what they were about. In that case, I just scrolled them to the side and back.

RESEARCHER: Alright, thank you for your time.

A.3.17 Id16

RESEARCHER: You had the Video Store on one, the Tubes on two, and the Record Store on three. Why?

PARTICIPANT: First, I had the record store on 3. I didn't like the fact that things were close together. So you had to be very careful to put your hand in between. And then you hit the other one. I liked it the least for previewing. With the other two, it was a lot easier to preview. But the lever system was a bit of an extra step. It didn't add much, and it made it funnier, but it also took longer. It was more work compared tot the Video Store. For the Video Store, It was fun to take a look around, look closely, click, and then watch. So that was the easiest to use, and the fastest to go through. And the most overview, as you have a cabinet with options in front of you compared to a wheel that you need to rotate.

RESEARCHER: As far as I understand it, it's the overview of what's in each category important. And the interaction.

PARTICIPANT: Yes

RESEARCHER: Alright, we talked about the overview and the interaction. Are there any other pros and cons?

PARTICIPANT: What makes the tubes funnier is that you pull a lever, and the video comes floating down. However, I think that feeling will fade quickly.

RESEARCHER: Any other general remarks?

PARTICIPANT: No.

RESEARCHER: Alright, thank you for your time.

A.3.18   Id17

RESEARCHER: If I remember correctly, you had the Video Store on one, the Record Store on two and the Tubes on three. Why?

PARTICIPANT: It was mainly about how fast you could get through it and how fast you had an idea of what you had. With the VideoStore, that was the smoothest. You literally walk through the closets and you have a pretty quick overview of what you have. The only thing is that the bottom shelf is a bit more complicated. The same goes for the records store. But depending on how good the thumbnail is, it can be a bit more difficult to see the videos that are a bit further back. In that case, you have to go to the videos and grab it. And then the Tubes. You had to go through a lot of places and you had to turn it around so you couldn't see everything. It was very easy to see what all the subjects are. And then I like to teleport in front of a Tube and look through it. While the bookshelves tended to just walk through it. And then indeed see what all the subjects are, without knowing what is on the other side of the bookshelf. Because you only get there later. And with the Records, it was even more of a walking experience. Because you really only stand in front of the box and have to look at the bottom of the box for the category. Because at first, I didn't realize that it was there, but it was there. But you only really see that when you stand in front of the box. So you also go in a slightly different way to find videos that you like. First with the Tubes on subjects. And then very easily teleport. With the others, I had more of a tendency to walk and look at subjects that interested me. Or if I saw something that seemed interesting to me because of the thumbnail.

RESEARCHER: So if I understand you correctly, is it important for you to be able to see at a glance which videos are in each category? And it is more important than having an overview of the entire store. Is that correct?

PARTICIPANT: Yes, I think most of the time with social media it is. Because the themes are quite clear. What you are recommended is often in what seems interesting. And then it is the question of what is really the content that is underneath. What do you think is really interesting in terms of title or image. Being able to walk through it quickly and seeing what the subject is quickly helps to smoothly walk through it.

RESEARCHER: Any other pros and/or cons?

PARTICIPANT: No.

RESEARCHER: Any other general remarks?

PARTICIPANT: No.

RESEARCHER: In that case, thank you for your time.

A.3.19 Id18

RESEARCHER: If I'm correct, you had the Video Store on one, the tubes on two, and the record store on three, right?

PARTICIPANT: Yes

RESEARCHER: Why?

PARTICIPANT: ehm..., because I found that the record store, the images that are behind each other, you aren't able to pick one up as easily. Because they are close to each other and they keep switching. I found that the least useful to select a video. And I thought the..., how do say that? Not the tube but the other one.

RESEARCHER: The Video Store.

PARTICIPANT: That one. I found it the most clear and I also found it easy to move around. And with the tubes, it was a bit in between. Not very easy, but also not hard.

RESEARCHER: Any other pros or cons?

PARTICIPANT: No.

RESEARCHER: Alright, thanks for your time.

A.3.20 Id19

RESEARCHER: If I remember correctly, you had the Tubes on one, the Video Store on two, and the Record Store on three.

PARTICIPANT: Yes.

RESEARCHER: Okay, why?

PARTICIPANT: For the Record Store, I couldn't see everything. For the Video Store, you were able to see everything. Just like if you are scrolling in YouTube. With the tubes I liked that you were able to use your hands to rotate the videos and pull the lever.

RESEARCHER: So, if I understand correctly, it's one part overview. And the other part is the interaction. So the Tubes are more interesting then the Video Store.

PARTICIPANT: Yes. and it makes it a bit more exciting. Or a bit more fun to just go through it. As you don't see everything at once.

RESEARCHER: Are there any other advantages or disadvantages that we haven't discussed yet?

PARTICIPANT: No, I think that's it.

RESEARCHER: Any other remarks?

PARTICIPANT: No.

RESEARCHER: Alright, thank you for your time.

A.4 Experiment Observations

As the study was performed in person, it allowed for the ability to make qualitative observations. In this section, the most notable observations are grouped together with the number of times they occurred.

Observation	Occurences
Participant Looks at the equirectangular thumbnail image to make a decision	6
Participant Looks around a lot/playing with VR	2
Participant missed the title of the videos	1

Table 25: Experiment observations

B Study Setup

B.1 Questionnaire

This section contains all the used questionnaires.

B.1.1 Demographic information

What is your Gender?	
Male	o
Female	o
Other/Prefer not to answer	o

What is your age?	
18-24 years old	o
25-30 years old	o
31-40 years old	o
41-50 years old	o
51-60 years old	o
61-70 years old	o
70 years or older	o

How often do you use a VR headset	
Never	o
Rarely	o
Monthly	o
Weekly	o
Daily	o

How often do you access video libraries such as YouTube, Netflix, and Disney+?	
Never	o
Rarely	o
Monthly	o
Weekly	o
Daily	o

How often do you watch 360° videos on the following platforms?	Never	Rarely	Monthly	Weekly	Daily
Laptop or Desktop	o	o	o	o	o
Mobile phone	o	o	o	o	o
Tablet	o	o	o	o	o
VR headset	o	o	o	o	o

If you watch 360° videos with a VR headset, which of the following applications do you use?	
Youtube VR	☐
Viveport Video	☐
Oculus Video	☐
Other	☐
None	☐

B.1.2   UEQ-S

obstructive	o o o o o o o	supportive
complicated	o o o o o o o	easy
inefficient	o o o o o o o	efficient
confusing	o o o o o o o	clear
boring	o o o o o o o	exciting
not interesting	o o o o o o o	interesting
conventional	o o o o o o o	inventive
usual	o o o o o o o	leading edge

B.1.3 VIRTUAL REALITY SICKNESS QUESTIONNAIRE

General discomfort	None	Slight	Moderate	Sever
Headache	None	Slight	Moderate	Sever
Fatigue	None	Slight	Moderate	Sever
Eye strain	None	Slight	Moderate	Sever
Difficulty focusing	None	Slight	Moderate	Sever
Fullness of the Head	None	Slight	Moderate	Sever
Blurred vision	None	Slight	Moderate	Sever
Dizziness with eyes closed	None	Slight	Moderate	Sever
Vertigo	None	Slight	Moderate	Sever

B.1.4 Performance

How satisfied are you with the playlist you created?		
Not Satisfied	o o o o o o o	Satisfied
Were you able to inspect all the videos you wanted to inspect?		
I wasn't able to inspect any videos	o o o o o o o	I could inspect all videos I wanted

B.1.5 Ranking

As "Abstract" could be subjective, we opted for a more descriptive term (Tubes) to indicate the abstract store design in the ranking questionnaire.

Please rank the interfaces from best to worst based on your experience.	1st	2nd	3rd
Video Store	☐	☐	☐
Record Store	☐	☐	☐
Tubes	☐	☐	☐

B.1.6 Final interview

In the final interview, the following questions are asked:

- Why did you decide on this ranking?

- Could you list any pros or cons for the designs?

- Do you have any other remarks?

B.2 Process
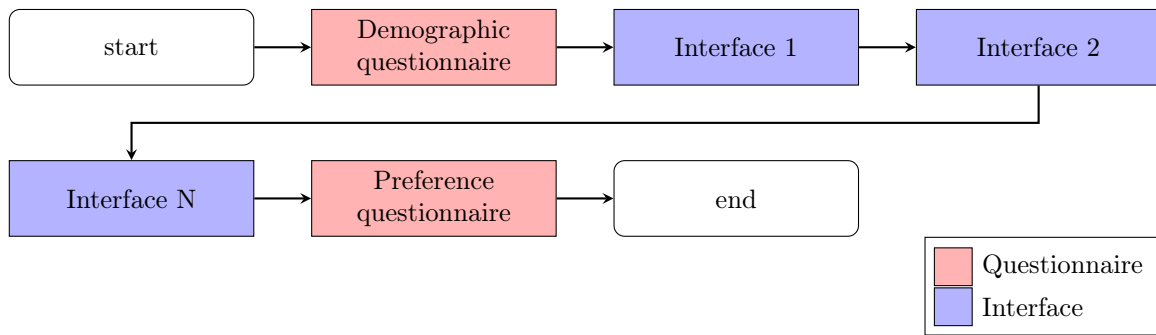
Figure 33: Study process
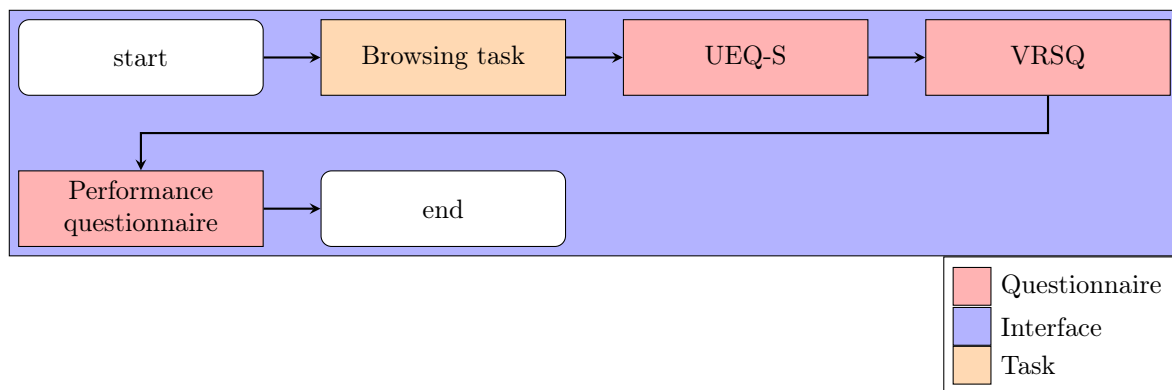
Figure 34: Process of a single interface

Figure 33 depicts the process of a single participant in this study. At the start, the participant will be given general remarks about the study. The demographic questionnaire will then be used to gather general information about the participant, and the participant will be asked to sign an informed consent form. Finally, before starting the study, the participant will be told that they can stop at any given moment without needing to explain. Once this is finished, the player will be loaded into a short introduction scene where it is again repeated that the participant can stop at any given time. Once the participant clicks the start button, they will be loaded into a tutorial scene. In this tutorial scene, the controls are explained, and one of each design is placed for the participant to interact with. This is done to allow the user to get accustomed to the controls and to the different interaction types. Once the user indicates that they are ready to start, they will be loaded into the first interface. The process per interface is shown in Figure 34. A screen is shown with the task description. For each design, the task is the same namely: "You have 5 minutes to create a playlist of 10 videos. Once you are finished or the 5 minutes are over, you will be loaded into a questionnaire." Once the participant is ready, they press the start button to start the timer. When the task is finished, the UEQ-S and VRSQ will be administered to measure the user experience and cybersickness, respectively. Finally, the Performance questionnaire will be administered. This process is repeated for each available interface due to the within-subject design of this study. When the participant finishes the final interface process, they will be prompted with a small ending questionnaire in which they are asked to rank the interfaces based on their preference.

B.2.1 Design Order

Table 26 shows the order in which the participants walked through the study. The order followed a balanced Latin square and was generated with the balanced Latin square generator by Damien Masson[37]. Due to an error on the side of the researcher, the order starts does not start with A, B, and C but rather with A, C, and B. Where A denotes the Video Store, B the Abstract Store, and C the Record Store

ID 1	Video Store	Record Store	Abstract Store
ID 2	Record Store	Video Store	Abstract Store
ID 3	Record Store	Abstract Store	Video Store
ID 4	Abstract Store	Record Store	Video Store
ID 5	Abstract Store	Video Store	Record Store
ID 6	Video Store	Abstract Store	Record Store
ID 7	Video Store	Record Store	Abstract Store
ID 8	Record Store	Video Store	Abstract Store
ID 9	Record Store	Abstract Store	Video Store
ID 10	Abstract Store	Record Store	Video Store
ID 11	Abstract Store	Video Store	Record Store
ID 12	Video Store	Abstract Store	Record Store
ID 13	Video Store	Record Store	Abstract Store
ID 14	Record Store	Video Store	Abstract Store
ID 15	Record Store	Abstract Store	Video Store
ID 16	Abstract Store	Record Store	Video Store
ID 17	Abstract Store	Video Store	Record Store
ID 18	Video Store	Abstract Store	Record Store
ID 19	Video Store	Record Store	Abstract Store

Table 26: Order of the designs for each participant

B.3   Implementation

This section contains screenshots of the developed implementation. Note that in some images, there is white text in the left-hand upper corner. This text was **<u>not</u>** visible to the participants wearing the VR HMD and does not represent the controls for the participant. These controls are only available when there is no VR HMD connected to the Unity Editor.

B.3.1   Start
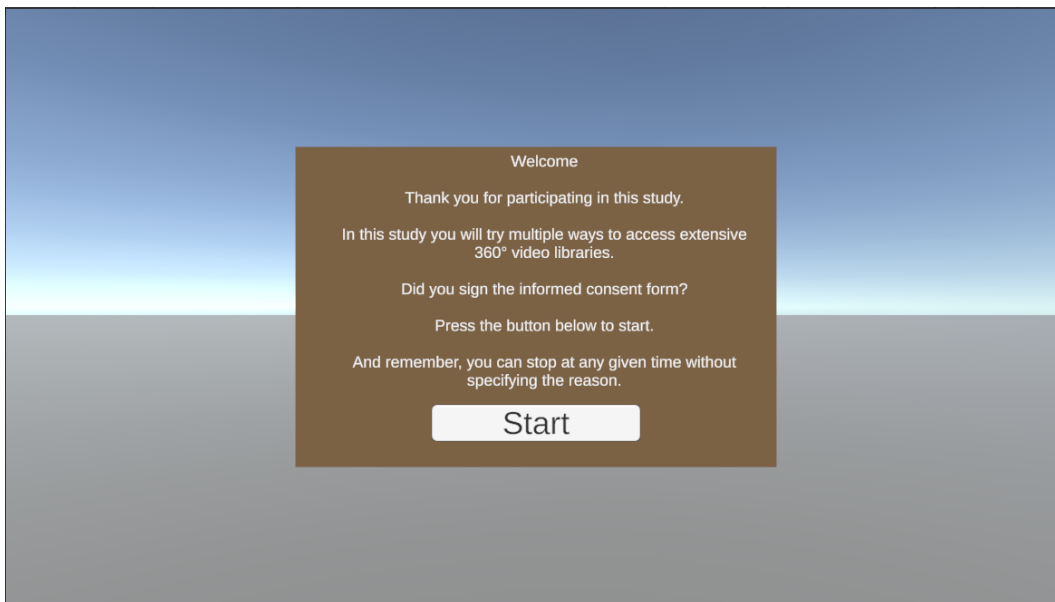
Figure 35: Screenshot of the start screen

B.3.2 Demographic Questionnaire
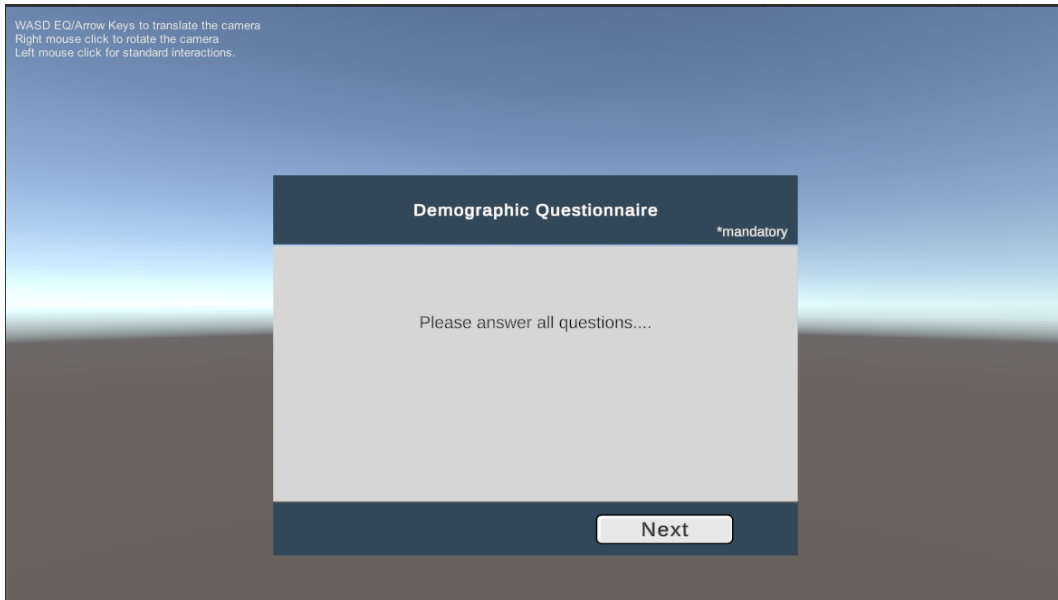
(a)
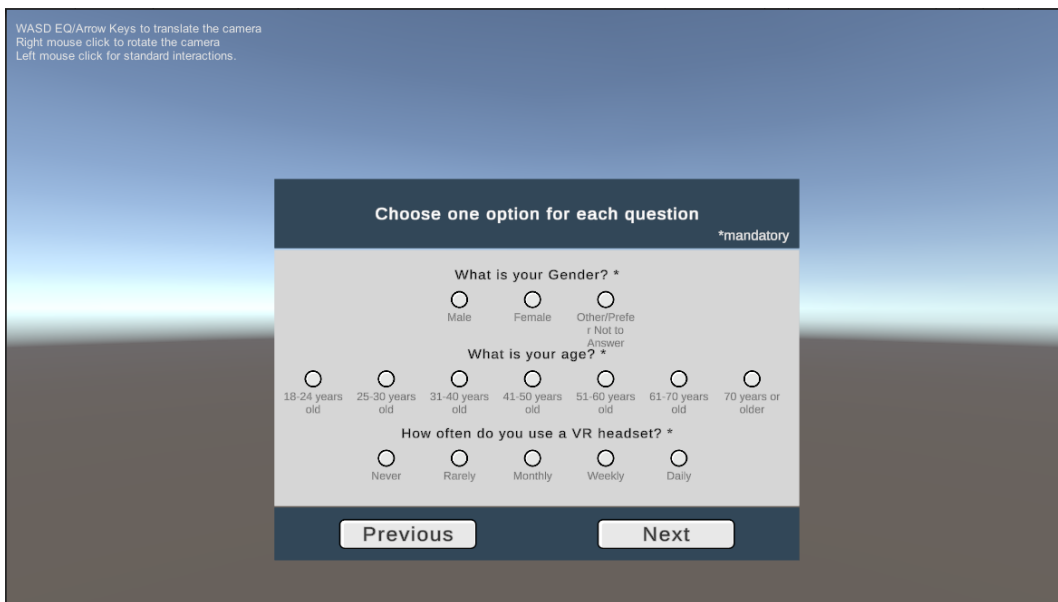
(b)

Figure 36: Screenshots of the Demographic Questionnaire
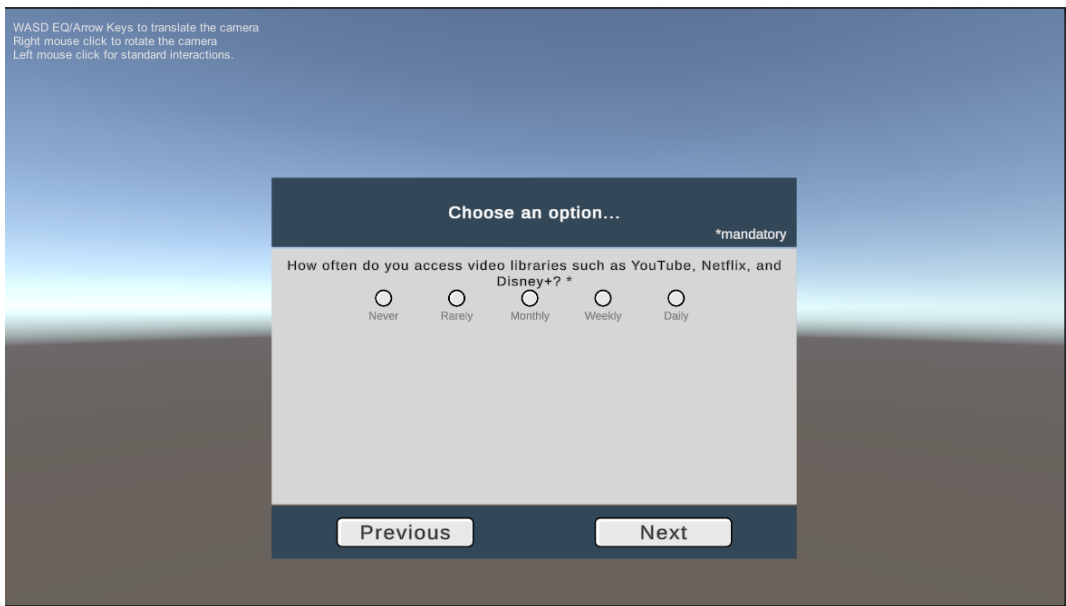
(c)
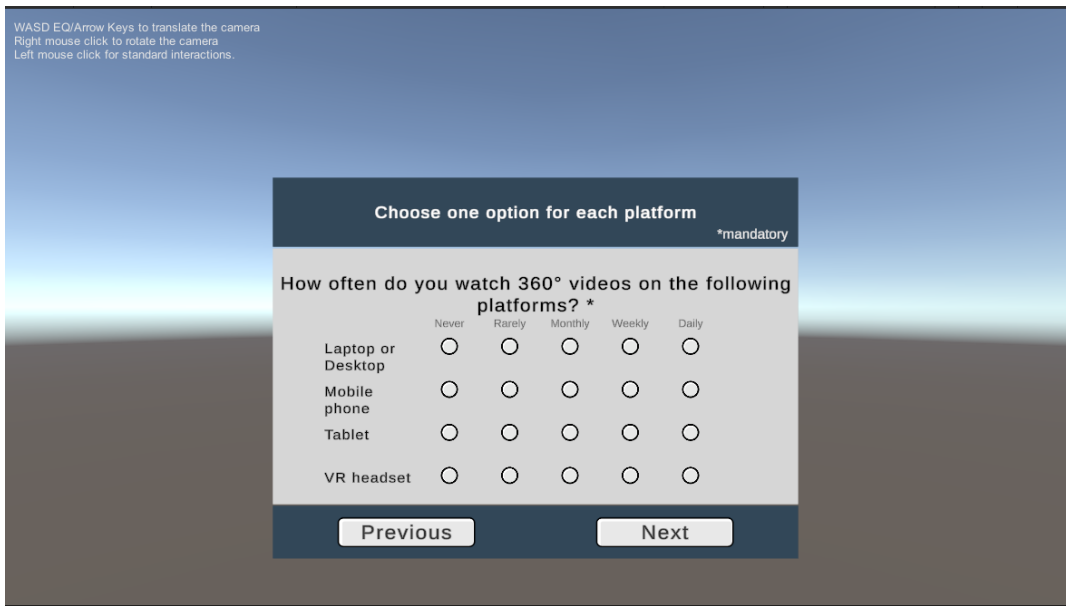
(d)

Figure 36: Screenshots of the Demographic Questionnaire
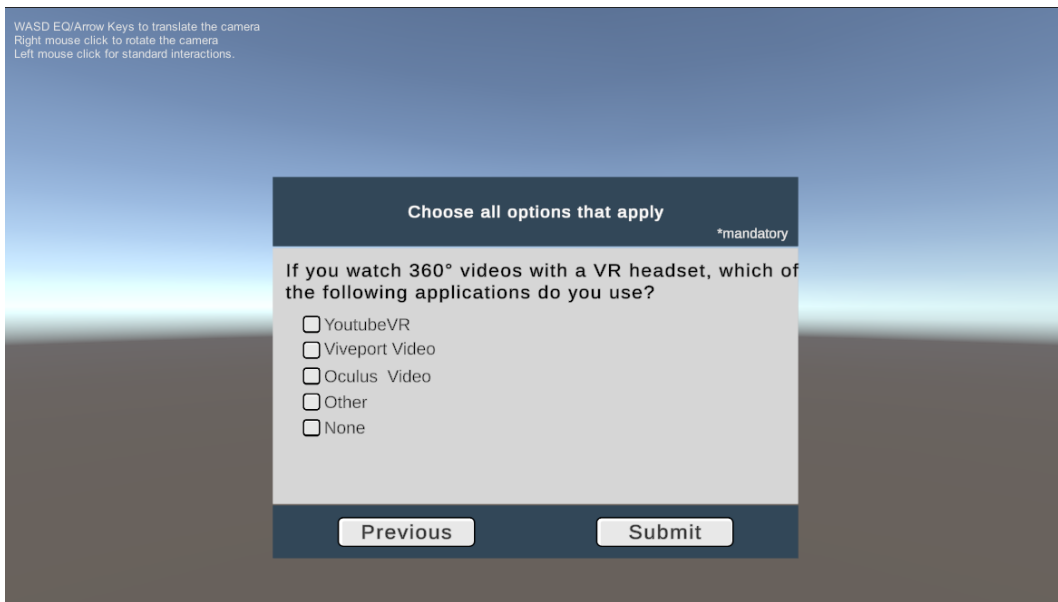
(e)

(f)

Figure 36: Screenshots of the Demographic Questionnaire

B.3.3 Tutorial

In the tutorial, all the controls are added as text. Note that initially, the researcher walks the participants through the controls verbally. The text is merely meant as a reminder whilst the participant is getting accustomed to the controls.
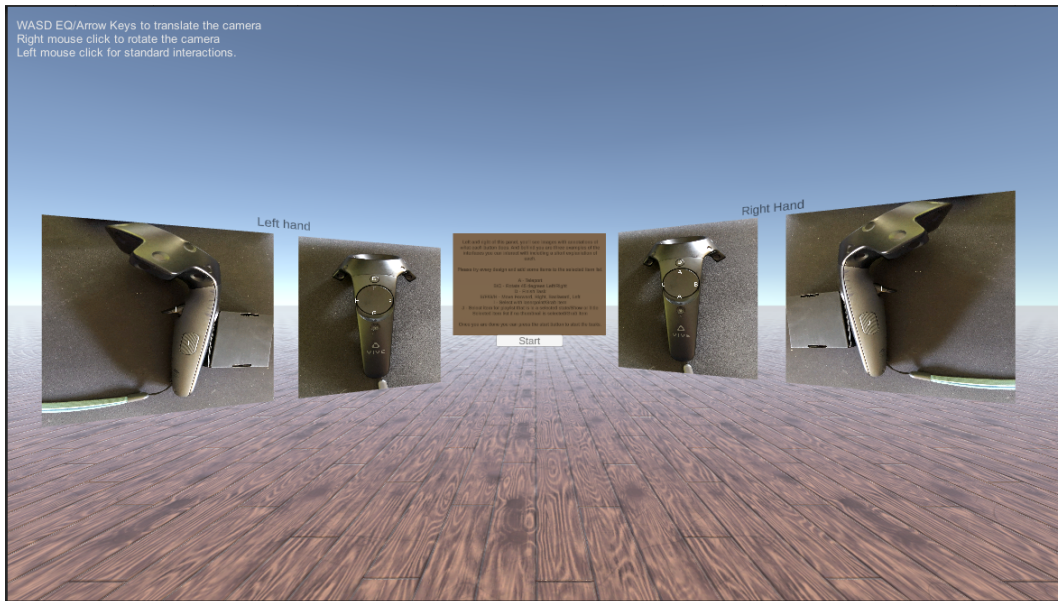
(a)
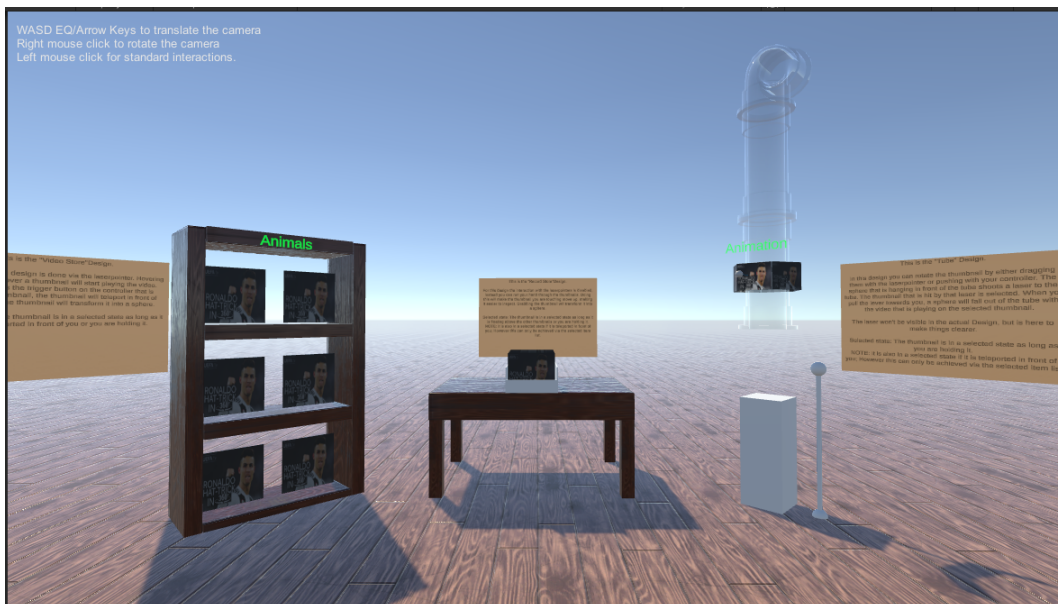
(b)

Figure 37: Screenshots of the Tutorial

B.3.4 Video Store

(a)

(b)

Figure 38: Screenshots of the Video Store design

(c)

(d)

Figure 38: Screenshots of the Video Store design

(e)

(f)

Figure 38: Screenshots of the Video Store design

B.3.5 Record Store

(a)

(b)

Figure 39: Screenshots of the Record Store design

WASD EQ/Arrow Keys to translate the camera
Right mouse click to rotate the camera
Left mouse click for standard interactions.

(c)

WASD EQ/Arrow Keys to translate the camera
Right mouse click to rotate the camera
Left mouse click for standard interactions.

Primorsky Safari Park, Russia

Sygic Travel

Kitties in VR

Animals

360

Animals 2

Animation
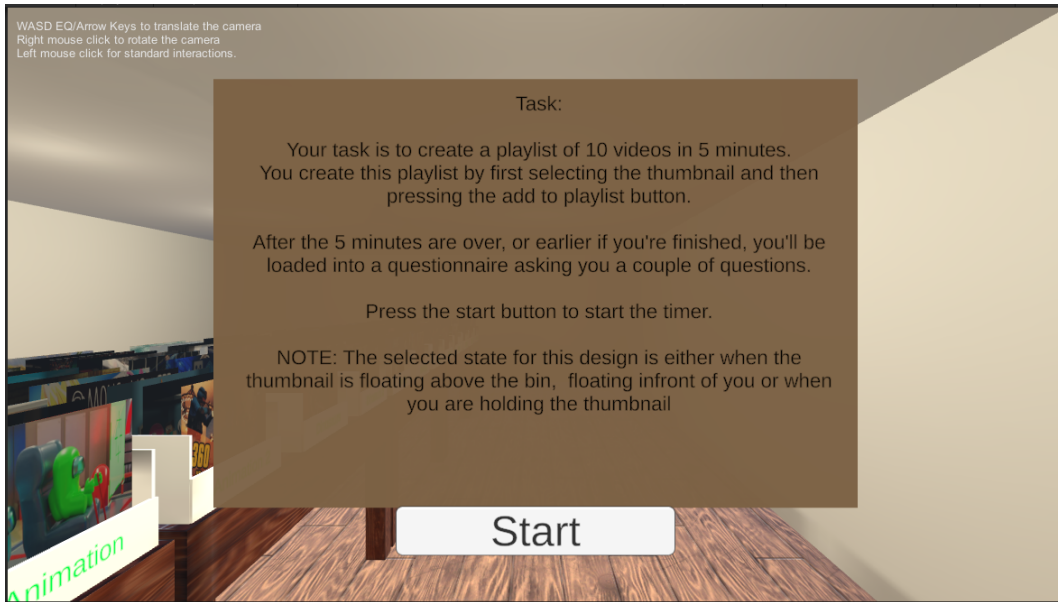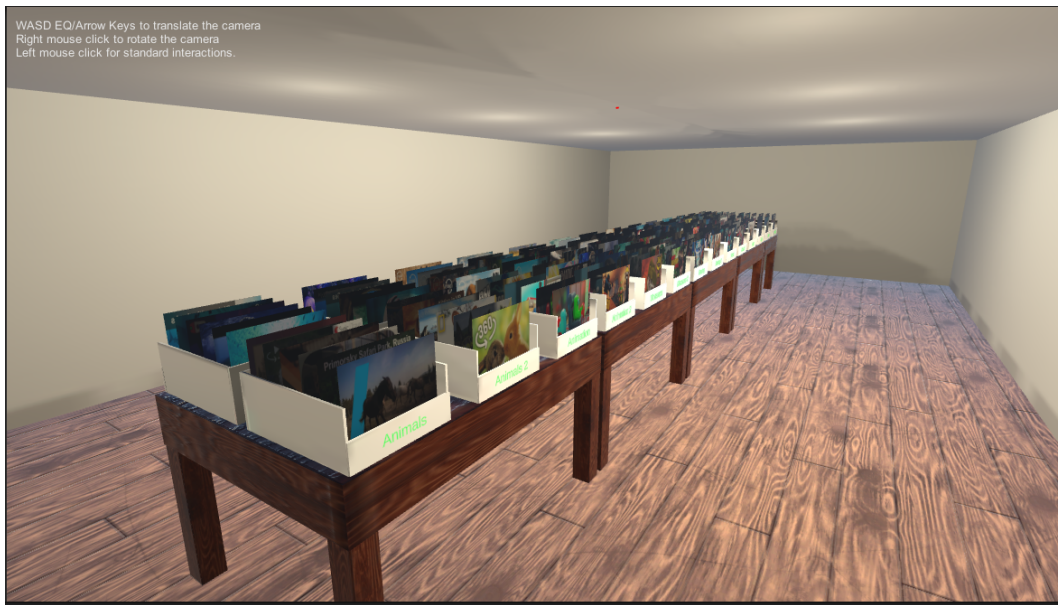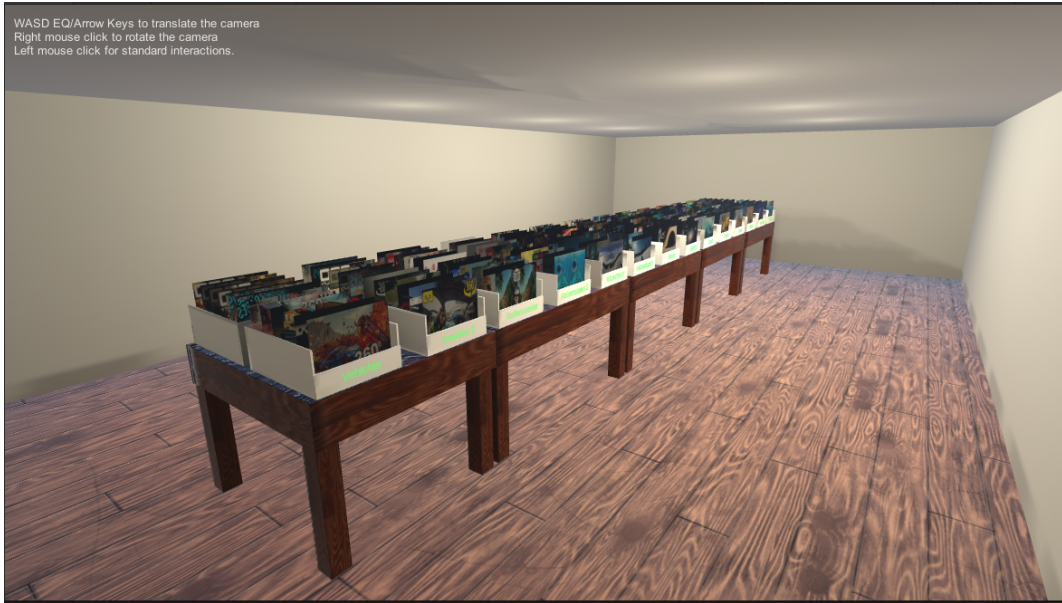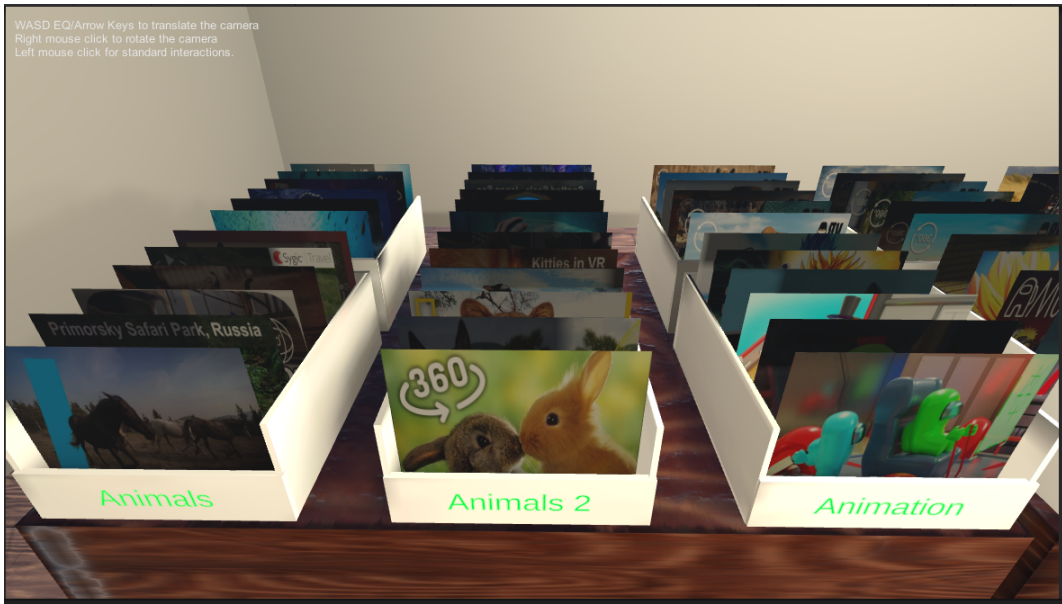
(d)

Figure 39: Screenshots of the Record Store design
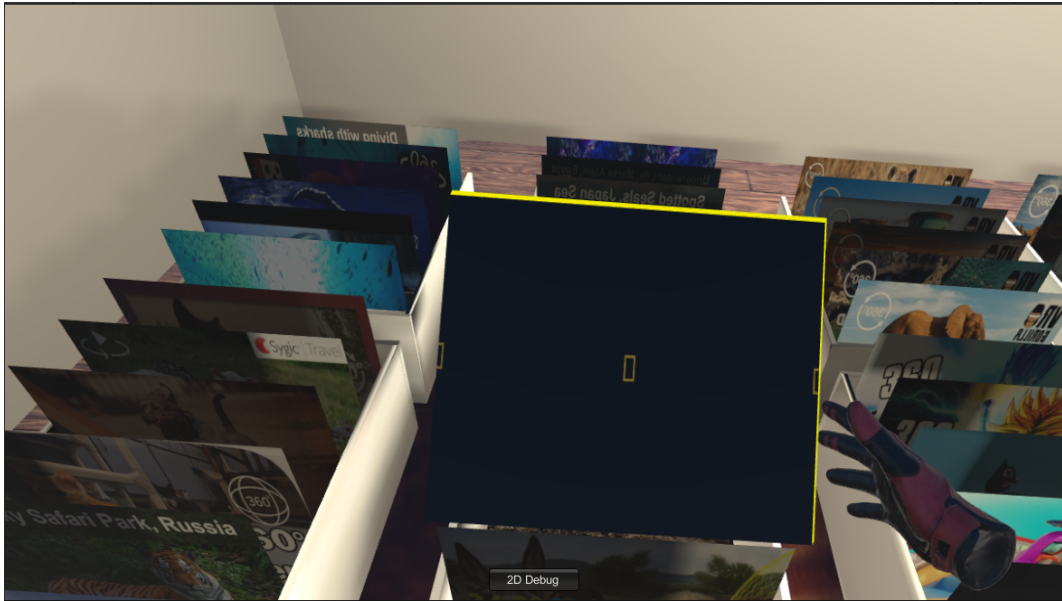
(e)

(f)

Figure 39: Screenshots of the Record Store design

B.3.6   Abstract Store
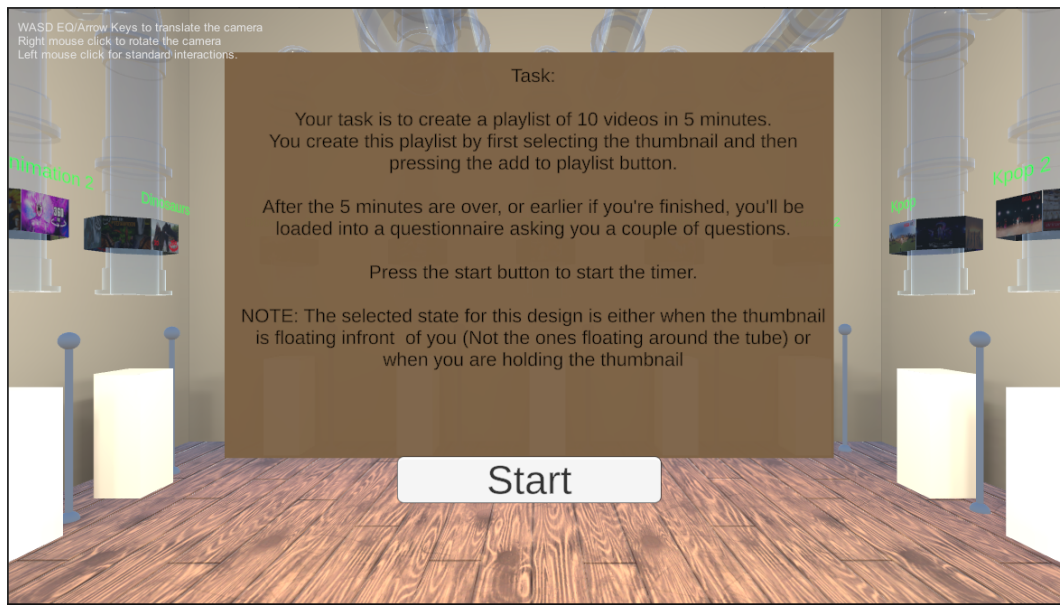
(a)

(b)

Figure 40: Screenshots of the Abstract Store design
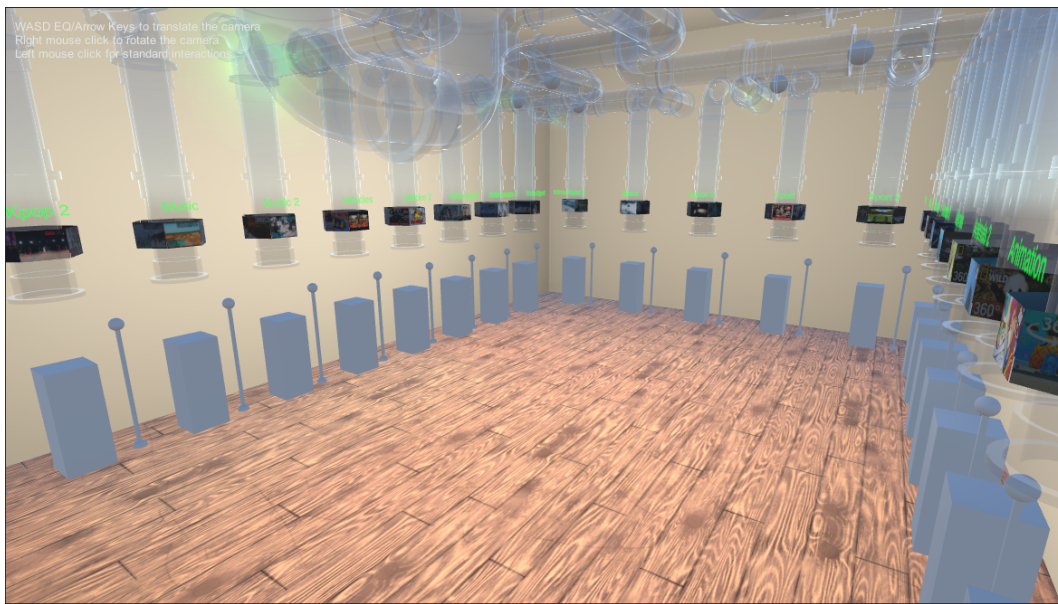
(c)
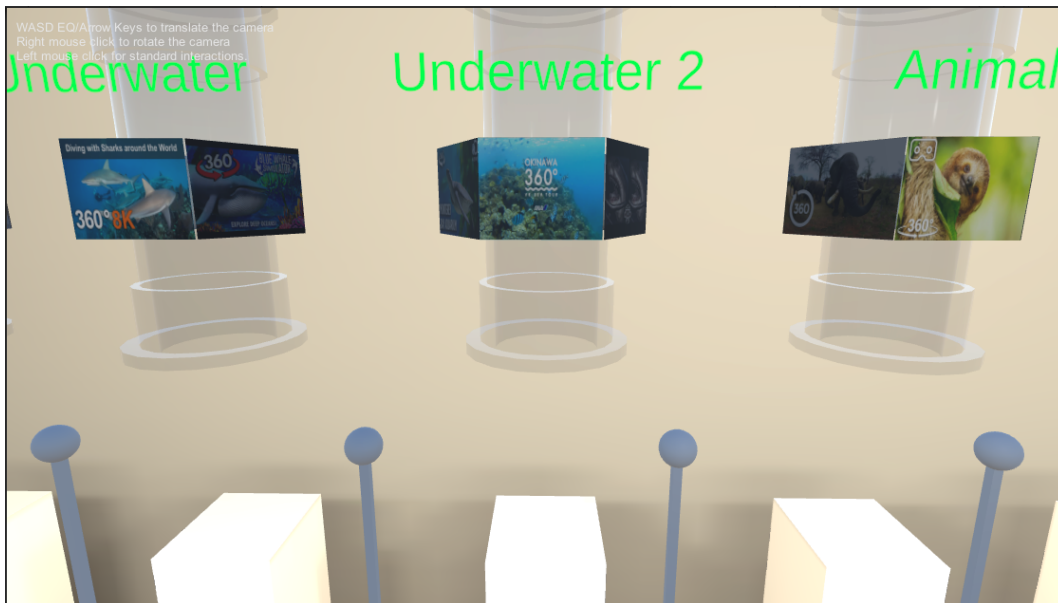
(d)

Figure 40: Screenshots of the Abstract Store design
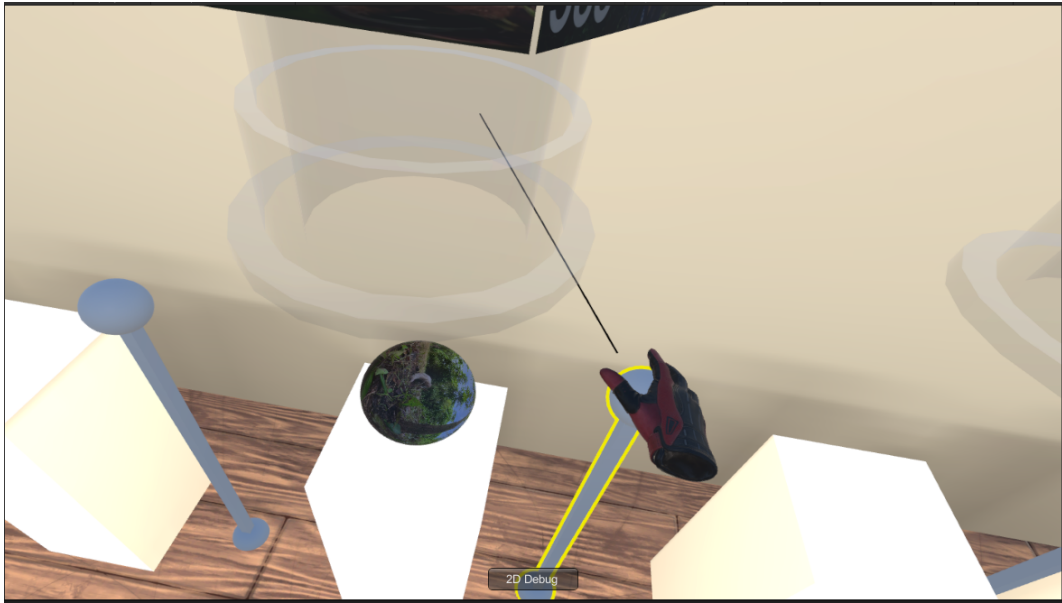
(e)

(f)

Figure 40: Screenshots of the Abstract Store design
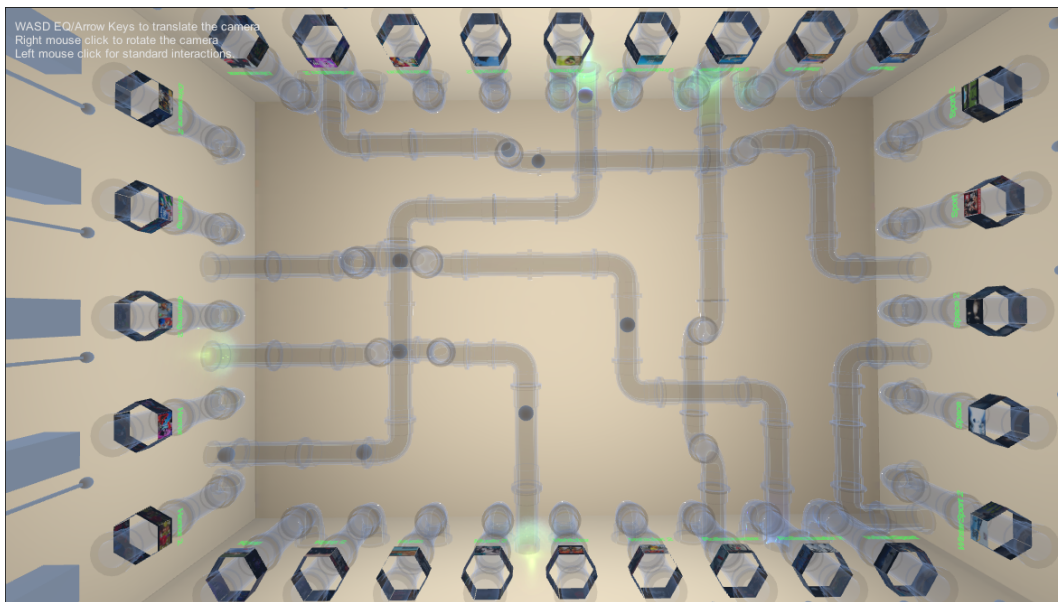
(g)
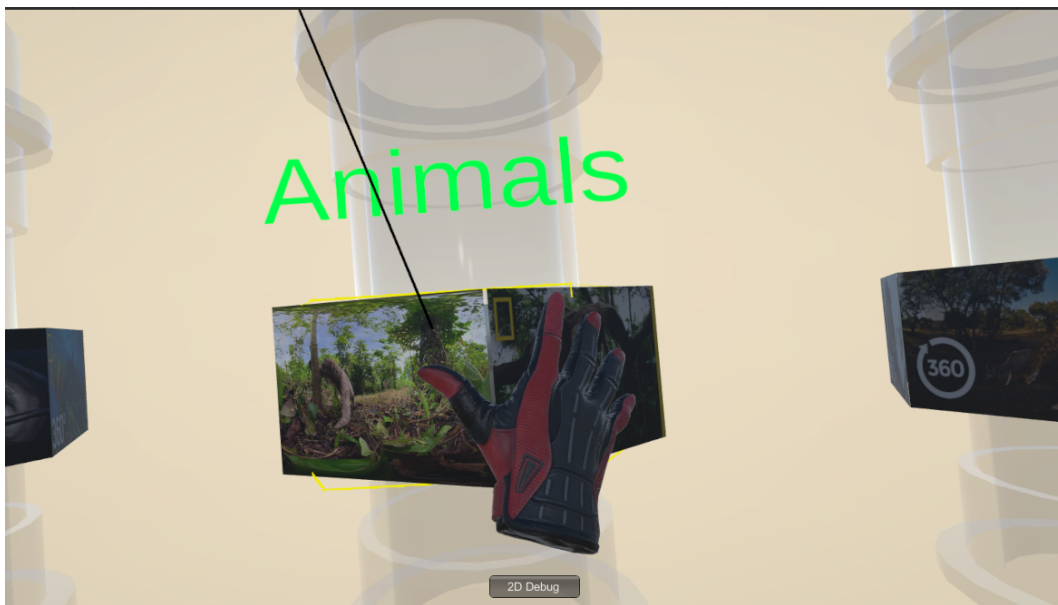
(h)

Figure 40: Screenshots of the Abstract Store design

(i)

(j)

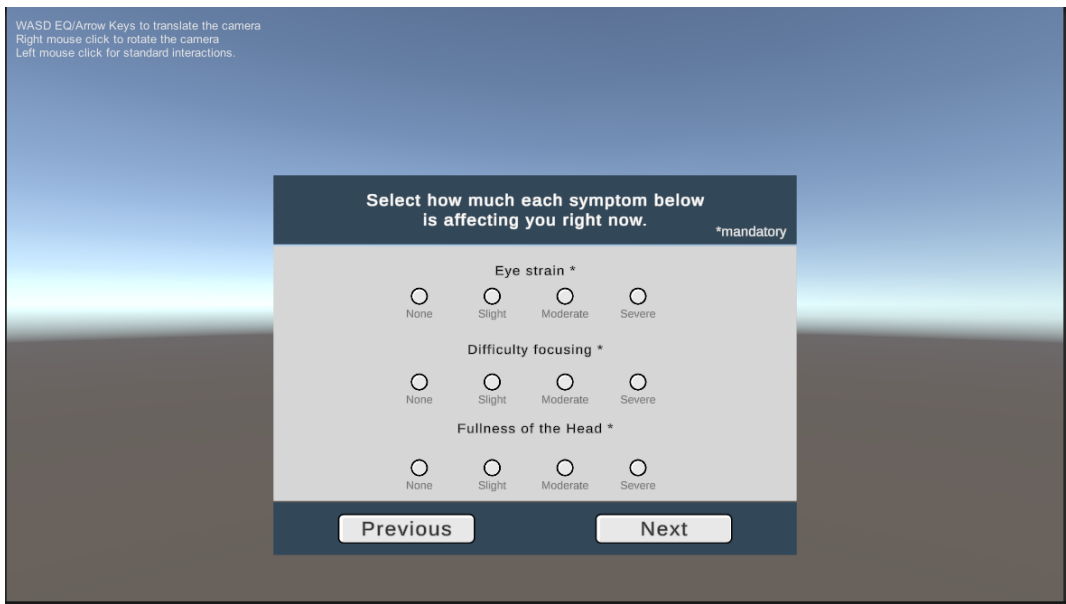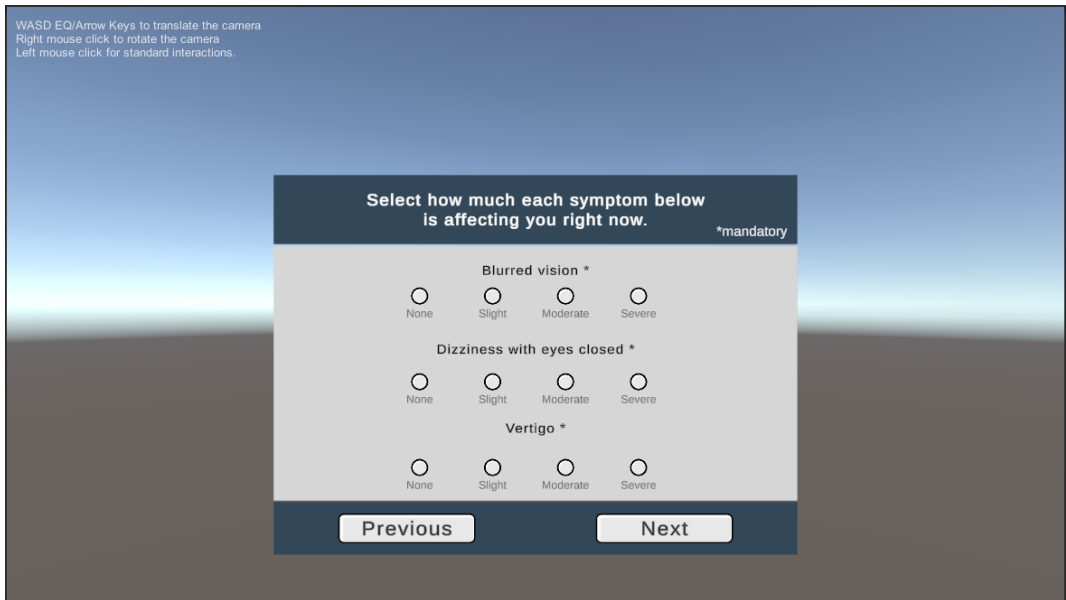Figure 40: Screenshots of the Abstract Store design
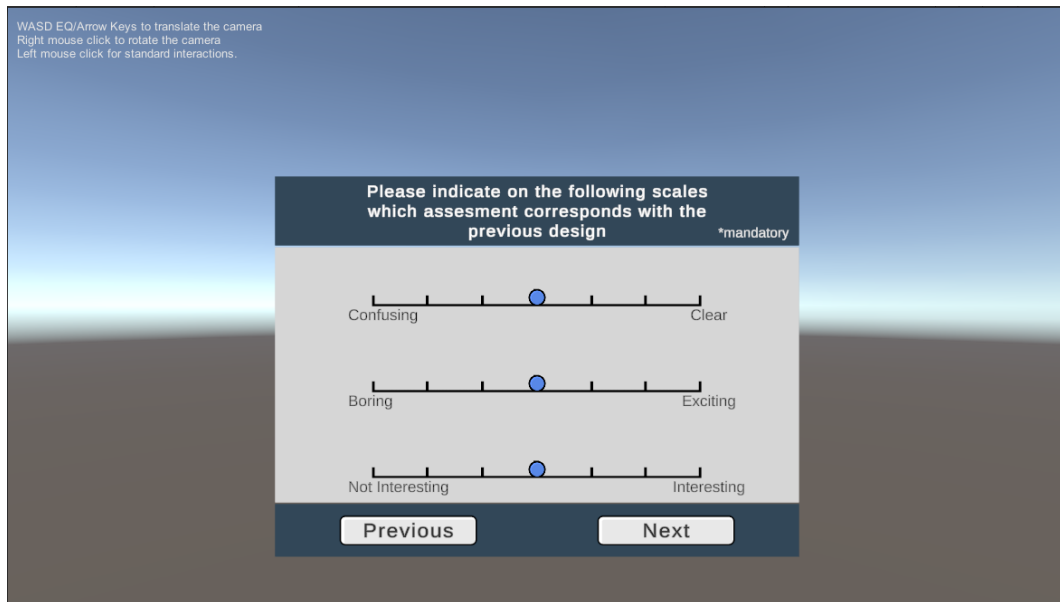
B.3.7 VRSQ
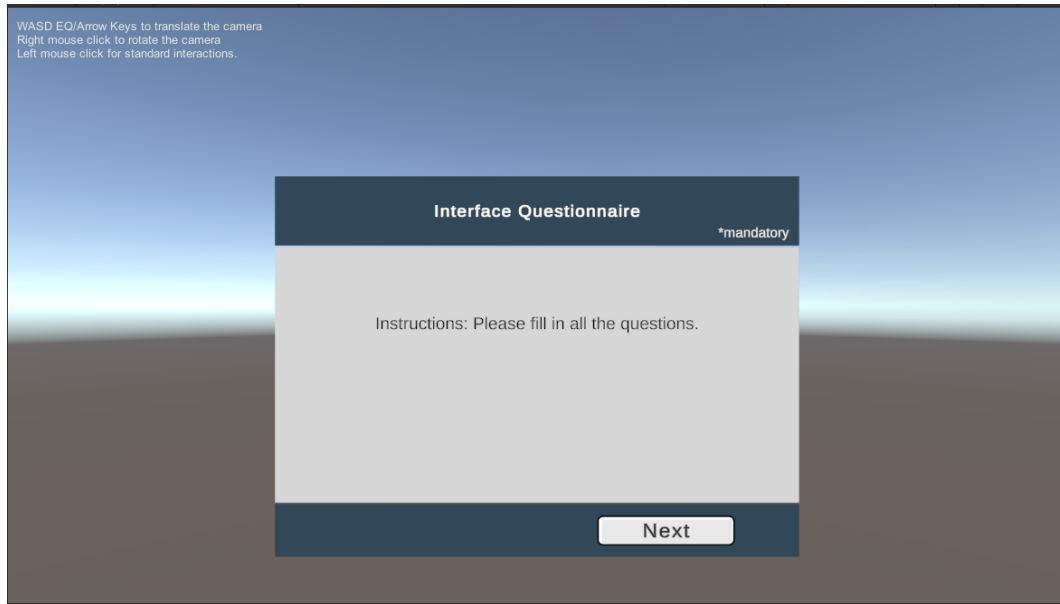
(a)
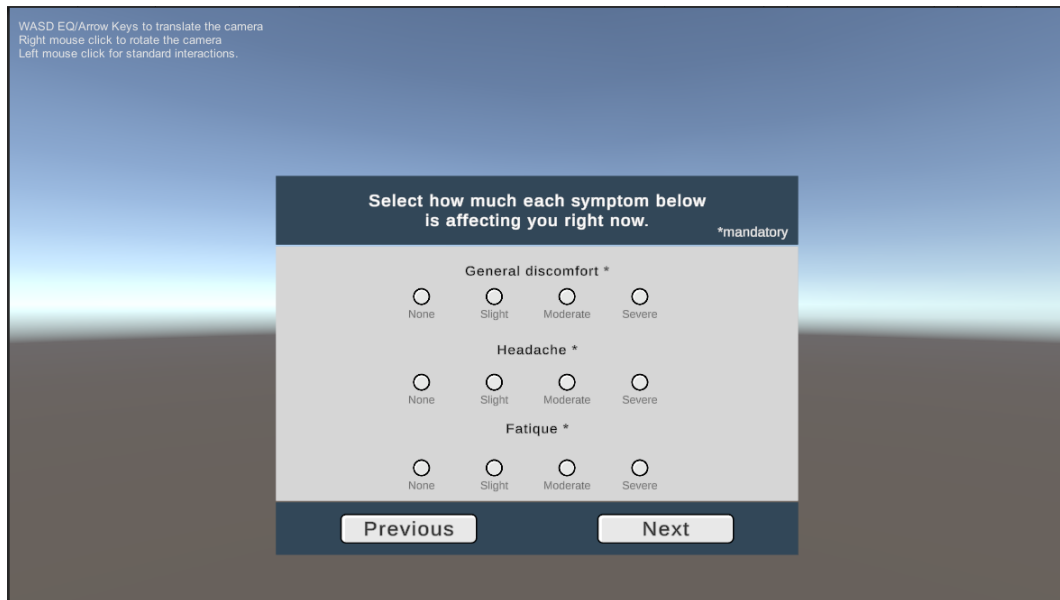
(b)

Figure 41: Screenshots of the VRSQ

(c)

(d)

Figure 41: Screenshots of the VRSQ

B.3.8 UEQ-S

(a)

(b)

Figure 42: Screenshots of the UEQ-S
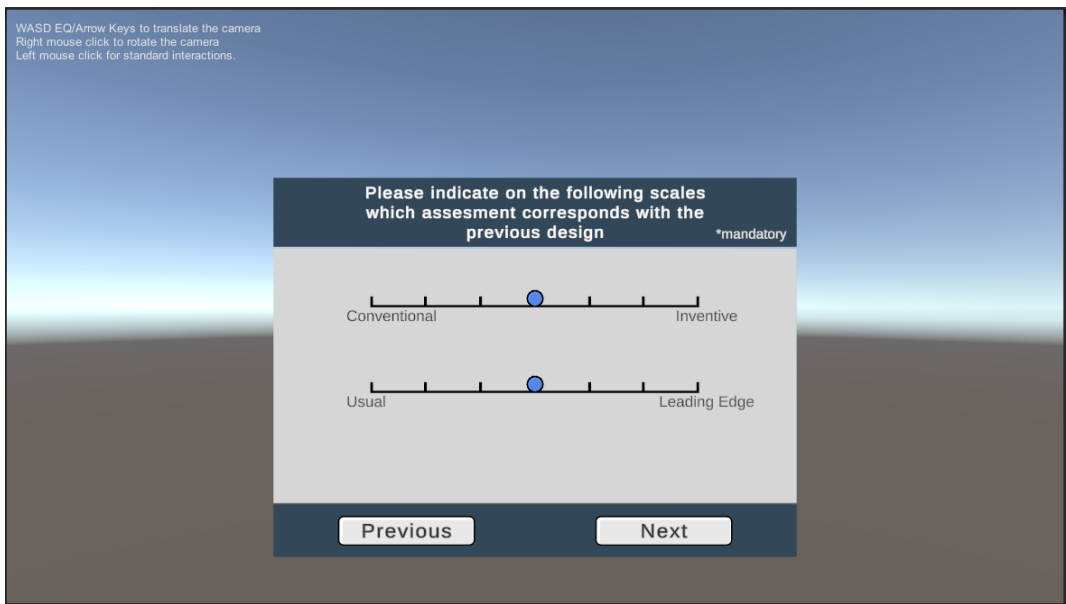
(c)

Figure 42: Screenshots of the UEQ-S

B.3.9 Performance

(a)

Figure 43: Screenshots of the Performance Questionnaire

B.3.10   Ranking

(a)

(b)

Figure 44: Screenshots of the Ranking Questionnaire

B.3.11   End

WASD EQ/Arrow Keys to translate the camera
Right mouse click to rotate the camera
Left mouse click for standard interactions.

You have completed the questionnaire

*mandatory

Thank you very much for taking part in the experiment! You
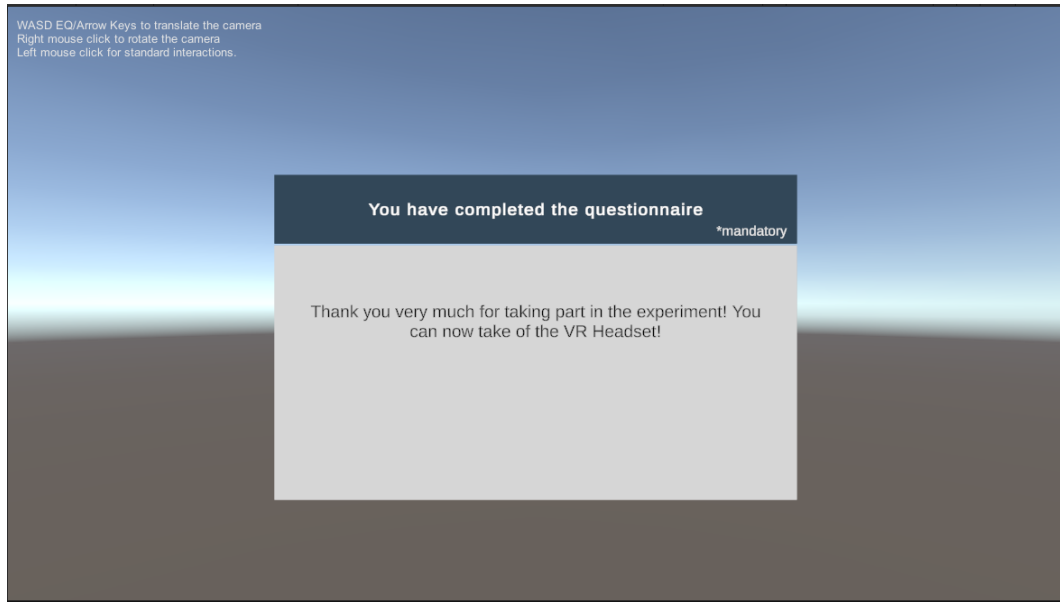can now take of the VR Headset!

Figure 45: Screenshot of the end screen
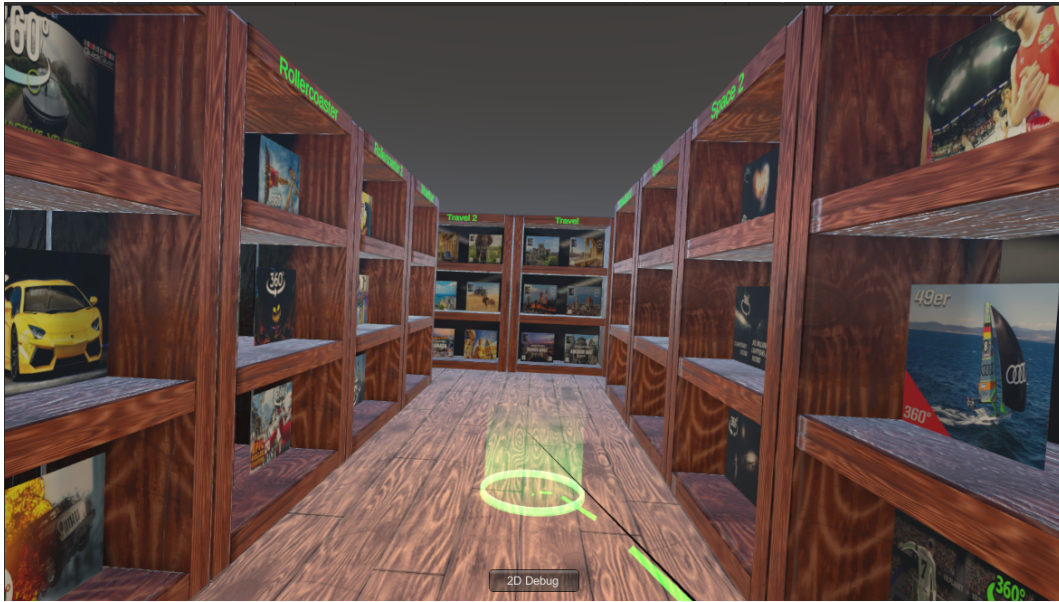
B.3.12 Teleport

Figure 46: Screenshot of teleportation

C 360° video Library

C.1 Categories

The used videos are split in the following categorie.

- Animals
- Animation
- Dinosaurs
- Gaming
- Horror
- Kpop
- Music
- RoadVehicles
- RollerCoaster
- Snow
- Space
- Sport
- Travel
- Underwater

Each category contains twelve videos per design for a total of 504 videos.

C.2 Used Videos

This section contains all the URLs of the used videos. Tables 27, 28, and 29 show the links for respectively the Video Store, Record Store, and Abstract Store designs. Table 30 contains the link of the video that was used in the tutorial.

These videos were downloaded via youtube-dl [4]. The following command was used.

```
youtube-dl.exe --write-thumbnail --no-overwrites -r 1M -f bestvideo[height<=1080]
--batch-file {fileLocation} --no-playlist
```

This command downloads the best available video with a quality of at most 1080p for each link that is contained in the batch file at a rate of at most 1MB. The –no-playlist command prevents it from downloading a playlist if that is contained in the link. To download the thumbnails at the same time, the –write-thumbnail option was added. As YouTube could sometimes rate limit the download or even deny the download, the –no-overwrite modifier was added. With this, we can simply rerun the command, an already downloaded files will be skipped.

The links themselves were selected via search queries with the filter option for 360° videos. If the video were contained inside a playlist, the playlist would be inspected to see if there were other suitable videos and these were added to the batch file.

Some of the videos were stored in YouTube's own cubemap format. These need to be converted to the necessary equirectangular projection format. To do this, a script was written that first checked the resolution of the video before converting it to a format we could use. This script uses FFmpeg [1] and an example of the result of the script is as follows.

```
ffmpeg -n -t 60 -i {inputFile} -vf v360=c3x2:e:cubic:in_forder=lfrdbu
:in_frot=000313,scale=1920:1080,setsar=1:1 -c:v libx264 -preset faster -crf 21 -c:a copy
-movflags +faststart {outputFile}
```

FFmpeg was also used to transform the thumbnail images in case they were not already in a JPG format. This was done with the following command.

```
ffmpeg -n -i {inputFile} {outputFile}
```

Where outputfile has the JPG extensions

C.2.1 Video Store

URL	Categorie
https://www.youtube.com/watch?v=5qmmms4VP2k	Animals
https://www.youtube.com/watch?v=VRjpO5GJAVc	Animals
https://www.youtube.com/watch?v=xal78egELos	Animals
https://www.youtube.com/watch?v=Q4VNF0BixbQ	Animals
https://www.youtube.com/watch?v=ZO6kHlFa28A	Animals
https://www.youtube.com/watch?v=cz6kHprEDjc	Animals
https://www.youtube.com/watch?v=xal78egELos	Animals
https://www.youtube.com/watch?v=FfB-blPpXBc	Animals
https://www.youtube.com/watch?v=GdP1NnbtkAc	Animals
https://www.youtube.com/watch?v=caooJknsZGs	Animals
https://www.youtube.com/watch?v=7IWp875pCxQ	Animals
https://www.youtube.com/watch?v=el2LP1g6Zrk	Animals
https://www.youtube.com/watch?v=NBIGi6iTMB8	Animations
https://www.youtube.com/watch?v=NjJ6mL$_m$6G4	Animations
https://www.youtube.com/watch?v=6Oh3jMVXhC0	Animations
https://www.youtube.com/watch?v=r2URKFqtL50	Animations
https://www.youtube.com/watch?v=jxXULGA5XCA	Animations
https://www.youtube.com/watch?v=MyPfXIT$_Y$eY	Animations
https://www.youtube.com/watch?v=GkZ9bhxjpao	Animations
https://www.youtube.com/watch?v=QOaoRDqJOds	Animations

URL	Category
https://www.youtube.com/watch?v=jBfuyoHrCzw	Animations
https://www.youtube.com/watch?v=$_t8VMrOwIU4$	Animations
https://www.youtube.com/watch?v=Cn-1ddN38ao	Animations
https://www.youtube.com/watch?v=cjPa6LYTDh0	Animations
https://www.youtube.com/watch?v=93nxeejhPkU	Dinosaurs
https://www.youtube.com/watch?v=DkzoFU4jFHg	Dinosaurs
https://www.youtube.com/watch?v=zwQ9jeK2CFI	Dinosaurs
https://www.youtube.com/watch?v=wXVwTxX9skc	Dinosaurs
https://www.youtube.com/watch?v=up6nEkhX7P4	Dinosaurs
https://www.youtube.com/watch?v=wNeARwbC-7s	Dinosaurs
https://www.youtube.com/watch?v=CDHwXHpko9o	Dinosaurs
https://www.youtube.com/watch?v=k87ETyeNAVM	Dinosaurs
https://www.youtube.com/watch?v=I-CFWNtYI-I	Dinosaurs
https://www.youtube.com/watch?v=mPJdpoZlPos	Dinosaurs
https://www.youtube.com/watch?v=YeRoKysXp6Q	Dinosaurs
https://www.youtube.com/watch?v=P1kFSGsw0Ds	Dinosaurs
https://www.youtube.com/watch?v=9qUN4a1yqMY	Gaming
https://www.youtube.com/watch?v=$-_eMuXOMvh8$	Gaming
https://www.youtube.com/watch?v=g7ox5x0BoaY	Gaming
https://www.youtube.com/watch?v=6evoEiABAgQ	Gaming
https://www.youtube.com/watch?v=wWMRQnYdJ4I	Gaming
https://www.youtube.com/watch?v=uXaxJVgEH8I	Gaming
https://www.youtube.com/watch?v=rbdjDObMJiQ	Gaming
https://www.youtube.com/watch?v=$DgGi_YDv4c8$	Gaming
https://www.youtube.com/watch?v=EnMh9OqDi2M	Gaming
https://www.youtube.com/watch?v=pCmHmTvNiiE	Gaming
https://www.youtube.com/watch?v=v9WzDFe2QKY	Gaming
https://www.youtube.com/watch?v=$_c2JQ1Dj1UU$	Gaming
https://www.youtube.com/watch?v=4GLjNpM0m7s	Horror
https://www.youtube.com/watch?v=gKozVfSomN4	Horror
https://www.youtube.com/watch?v=2HRaW6LRXXA	Horror
https://www.youtube.com/watch?v=vEbVHN4GsTg	Horror
https://www.youtube.com/watch?v=6yySMPplXZI	Horror
https://www.youtube.com/watch?v=ESo7rfIcHTE	Horror
https://www.youtube.com/watch?v=JxdEguW8ZoY	Horror
https://www.youtube.com/watch?v=eIY6pgY-Xvw	Horror
https://www.youtube.com/watch?v=Yd7xXqDyv08	Horror
https://www.youtube.com/watch?v=$y5CYOG_xusc$	Horror
https://www.youtube.com/watch?v=$DxeUn_jbEQY$	Horror
https://www.youtube.com/watch?v=OcMx8P3YI8Y	Horror
https://www.youtube.com/watch?v=$Hg3Nd_K5pUY$	Kpop
https://www.youtube.com/watch?v=$jHH0_5gU8no$	Kpop
https://www.youtube.com/watch?v=Ywj8wnV2B1U	Kpop
https://www.youtube.com/watch?v=ltTuxi4U8zc	Kpop
https://www.youtube.com/watch?v=RuW7kzh3TH0	Kpop
https://www.youtube.com/watch?v=$WPKd5jkPx_c$	Kpop
https://www.youtube.com/watch?v=$93juF-E_B3g$	Kpop
https://www.youtube.com/watch?v=-iFgSVcKB-Q	Kpop
https://www.youtube.com/watch?v=0rDz0x1mCb4	Kpop
https://www.youtube.com/watch?v=k5q6UuQTTMQ	Kpop
https://www.youtube.com/watch?v=1wvAzW3aN2U	Kpop
https://www.youtube.com/watch?v=$e1n38T_OZek$	Kpop
https://www.youtube.com/watch?v=$B_AXbpDyVUQ$	Music
https://www.youtube.com/watch?v=DMH4ZLJ8BW0	Music
https://www.youtube.com/watch?v=6LgeX7d-ZiI	Music
https://www.youtube.com/watch?v=RgQQAEKrMsY	Music

URL	Category
https://www.youtube.com/watch?v=Q7FMQeyB7YM	Music
https://www.youtube.com/watch?v=95iHJhm85xI	Music
https://www.youtube.com/watch?v=oaXlmoEIdiQ	Music
https://www.youtube.com/watch?v=JhxAYLkKJ7c	Music
https://www.youtube.com/watch?v=86XtW5EvVR4	Music
https://www.youtube.com/watch?v=ZbzSQ-zGxP4	Music
https://www.youtube.com/watch?v=LJrnKkJYDh8	Music
https://www.youtube.com/watch?v=ghZHmu$_a$Gxc	Music
https://www.youtube.com/watch?v=rFHWH6THL3s	Road Vehicles
https://www.youtube.com/watch?v=qVqNqET1e5A	Road Vehicles
https://www.youtube.com/watch?v=-zV7RiTITxM	Road Vehicles
https://www.youtube.com/watch?v=oOOtv6HdAn8	Road Vehicles
https://www.youtube.com/watch?v=n7K1zMf17lc	Road Vehicles
https://www.youtube.com/watch?v=agbGtX2UBCY	Road Vehicles
https://www.youtube.com/watch?v=vaSB9KbIusA	Road Vehicles
https://www.youtube.com/watch?v=AUBj2PDNTcU	Road Vehicles
https://www.youtube.com/watch?v=OdKyKxEMZIw	Road Vehicles
https://www.youtube.com/watch?v=ny62zkZwszU	Road Vehicles
https://www.youtube.com/watch?v=bNqBEwmrH8o	Road Vehicles
https://www.youtube.com/watch?v=nJciOYj9p38	Road Vehicles
https://www.youtube.com/watch?v=P3o0TgKG7kU	RollerCoaster
https://www.youtube.com/watch?v=KGBniaL6esA	RollerCoaster
https://www.youtube.com/watch?v=MRzBO8ceUDM	RollerCoaster
https://www.youtube.com/watch?v=a61sgtnhrjA	RollerCoaster
https://www.youtube.com/watch?v=kxPZfwAM2bE	RollerCoaster
https://www.youtube.com/watch?v=cdRL3PaYe30	RollerCoaster
https://www.youtube.com/watch?v=7vMhf-izSOk	RollerCoaster
https://www.youtube.com/watch?v=i63isci03EA	RollerCoaster
https://www.youtube.com/watch?v=$_6$YVoR2fBLQ	RollerCoaster
https://www.youtube.com/watch?v=guzMiHGhdiM	RollerCoaster
https://www.youtube.com/watch?v=57s6QXsfxA4	RollerCoaster
https://www.youtube.com/watch?v=mKOo2j5OISg	RollerCoaster
https://www.youtube.com/watch?v=JNWtgA6ZaEo	Snow
https://www.youtube.com/watch?v=7rJe4ue4IWo	Snow
https://www.youtube.com/watch?v=idCX7o-9Hr4	Snow
https://www.youtube.com/watch?v=g7pQwgA1mQQ	Snow
https://www.youtube.com/watch?v=1EOVt1wbAxk	Snow
https://www.youtube.com/watch?v=NDpgOthFaOE	Snow
https://www.youtube.com/watch?v=YljKr7M6VKY	Snow
https://www.youtube.com/watch?v=vpMNkolKO40	Snow
https://www.youtube.com/watch?v=JsJY9U74l7w	Snow
https://www.youtube.com/watch?v=lZ23WSc-VnE	Snow
https://www.youtube.com/watch?v=230$_G$kipIEs	Snow
https://www.youtube.com/watch?v=qleX5smNM5o	Snow
https://www.youtube.com/watch?v=qHmay2XCNWo	Space
https://www.youtube.com/watch?v=OrfaCeYEgYA	Space
https://www.youtube.com/watch?v=9m$_m$yjDMMsA	Space
https://www.youtube.com/watch?v=EknTLmXG89Q	Space
https://www.youtube.com/watch?v=jdDFS5Nsnqw	Space
https://www.youtube.com/watch?v=MPdDJ5siFJs	Space
https://www.youtube.com/watch?v=jGEcLRkUOiU	Space
https://www.youtube.com/watch?v=wfmRcq3cKjk	Space
https://www.youtube.com/watch?v=p-S2ujvN6qw	Space
https://www.youtube.com/watch?v=hGspeOTzQBQ	Space
https://www.youtube.com/watch?v=7S6PzDo2rqY	Space
https://www.youtube.com/watch?v=yiueNP8DqHE	Space

https://www.youtube.com/watch?v=7gjR60TSn8Q	Sport
https://www.youtube.com/watch?v=YnXh3Tec0v8	Sport
https://www.youtube.com/watch?v=y2HS07WGo-E	Sport
https://www.youtube.com/watch?v=LnbuzJJkKxU	Sport
https://www.youtube.com/watch?v=1odSqLNRp2k	Sport
https://www.youtube.com/watch?v=ghymxTwVm84	Sport
https://www.youtube.com/watch?v=IDxJIbxJ7Pg	Sport
https://www.youtube.com/watch?v=pQry1Iiq8Ys	Sport
https://www.youtube.com/watch?v=yEZCXe7ALDY	Sport
https://www.youtube.com/watch?v=ReGk981p85o	Sport
https://www.youtube.com/watch?v=YFM6O-bR0Ow	Sport
https://www.youtube.com/watch?v=Nlm$_j$aVQiFI	Sport
https://www.youtube.com/watch?v=qAricm0SHhY	Travel
https://www.youtube.com/watch?v=78Cb6rbgTG8	Travel
https://www.youtube.com/watch?v=UNo-bSBnyZU	Travel
https://www.youtube.com/watch?v=lU$_a$ABpv3ak	Travel
https://www.youtube.com/watch?v=fHqTR9yiLCA	Travel
https://www.youtube.com/watch?v=txPH3–0D-Q	Travel
https://www.youtube.com/watch?v=PW9hxfuMt08	Travel
https://www.youtube.com/watch?v=FwLppp6sVUI	Travel
https://www.youtube.com/watch?v=6oAUG7eRLQY	Travel
https://www.youtube.com/watch?v=QKfKu2UmT-M	Travel
https://www.youtube.com/watch?v=lHz-0tprXHA	Travel
https://www.youtube.com/watch?v=66rRr3fFTLw	Travel
https://www.youtube.com/watch?v=GNoAQQG-YS8	Under Water
https://www.youtube.com/watch?v=eXsNX$_2$AzM8	Under Water
https://www.youtube.com/watch?v=kLVajtkrG$_4$	Under Water
https://www.youtube.com/watch?v=XEkUy7a8vfI	Under Water
https://www.youtube.com/watch?v=be6R3maxhCM	Under Water
https://www.youtube.com/watch?v=fi94ayR77vw	Under Water
https://www.youtube.com/watch?v=GKWJ9wxt2XE	Under Water
https://www.youtube.com/watch?v=pniKBv$_i$ETM	Under Water
https://www.youtube.com/watch?v=c9YRl7Yu-p8	Under Water
https://www.youtube.com/watch?v=EbUHKw8r5xA	Under Water
https://www.youtube.com/watch?v=ypnspTcgw3A	Under Water
https://www.youtube.com/watch?v=533QhqMQWQ4	Under Water

Table 27: Used videos in the Video Store design

C.2.2 Record Store

URL	Categorie
https://www.youtube.com/watch?v=dvBUtAg$_1$0g	Animals
https://www.youtube.com/watch?v=Zgaw2eNP9eo	Animals
https://www.youtube.com/watch?v=mRHx$_X cQM-A$	Animals
https://www.youtube.com/watch?v=T-aOVE22lEw	Animals
https://www.youtube.com/watch?v=QjqGlLVIAtg	Animals
https://www.youtube.com/watch?v=mlOiXMvMaZo	Animals
https://www.youtube.com/watch?v=oo2F0WOziMU	Animals
https://www.youtube.com/watch?v=nF8UTFHpmjE	Animals
https://www.youtube.com/watch?v=caTe12xaiso	Animals
https://www.youtube.com/watch?v=mJ1vEZgA698	Animals
https://www.youtube.com/watch?v=$_X$0$oAFdl$4A4	Animals
https://www.youtube.com/watch?v=KN5yfbp4iGI	Animals
https://www.youtube.com/watch?v=E3BEwQNu4z4	Animations
https://www.youtube.com/watch?v=KL1odfJa2Ac	Animations
https://www.youtube.com/watch?v=fT-xun9NOEk	Animations
https://www.youtube.com/watch?v=UuPh-zA7vkI	Animations
https://www.youtube.com/watch?v=TcFkBUTHFeo	Animations
https://www.youtube.com/watch?v=aJTv1R68k74	Animations
https://www.youtube.com/watch?v=QRWKaOZebFQ	Animations
https://www.youtube.com/watch?v=n2wWSFjg8nY	Animations
https://www.youtube.com/watch?v=gq$_R-je$3Cu8	Animations
https://www.youtube.com/watch?v=VKWNFk86m4M	Animations
https://www.youtube.com/watch?v=cgSnJ0PS5SM	Animations
https://www.youtube.com/watch?v=pZFSl4Nn8B8	Animations
https://www.youtube.com/watch?v=LnxmSFBjywU	Dinosaurs
https://www.youtube.com/watch?v=EVVvO$_r fg$0k	Dinosaurs
https://www.youtube.com/watch?v=luSR3pYPjeI	Dinosaurs
https://www.youtube.com/watch?v=wN5Hu1rdRn8	Dinosaurs
https://www.youtube.com/watch?v=WeHjAohH$_I E$	Dinosaurs
https://www.youtube.com/watch?v=DTPQBYIGm7c	Dinosaurs
https://www.youtube.com/watch?v=Rr0vrcdt60c	Dinosaurs
https://www.youtube.com/watch?v=3OSijZB2gE8	Dinosaurs
https://www.youtube.com/watch?v=b4Nwht22$_G g$	Dinosaurs
https://www.youtube.com/watch?v=2SxUINipaOA	Dinosaurs
https://www.youtube.com/watch?v=XyXdutd9iHs	Dinosaurs
https://www.youtube.com/watch?v=EhdvHjJGknA	Dinosaurs
https://www.youtube.com/watch?v=m15UTKtl0U4	Gaming
https://www.youtube.com/watch?v=NB$_t$3PFo14E	Gaming
https://www.youtube.com/watch?v=mYP6YQxwkTw	Gaming
https://www.youtube.com/watch?v=KAFlPzXvo00	Gaming
https://www.youtube.com/watch?v=FicnwNxgESs	Gaming
https://www.youtube.com/watch?v=LNJ26JYh5as	Gaming
https://www.youtube.com/watch?v=okgCiUFCmyQ	Gaming
https://www.youtube.com/watch?v=s9JxrhF-ptk	Gaming
https://www.youtube.com/watch?v=Ju1FrgReGog	Gaming
https://www.youtube.com/watch?v=4qxVmpE8aW4	Gaming
https://www.youtube.com/watch?v=F3gLnnZyG4s	Gaming
https://www.youtube.com/watch?v=SUkOB8PSXNo	Gaming
https://www.youtube.com/watch?v=kRGzaWpKK-g	Horror
https://www.youtube.com/watch?v=51dhmjh7jco	Horror
https://www.youtube.com/watch?v=3QMj5lnH6O4	Horror
https://www.youtube.com/watch?v=NkyB7ClT96k	Horror
https://www.youtube.com/watch?v=NxdbLl0s0II	Horror

URL	Category
https://www.youtube.com/watch?v=vHP-$_R XJu_s$	Horror
https://www.youtube.com/watch?v=rB4fffCvitc	Horror
https://www.youtube.com/watch?v=0t-fpnRU$_n Q$	Horror
https://www.youtube.com/watch?v=Lfe4b7t-dn8	Horror
https://www.youtube.com/watch?v=Hb841Can99c	Horror
https://www.youtube.com/watch?v=geVnarqLVPQ	Horror
https://www.youtube.com/watch?v=2Mg45eogh3E	Horror
https://www.youtube.com/watch?v=Bfyy7gDTZqA	Kpop
https://www.youtube.com/watch?v=4ahjy7MklMw	Kpop
https://www.youtube.com/watch?v=PRyU7WhNvQ0	Kpop
https://www.youtube.com/watch?v=ZdCwMiqgkQs	Kpop
https://www.youtube.com/watch?v=sZvGJjeLUlg	Kpop
https://www.youtube.com/watch?v=pVKpCvA2UxM	Kpop
https://www.youtube.com/watch?v=jFyUlNnsWLU	Kpop
https://www.youtube.com/watch?v=DO5okgF$_K a8$	Kpop
https://www.youtube.com/watch?v=vbiVb4I8-To	Kpop
https://www.youtube.com/watch?v=nEi6u2lAYHg	Kpop
https://www.youtube.com/watch?v=uAt5srzLt4I	Kpop
https://www.youtube.com/watch?v=TAHknF5aaAs	Kpop
https://www.youtube.com/watch?v=61IVCL-mkDw	Music
https://www.youtube.com/watch?v=Sx0xehwuSA8	Music
https://www.youtube.com/watch?v=$0_- dEEZE - u8$	Music
https://www.youtube.com/watch?v=6y3plrhdKY8	Music
https://www.youtube.com/watch?v=6F-S37qs1QU	Music
https://www.youtube.com/watch?v=kNKcSWRkOQo	Music
https://www.youtube.com/watch?v=CVNsCMDwOmQ	Music
https://www.youtube.com/watch?v=EmDWxC2j8lQ	Music
https://www.youtube.com/watch?v=lMSr8LYj50A	Music
https://www.youtube.com/watch?v=fT7dxFY-zg8	Music
https://www.youtube.com/watch?v=4ZtcVZAgh1g	Music
https://www.youtube.com/watch?v=5hTitJw0-CA	Music
https://www.youtube.com/watch?v=DhE9J$_X beK4$	Road Vehicles
https://www.youtube.com/watch?v=ZLEizWflDEo	Road Vehicles
https://www.youtube.com/watch?v=gTlvPAmAaSY	Road Vehicles
https://www.youtube.com/watch?v=RWLPHdz7jMk	Road Vehicles
https://www.youtube.com/watch?v=BDngsynQzrU	Road Vehicles
https://www.youtube.com/watch?v=SIHezJ$_R FuY$	Road Vehicles
https://www.youtube.com/watch?v=G$_z 4WHr5cC8$	Road Vehicles
https://www.youtube.com/watch?v=Za78gJU5Tfc	Road Vehicles
https://www.youtube.com/watch?v=aBiNNgfB7jI	Road Vehicles
https://www.youtube.com/watch?v=Yae-fS1WCVc	Road Vehicles
https://www.youtube.com/watch?v=WP4vMIoDz4I	Road Vehicles
https://www.youtube.com/watch?v=469VxgNqbgQ	Road Vehicles
https://www.youtube.com/watch?v=6PHmxYFq$_H M$	RollerCoaster
https://www.youtube.com/watch?v=82gWsrqZq$_w$	RollerCoaster
https://www.youtube.com/watch?v=-WmnnkgtMcw	RollerCoaster
https://www.youtube.com/watch?v=hiNusUnJ6Ew	RollerCoaster
https://www.youtube.com/watch?v=z4qoHTWXbUE	RollerCoaster
https://www.youtube.com/watch?v=S5ki1d5ZILs	RollerCoaster
https://www.youtube.com/watch?v=9wIgPxoqDOE	RollerCoaster
https://www.youtube.com/watch?v=zaTnYfg38JU	RollerCoaster
https://www.youtube.com/watch?v=6XVfL3JyRQM	RollerCoaster
https://www.youtube.com/watch?v=EmqTikV0aBw	RollerCoaster
https://www.youtube.com/watch?v=dtTvEZquitE	RollerCoaster
https://www.youtube.com/watch?v=jgUHUX33XEM	RollerCoaster
https://www.youtube.com/watch?v=at95fsD2eqI	Snow

URL	Category
https://www.youtube.com/watch?v=lYITD9r-b4E	Snow
https://www.youtube.com/watch?v=F9DqISg$_C y A$	Snow
https://www.youtube.com/watch?v=sg-Fw9uqKak	Snow
https://www.youtube.com/watch?v=6$_l qOuexmro$	Snow
https://www.youtube.com/watch?v=k-8-Hi3vnRc	Snow
https://www.youtube.com/watch?v=d2dXfOyCDzg	Snow
https://www.youtube.com/watch?v=m9pbCzUPmY8	Snow
https://www.youtube.com/watch?v=yooQBXeDsXI	Snow
https://www.youtube.com/watch?v=MD3YOcHyZ3s	Snow
https://www.youtube.com/watch?v=-GOKxPXju4A	Snow
https://www.youtube.com/watch?v=MgpLAtYrPKM	Snow
https://www.youtube.com/watch?v=GOwJtZjwscs	Space
https://www.youtube.com/watch?v=Gf0Wlo6hJMg	Space
https://www.youtube.com/watch?v=BFbgEmmZLcM	Space
https://www.youtube.com/watch?v=wteVGoaBNfY	Space
https://www.youtube.com/watch?v=-f$_Z qEqTtuY$	Space
https://www.youtube.com/watch?v=3offgJ5kSM0	Space
https://www.youtube.com/watch?v=0D-UfnDziAY	Space
https://www.youtube.com/watch?v=bRYPMYHxmgc	Space
https://www.youtube.com/watch?v=PYPRGIqLZ8U	Space
https://www.youtube.com/watch?v=30YQHJSzseg	Space
https://www.youtube.com/watch?v=2drSpu$_{BC}Y$	Space
https://www.youtube.com/watch?v=UvEPm0qnAYc	Space
https://www.youtube.com/watch?v=uwfS57UbJCM	Sport
https://www.youtube.com/watch?v=nKpWd4P1XQk	Sport
https://www.youtube.com/watch?v=Df91OoSV36M	Sport
https://www.youtube.com/watch?v=JnaIm6OpAGs	Sport
https://www.youtube.com/watch?v=gzSw8bqf8a8	Sport
https://www.youtube.com/watch?v=lmX956HnrpY	Sport
https://www.youtube.com/watch?v=YLMxpzP4Raw	Sport
https://www.youtube.com/watch?v=MKWWhf8RAV8	Sport
https://www.youtube.com/watch?v=Lx$_E cJulN8c$	Sport
https://www.youtube.com/watch?v=tIlujhBWSCk	Sport
https://www.youtube.com/watch?v=LnvOlquRAbI	Sport
https://www.youtube.com/watch?v=8ozKrZ6BBjo	Sport
https://www.youtube.com/watch?v=QgNwir5enf4	Travel
https://www.youtube.com/watch?v=VCObIPRU4B0	Travel
https://www.youtube.com/watch?v=wI9MS9M8yCU	Travel
https://www.youtube.com/watch?v=5unXlFv2YL8	Travel
https://www.youtube.com/watch?v=eFpYYqDK4wQ	Travel
https://www.youtube.com/watch?v=h8JXa3dz0$_E$	Travel
https://www.youtube.com/watch?v=A3wriE0MPos	Travel
https://www.youtube.com/watch?v=ajvoGCiMkv0	Travel
https://www.youtube.com/watch?v=r4QisBVtRgQ	Travel
https://www.youtube.com/watch?v=m9EClKA1VeQ	Travel
https://www.youtube.com/watch?v=vmNO1$_y h5EU$	Travel
https://www.youtube.com/watch?v=q49G2MXCIk0	Travel
https://www.youtube.com/watch?v=eUvAIv$_p WN4$	Under Water
https://www.youtube.com/watch?v=rG4jSz$_2 HDY$	Under Water
https://www.youtube.com/watch?v=psuZXyU7rW8	Under Water
https://www.youtube.com/watch?v=eKumVFvGHFA	Under Water
https://www.youtube.com/watch?v=v64KOxKVLVg	Under Water
https://www.youtube.com/watch?v=j4ZT$_X lhZBQ$	Under Water
https://www.youtube.com/watch?v=3-xsLz7vOJo	Under Water
https://www.youtube.com/watch?v=Dy-M8JhvZhk	Under Water
https://www.youtube.com/watch?v=YM8ZT8kHvlQ	Under Water

https://www.youtube.com/watch?v=6IZK1k1elBU	Under Water
https://www.youtube.com/watch?v=rExIaDvPUdU	Under Water
https://www.youtube.com/watch?v=sl3rB6KGybQ	Under Water

Table 28: Used videos in the Record Store design

C.2.3 Abstract Store

URL	Categorie
https://www.youtube.com/watch?v=0XrH2WO1Mzs	Animals
https://www.youtube.com/watch?v=14O7AxqjiVY	Animals
https://www.youtube.com/watch?v=G5Y$_X$9$VeNrw$	Animals
https://www.youtube.com/watch?v=0m6c6C2lHaI	Animals
https://www.youtube.com/watch?v=GgXtU-rpzYM	Animals
https://www.youtube.com/watch?v=OLXIgL3ETGo	Animals
https://www.youtube.com/watch?v=sPyAQQklc1s	Animals
https://www.youtube.com/watch?v=eW0NfcEL2Dk	Animals
https://www.youtube.com/watch?v=-4xtQ2bUUoQ	Animals
https://www.youtube.com/watch?v=6Scd9baRjf8	Animals
https://www.youtube.com/watch?v=FMU0jd2IUks	Animals
https://www.youtube.com/watch?v=$_v XUwAFYEbU$	Animals
https://www.youtube.com/watch?v=1wADwhhrD40	Animations
https://www.youtube.com/watch?v=PymwWNav33c	Animations
https://www.youtube.com/watch?v=5WtBORwwfRA	Animations
https://www.youtube.com/watch?v=FsWaf6tpIRw	Animations
https://www.youtube.com/watch?v=3nF3dkYm9ec	Animations
https://www.youtube.com/watch?v=zfyT7D3G1M8	Animations
https://www.youtube.com/watch?v=Vpn73XvhQok	Animations
https://www.youtube.com/watch?v=KZn$_G$45$Nwgc$	Animations
https://www.youtube.com/watch?v=kp2tYUUwngw	Animations
https://www.youtube.com/watch?v=Sv7Zz3N$_o PM$	Animations
https://www.youtube.com/watch?v=Iy$_g$s6$AkfLQ$	Animations
https://www.youtube.com/watch?v=KT1Hq9IQY64	Animations
https://www.youtube.com/watch?v=N0EePj0l-wI	Dinosaurs
https://www.youtube.com/watch?v=VjdW73PhhK4	Dinosaurs
https://www.youtube.com/watch?v=aLEryun-fsc	Dinosaurs
https://www.youtube.com/watch?v=0OzYI31kjO0	Dinosaurs
https://www.youtube.com/watch?v=FfUQk4mG3eo	Dinosaurs
https://www.youtube.com/watch?v=jPcARhVWH94	Dinosaurs
https://www.youtube.com/watch?v=VUybRLJ6464	Dinosaurs
https://www.youtube.com/watch?v=kbCxTEN8aQw	Dinosaurs
https://www.youtube.com/watch?v=KtAAyfgzw0k	Dinosaurs
https://www.youtube.com/watch?v=WIcuy-74$_M U$	Dinosaurs
https://www.youtube.com/watch?v=2Ufacl9lr70	Dinosaurs
https://www.youtube.com/watch?v=snssnSe8EW8	Dinosaurs
https://www.youtube.com/watch?v=mBbRjE81uMw	Gaming
https://www.youtube.com/watch?v=OTyzl5VtMvA	Gaming
https://www.youtube.com/watch?v=vUerzNaneMc	Gaming
https://www.youtube.com/watch?v=Tr7rc$_q EyvQ$	Gaming
https://www.youtube.com/watch?v=uo3Rf4PI9C0	Gaming
https://www.youtube.com/watch?v=2WH2kxEk1uE	Gaming
https://www.youtube.com/watch?v=tbFogLtBDPg	Gaming
https://www.youtube.com/watch?v=DneTRJ66sPE	Gaming
https://www.youtube.com/watch?v=RdgjX3BUnuk	Gaming
https://www.youtube.com/watch?v=guL8NOBj988	Gaming
https://www.youtube.com/watch?v=R5WPqOwOROs	Gaming
https://www.youtube.com/watch?v=aD25dgo99nM	Gaming
https://www.youtube.com/watch?v=−WJpvw1vGI	Horror
https://www.youtube.com/watch?v=dMg1QljXucA	Horror
https://www.youtube.com/watch?v=lpACYcfC8Rw	Horror
https://www.youtube.com/watch?v=ku1xtEiEDyI	Horror
https://www.youtube.com/watch?v=vD3sStG0Pgs	Horror

URL	Category
https://www.youtube.com/watch?v=BLvqNeOLtw4	Horror
https://www.youtube.com/watch?v=8t8a2UjAhK0	Horror
https://www.youtube.com/watch?v=yPnMG2zYxa8	Horror
https://www.youtube.com/watch?v=FdWse6RG0tM	Horror
https://www.youtube.com/watch?v=BLF9OXRxZ$_A$	Horror
https://www.youtube.com/watch?v=3P9Mcy3azeo	Horror
https://www.youtube.com/watch?v=h6bgKHU5ZxY	Horror
https://www.youtube.com/watch?v=IYhd1MkUmtA	Kpop
https://www.youtube.com/watch?v=Zeay-AEPKvA	Kpop
https://www.youtube.com/watch?v=A9Wvl32W$_A$s	Kpop
https://www.youtube.com/watch?v=G7IUOoS5AUI	Kpop
https://www.youtube.com/watch?v=5Qb56PZvgn0	Kpop
https://www.youtube.com/watch?v=uglook6iETE	Kpop
https://www.youtube.com/watch?v=UxBOKpPaiFY	Kpop
https://www.youtube.com/watch?v=cW4f7Hfs$_F$w	Kpop
https://www.youtube.com/watch?v=lWDlbK34UI0	Kpop
https://www.youtube.com/watch?v=ek2bldK5ijU	Kpop
https://www.youtube.com/watch?v=nM0rC$_s$iCh8	Kpop
https://www.youtube.com/watch?v=8ptv8UZsQMM	Kpop
https://www.youtube.com/watch?v=00zUY7tgYhw	Music
https://www.youtube.com/watch?v=flYiLjG04U8	Music
https://www.youtube.com/watch?v=c$_G$1nNykgoY	Music
https://www.youtube.com/watch?v=ojSrh$_f$Xwho	Music
https://www.youtube.com/watch?v=d1Pbh6bSVL0	Music
https://www.youtube.com/watch?v=qIqhEWMz2RI	Music
https://www.youtube.com/watch?v=iXoLwDy-80Y	Music
https://www.youtube.com/watch?v=n7TCwteyEUQ	Music
https://www.youtube.com/watch?v=NXVPsPXTLLc	Music
https://www.youtube.com/watch?v=3bu4gDG5l8Q	Music
https://www.youtube.com/watch?v=CP2$_g$YSPRb4	Music
https://www.youtube.com/watch?v=v6IX1HMngps	Music
https://www.youtube.com/watch?v=NOE-RTLercU	Road Vehicles
https://www.youtube.com/watch?v=5xGFxxDNTFo	Road Vehicles
https://www.youtube.com/watch?v=OqsueC6ECQQ	Road Vehicles
https://www.youtube.com/watch?v=4MpDCCx0h0o	Road Vehicles
https://www.youtube.com/watch?v=VF77LijYUYY	Road Vehicles
https://www.youtube.com/watch?v=a7b-wFFtHRM	Road Vehicles
https://www.youtube.com/watch?v=d-qVI2YhKHk	Road Vehicles
https://www.youtube.com/watch?v=UmWT8g7eE4o	Road Vehicles
https://www.youtube.com/watch?v=wfNvZwN87Hg	Road Vehicles
https://www.youtube.com/watch?v=rUex72h3p3s	Road Vehicles
https://www.youtube.com/watch?v=GnovFxOMcXM	Road Vehicles
https://www.youtube.com/watch?v=q7gygumHoos	Road Vehicles
https://www.youtube.com/watch?v=yF3QcEQoASg	RollerCoaster
https://www.youtube.com/watch?v=juvLELV7U8o	RollerCoaster
https://www.youtube.com/watch?v=Zr$_n$dyZB1ow	RollerCoaster
https://www.youtube.com/watch?v=sRAhl0eABuo	RollerCoaster
https://www.youtube.com/watch?v=bqbmX59H$_O$M	RollerCoaster
https://www.youtube.com/watch?v=znuGQ-HC1ys	RollerCoaster
https://www.youtube.com/watch?v=O5ImEasdt3Q	RollerCoaster
https://www.youtube.com/watch?v=ZZo7pc2cm3Q	RollerCoaster
https://www.youtube.com/watch?v=FzfAaIvRIwQ	RollerCoaster
https://www.youtube.com/watch?v=KS2A6zHmkOU	RollerCoaster
https://www.youtube.com/watch?v=g1lr94t4sdI	RollerCoaster
https://www.youtube.com/watch?v=hzWHIqoJBj0	RollerCoaster
https://www.youtube.com/watch?v=j1MbkXJisXA	Snow

https://www.youtube.com/watch?v=LoPk8ZJmHVY	Snow
https://www.youtube.com/watch?v=gCKUiduJneQ	Snow
https://www.youtube.com/watch?v=fDGDEMn62vo	Snow
https://www.youtube.com/watch?v=ZKgsnvvtbWs	Snow
https://www.youtube.com/watch?v=JD09Q5EcAHw	Snow
https://www.youtube.com/watch?v=7BrJSU8vDi4	Snow
https://www.youtube.com/watch?v=$PI_gki0-648$	Snow
https://www.youtube.com/watch?v=pFkzOUtUYtc	Snow
https://www.youtube.com/watch?v=pkFvQLrhGEk	Snow
https://www.youtube.com/watch?v=KRWS7b9c-4o	Snow
https://www.youtube.com/watch?v=FWnfi6Fig8I	Snow
https://www.youtube.com/watch?v=cGoM8FkBidA	Space
https://www.youtube.com/watch?v=jM4CeY0W8QU	Space
https://www.youtube.com/watch?v=rG0LcaJ5dxM	Space
https://www.youtube.com/watch?v=pflwAJ94vHU	Space
https://www.youtube.com/watch?v=AsNfT13czs4	Space
https://www.youtube.com/watch?v=zKgtQiSB8hQ	Space
https://www.youtube.com/watch?v=kmDYaZ0XZLo	Space
https://www.youtube.com/watch?v=J4jfYo1fIEY	Space
https://www.youtube.com/watch?v=qNW_{CMpQ5I}	Space
https://www.youtube.com/watch?v=hEdzv7D4CbQ	Space
https://www.youtube.com/watch?v=gdNUr4B15gc	Space
https://www.youtube.com/watch?v=ggLjwtku-oU	Space
https://www.youtube.com/watch?v=NPD1NnOXf6s	Sport
https://www.youtube.com/watch?v=d05Be0BbWFs	Sport
https://www.youtube.com/watch?v=zzc7oZVIwfc	Sport
https://www.youtube.com/watch?v=VpfIOdI33sc	Sport
https://www.youtube.com/watch?v=eZ8s4pF9qRU	Sport
https://www.youtube.com/watch?v=$pxH4_6TWsc4$	Sport
https://www.youtube.com/watch?v=FXoTwYdP4i8	Sport
https://www.youtube.com/watch?v=$xEbZV_BmkYw$	Sport
https://www.youtube.com/watch?v=K65s8BTJPFE	Sport
https://www.youtube.com/watch?v=$_nu6NmqjLGc$	Sport
https://www.youtube.com/watch?v=NoSMwDv0b4I	Sport
https://www.youtube.com/watch?v=BQc6mLTeRUw	Sport
https://www.youtube.com/watch?v=s4RAZxHwbL0	Travel
https://www.youtube.com/watch?v=V8hOk2T5Ewg	Travel
https://www.youtube.com/watch?v=FzrkpXlRP1M	Travel
https://www.youtube.com/watch?v=IUY6WczWLEc	Travel
https://www.youtube.com/watch?v=BnVmijTniMU	Travel
https://www.youtube.com/watch?v=0pXLBg1U-cQ	Travel
https://www.youtube.com/watch?v=FMU0jd2IUks	Travel
https://www.youtube.com/watch?v=Ac8uBHhcDso	Travel
https://www.youtube.com/watch?v=$i1hk6Vi_Dfs$	Travel
https://www.youtube.com/watch?v=mJrGKL3oSFo	Travel
https://www.youtube.com/watch?v=HkY7QTIP1PU	Travel
https://www.youtube.com/watch?v=SaeH8TtIHPg	Travel
https://www.youtube.com/watch?v=MMTVeYdiukw	Under Water
https://www.youtube.com/watch?v=nwEaMjbLHAM	Under Water
https://www.youtube.com/watch?v=0wbPUYztSDI	Under Water
https://www.youtube.com/watch?v=bzZEKGRoZwc	Under Water
https://www.youtube.com/watch?v=9GjAcbv0MBU	Under Water
https://www.youtube.com/watch?v=sT0hVLEe5mU	Under Water
https://www.youtube.com/watch?v=$xJDHGJ22_d4$	Under Water
https://www.youtube.com/watch?v=sU8oSjtZlx4	Under Water
https://www.youtube.com/watch?v=829IlQ8IbmU	Under Water

https://www.youtube.com/watch?v=VNChunf5RKQ	Under Water
https://www.youtube.com/watch?v=qIXT-hzWhiw	Under Water
https://www.youtube.com/watch?v=VCjaxyQl1yg	Under Water

Table 29: Used videos in the Abstract Store design

C.2.4 Tutorial

URL	Categorie
https://www.youtube.com/watch?v=boIJxFZ5WJ8	Tutorial

Table 30: Used video in the Tutorial

D Literature Study

D.1 Introduction

This Section provides a literature study conducted to prepare for this thesis about accessing 360°
video libraries. First, Sections D.1.1 and D.1.2 present a brief overview of the history and definition of
360° video. Next, Section D.2 discusses existing implementations to access 360° video libraries for VR
with HMDs and 2D screens. Then, Section D.3 highlights research about thumbnails for 360° videos,
and Section D.4 explores different measures for accessing 360° video libraries. In addition, Section
D.5 outlines multiple considerations for developing VR applications. Finally, Section D.6.1 explores
different available datasets containing 360° videos.

D.1.1 Short history overview of 360° media

360° media is a media that has existed for centuries. The oldest discovery of 360° media dates back
to at least 20 BCE. This 360° media is a 360° fresco in Villa Livia at Prima Porta [41]. However, the
modernization of 360° media did not begin until 1787 with an invention to paint cylindrical objects
by Robert Baker [5], and 1889 when one of the first panoramic cameras was developed by John R.
Cannon [7]. Eventually, all these inventions led to the development of the first widely available Virtual
Reality (VR) Head Mounted Display (HMD), such as the Oculus rift, which was released to consumers
in March 2016 [39]. This year also saw the release of other notable VR HMDs, including the HTC
Vive[42] and PlayStation VR[18].

D.1.2 What is 360° video

Now that we know a short history of 360° media, we must define the context of 360° video for this
thesis. 360° videos, also known as surround videos [38], are videos that capture the entire viewing
sphere, enabling the user to rotate 360° around all three axes and view the content of the video.
Therefore, 360° video shows the user's entire *surrounding*.

Multiple techniques exist to create 360° videos. Nielsen [38] describes two of these techniques for
creating 360° videos. The first technique Nielsen describes utilizes multiple cameras pointed in different
slightly overlapping orientations of the viewports. This allows us to capture the entire viewing sphere
and create a 360° video by stitching the videos together after filming. The downside of creating 360°
videos this way is that stitching the different videos together is a delicate task. Besides this, using
multiple cameras allows for the existence of something called the parallax phenomenon. The parallax
phenomenon refers to the difference in the apparent position of an object when viewed from different
points. The second approach Nielsen describes uses mirrors to increase the used camera's Field Of
View (FOV). This method reduces the parallax phenomenon as it only uses a single camera. However,
using a single camera does not allow the capture of the entire viewing sphere.

D.2 Accessing video libraries

Currently, consumers have two primary ways to access a 360° video. One is accessing the 360° video
via a 2 Dimensional(2D) monitor, and the other is way is done via an HMD. When accessing a 360°
video on a 2D screen, the video player allows the user to rotate the viewport. Two ways of rotating the
viewport that YouTube implements are dragging on the video player or using buttons like a D-pad.
The other way to access a 360° video is via HMDs. When using an HMD, the viewport of a 360° video
can be rotated by rotating the HMD itself.

Accessing 360° video libraries can be done similarly to the 360° videos described above. Namely on
a 2D screen or with an HMD. However, accessing 360° video libraries differs across various applications.
This difference lies in the different representation styles. Different consumer apllications use different
representation styles, such as grids, lists, carousels, and cover views. All these styles have in common
that they use the same type of thumbnail to represent a single video, but they differ in how a greater
subset of a 360° video library is displayed.

D.2.1 Grids

One of the used styles to represent a 360° video library is a grid. This style displays the thumbnails of a subset of a 360° video library in a 2D grid and allows the users to either move to a different page by pressing a button or scroll up and down to explore more of the video library. In contrast to the other mentioned representation styles, grids are present in both non-VR and VR applications.

D.2.1.1 Non-VR

Non-VR applications that use a grid to represent a subset of the 360° video library are, for example, Windows File Explorer and YouTUbe[35]. An example of how these applications use a grid can be seen in Figure 47a. In addition to simply displaying the thumbnails, Youtube has an extra feature allowing the user to hover over a thumbnail with the cursor. Once the user hovers over a thumbnail, the thumbnail starts playing the video and allows the user to use a scrollbar to manipulate said video.

D.2.1.2 VR

For VR applications, the grid style is used by most, if not all, available consumer applications. Some of the prominent applications that use a grid style are Viveport Video[54], Youtube VR[22], and Oculus Video[40]. The differences between the VR and non-VR versions of the grid implementation are predominantly that the grid itself is placed in a 3D environment and can be manipulated in that way. However, the grid itself is still only a 2D object. Another difference between the non-VR and VR implementations can be found in the behavior of the thumbnails. For 2D screens, in specific applications, hovering over the thumbnail starts playing a preview. This is in contrast to VR applications, where this does not happen. In VR applications, the thumbnails mostly use a still frame from the video or an image indicating the file type. The number of videos displayed on a single page of a grid varies between applications. In VR applications such as Viveport video and GizmoVR[21], the number of videos on a single grid page is 24 and 15, respectively.

D.2.2 Lists

Another way to display a subset of a 360° videos library is in a list. The thumbnails are placed below each other in one long list, as shown in Figure 47b. Examples of applications that use this implementation are Facebook and YouTube. YouTube uses the previously discussed grid representation on its main page, but this style is used once the user makes a search query. Besides the display style change, the hover interaction is also changed. It changes from playing the entire video and allowing usage of the scrollbar to playing a short video fragment on a loop.

D.2.3 Carousel

A carousel is a lesser-known technique to access a 360° videos library. The user initially sees one video when the videos are displayed in a carousel. However, the user can swipe either to the left or the right to switch to the next or the previous video. A platform that uses the carousel style is Instagram. Next to swiping to another video, the only other way to interact with it is by pausing and restarting the video. An example of a carousel is shown in Figure 47c

D.2.4 Covers

Apple uses covers to display files in its file explorer program finder. When a 360° video library is displayed as covers, the thumbnails are next to each other, with the currently selected item in full view and the others overlapping each other. An example of this can be seen in Figure 47d.

D.2.5 Video Browser Showdown - The Video Retrieval Competition

Sections D.2.1 through D.2.4 showed how video libraries are accessed in widely used consumer applications. For more scientific applications, the yearly Video Browser Showdown (VBS)[45] is an excellent source. At the VBS, teams compete for the best retrieval system for video libraries. Although this competition focuses more on the retrieval process of videos from an extensive library, it also showcases many different interfaces to represent these libraries. The list style, discussed in Section D.2.2, is a
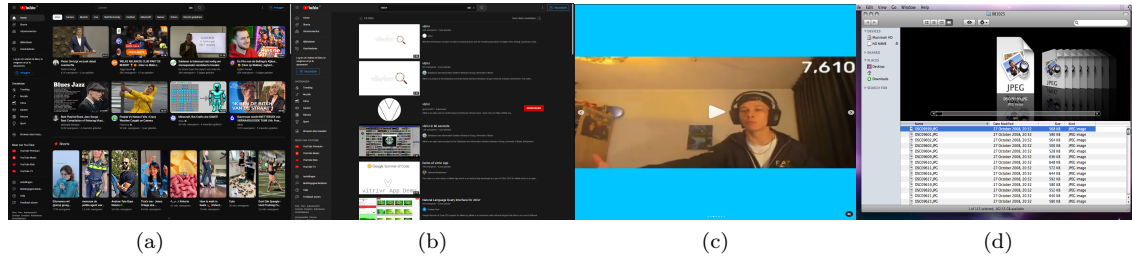
Figure 47: Examples of the different video library representations in 2D

commonly used way to implement access to the video library at VBS. Nonetheless, slight variations exist between the consumer-grade list style and the style often used at VBS. This difference directly results from the tasks teams need to fulfill at VBS. In short, at VBS, the teams need to be able to search inside a video (Temporal Queries). Therefore a query can return a timestamp inside a video instead of simply returning the entire video. This means that the interfaces should show which video the query returned and the different timestamps of where the results can be found in the video. The teams, therefore, use a list style to list each video, and in each listed item, they list all the found occurrences inside the video. The VR applications and how they represent the video libraries are more exciting interfaces to look into at the VBS. Only two teams have currently entered a VR application at the VBS. These applications are Vitrivr-VR[51] (Section D.2.5.1) and Eolas[52] (Section D.2.5.2'. Both Vitrivr-VR and Eolas first competed in 2021. Vitrivr-VR also made an appearance in 2022 and 2023.

D.2.5.1 Vitrivr-VR

Vitrivr-Vr[51] is built upon the existing multi-media retrieval system called Vitrivr[43]. Vitrivr-VR shows the query results in a grid-style manner, but compared to consumer applications, the grid is wrapped around the user. Furthermore, the result of the temporal queries is displayed like a filing cabinet. Both these interfaces are shown in Figure 48a.

D.2.5.2 Eolas

Eolas[52] is another multi-media retrieval system incorporating VR in its interface. Eolas was introduced at VBS in 2021. Where Vitrivr-VR only shows the grid in VR, Eolas goes a step further. They group the results based on similarity and display them in these groups in the Virtual Environment(VE), as shown in Figure 48a. Furthermore, they allow users to navigate the virtual space using the minimap or via teleporting.

Figure 48: Vitrivr-VR library representation[50] (a) and Eolas library representation[52] (b)

Figure 49: Equirectangular representation of a video(Ganainy [17])

D.3   Thumbnails

D.3.1   Proven solution

The most commonly used thumbnail type in both 2D and VR applications is a 2D rectangle. This thumbnail type is used regardless of whether the library consists of normal or 360° videos, and this poses a challenge when a thumbnail needs to be created off a 360° video. Currently, two methods exist to make a thumbnail of a 360° video. The first method is fitting the entire 360° view into the 2D rectangle via a projection, and the second method is culling away the portion of the video that exists outside of the viewport. The problem with the culling method is that we do not know how to orient the viewport, resulting in the possibility of removing important content. Therefore, the only viable option is to use a projection to fit the entire view into the 2D rectangle, ensuring that all the content is in said thumbnail. One of the most used projection types is the equirectangular projection. An example of an equirectangular projection is shown in Figure 49. As can be seen, using a projection has also a downside. Namely, the projection results in a distorted image; the further an item is removed from the equator, the more distorted the item becomes.

D.3.2   State-of-the-art

As discussed in Section D.3.1, the equirectangular projection is used as the default thumbnail in both 2D and VR applications for 360° videos. However, using a projection results in distorted images and does not use the full potential of VR with HMDs, such as larger display size, 3D environment, et cetera. Vermast proposes two solutions that address these points [53]. They propose spherical and cube-shaped thumbnails which the user can interact with. Vermast shows that using spherical thumbnails lead to a better user experience and performance in item search tasks in comparison to the thumbnails that use projections. Therefore, they show that using the 3D opportunities in VR can be favorable.

D.4   Which metrics to use

D.4.1   Use-cases

Before determining which metrics can be used, we must establish which use cases are present. We examine both video types (360° and normal) and library access types (VR and non-VR libraries). When looking at these, we can define three general use cases valid for the video and library access types. The first is browsing the video library. When a user browses a video library, they are not searching for specific information but are instead looking at what the library has to offer. The second use case is a high-level search. In this case, the user has a high-level subject they want to find while browsing the library. For example, the user wants to look at videos about games. The user does not care about which game the video is about. The user only cares about the overarching theme, which in this example is games. The third and final use case is a detailed search. In this use case, the user is looking for specific information and is actively searching through the video library. An example of this

includes lecture recordings. The user is following a course and is looking for a specific lecture where a particular topic was discussed.

D.4.2 Aspects

Now that the use cases are determined, we can look at what aspects are important for these specific use cases. When using VR with HMDs, there are three significant aspects we can look at. These are the usability of the interface, the user experience, and the immersion. For each of these aspects, their importance differs based on the use case. We consider the use cases described in Section D.4.1. For the first use case (Browsing), the user experience, usability, and immersion are all critical. This is because browsing is also a major part of the experience compared to the other two use cases where this is not the case. For the other two use cases, watching the found video is the experience, and the interface is merely a tool to gain access to this experience. Therefore, the user wants a smooth experience that things like menus or other intrusive UI elements should not hinder. For the second use case (High-level searching), the user experience and usability are still essential. The user wants a fluent and quick search process and should not struggle or fight with the system to be able to find the item he or she is looking for. However, the user's main goal here is to find the item. This means that the user does not need to be fully immersed, making immersion a less critical aspect than Usability and the user experience. For the third and final use case, we can follow the same reasoning as with the second use case. The user is actively searching for details. Therefore, usability and user experience are essential for the same reason that is given for the second use case. This means immersion is also less important for the third use case.

D.4.3 Usability

There are multiple questionnaires that can be utilized to measure usability. Examples of these questionnaires are The System Usability Scale(SUS), The Usability Metric for User Experience(UMUX and UMUX-LITE), and the Single Ease Question(SEQ).

D.4.3.1 The System Usability Scale

Johh Brooke published the System Usability Scale(SUS) in 1996[8]. Brooke created the SUS as a response to the need for a cheap and fast way to measure the usability of a system. The questionnaire exists of 10 questions rated on a 5-point Likert scale. To prevent response biases, the questions are alternating positive and negative statements. In 2008 Bangor et al. released a paper examining SUS data collected for 10 years[6]. They indicate that the SUS is a "highly robust and versatile tool for usability professionals." Furthermore, Lewis showed in 2018 that " Research into its psychometric properties (reliability, validity, and sensitivity) has been universally favorable"[31]. All this indicates that the SUS is a well-established short questionnaire to measure the usability of a system.

D.4.3.2 The Usability Metric for User Experience

The Usability Metric for User Experience (UMUX) was introduced in 2010 by Finstad [20]. The UMUX was developed to tackle a couple of problems the SUS had. According to Diefenbach et al. [15], a seven-point Likert scale outperforms a five-point Likert scale on reliability, accuracy, and ease of use. Another issue is that ten questions might still be too much when the questions are combined into larger questionnaires. The resulting questionnaire created by Finstad contains four questions scored on a 7-point Likert scale.

Based on the UMUX is another questionnaire presented in 2013 by Lewis et al.[32] called the UMUX-LITE. This questionnaire was created because a principal component analysis suggests that the UMUX was bidimensional rather than unidimensional. Lewis et al. ultimately narrowed the UMUX to two questions called the UMUX-LITE questionnaire.

D.4.3.3 The Single Ease Question

The Single Ease Question(SEQ) is not really a questionnaire. As its name states, the SEQ consists of only one single question. This question is answered based on a 7-point Likert scale. Jeff Sauro and

Joseph S. Dumas have shown a high correlation between a 7-point Likert scale question and other measures [44]. Meaning that there is evidence for concurrent validity.

D.4.4 User experience

Like usability, there is no standard questionnaire for measuring the user experience. The User Experience Questionaire and the ENJOY questionnaire are often used to measure the user experience.

D.4.4.1 The User Experience Questionaire

The User Experience Questionaire(UEQ) was first published by Laugwitz et al. in 2006 in the German language [30]. In 2008 they published the English translation[29], and in 2015 one of the co-authors, Schrepp, published a handbook on using the UEQ [47]. The UEQ exists out of six scales containing twenty-six 7-point questions. The scales that are present in the UEQ are:

- Attractiveness

- Perspicuity

- Efficiency

- Dependability

- Stimulation

- Novelty

Here efficiency, perspicuity, and dependability measure the pragmatic quality. At the same time, stimulation and novelty measure the hedonic quality. The questions themselves have the form of a semantic differential, meaning that the two sides of the question have opposite meanings. The handbook by Schrepp also explains how an easy statistical comparison can compare UEQ results of two different products. Furthermore, the UEQ allows for the deletion of a full scale from the questionnaire if this scale is not of interest to the researcher.

In specific scenarios, it is possible that filling out an entire UEQ is infeasible. Therefore, Scherpp et al. designed a shorter version of the UEQ called the UEQ-S [48]. One of the scenarios they note is where participants are asked to judge the user experience of multiple products in one session. Using the longer UEQ can lead to increased stress for the user, diminishing the answers' quality. Compared to the UEQ, the UEQ-S measures pragmatic and hedonic qualities directly. With this in mind, Scherp et al. could reduce the number of questions to eight instead of twenty-six.

D.4.4.2 ENJOY

The enjoyment a user has is a part of the user experience. Therefore, measuring a user's enjoyment whilst using a prototype can be of added value. In 2018 Davidson created and validated a multi-dimensional measure of enjoyment[13]. The created ENJOY scale consists of the subscales:

- Pleasure

- Relatedness

- Competence

- Challenge/Improvement

- Engagement

Each of these subscales consists of five 7-point Likert scale questions.

D.4.5 Immersion

One added benefit of using VR with HMDs is an increase in immersion. Because of this, measuring the immersion a user is experiencing might be beneficial. Some available questionnaires are the Immersive Tendencies questionnaire, the Presence Questionnaire, and the Immersive Experience Questionnaire.

D.4.5.1   Immersive Tendencies questionnaire

In 1998 Witmer and Michael released the Immersive Tendencies questionnaire (ITQ)[55]. The ITQ was developed to measure the tendency users have to be immersed. The ITQ uses a 7-point Likert scale based on semantic differentials.

D.4.5.2   Presence Questionnaire

Witmer and Michael also developed the Presence Questionnaire(PQ) and released it in 1998[55]. Just like the ITQ, the PQ uses a 7-point Likert scale; However, it measures the degree of immersion and the contributing factors instead of the tendencies. The PQ questions can be divided into four major factor categories and six subscales. The major factor categories are Control Factors, Sensory Factors, Distraction Factors, and Realism Factors. And the subscales are Involvement/Control, Natural, Auditory, Haptic, Resolution, and Interface Quality. Witmer and Michael found that all involvement items were significantly correlated with the PQ total. This suggests that involvement is an important determinant. The final PQ contains nineteen items with a Cronbach's alpha of 0.88.

D.4.5.3   Immersive Experience Questionnaire

The Immersive Experience Questionnaire(IEQ) was introduced by Jennet et al. to try to quantitatively define immersion [25]. They developed the first version of the IEQ and tested it on two separate occasions. On these occasions, they found that the questionnaire returned a significantly higher level of immersion when tested between immersive and non-immersive conditions. They constructed a shorter and simpler worded questionnaire with the experience they gained from these two experiments.

D.4.6   Searching

Two of the three use cases described in Section D.4.1 contain a search task in which a user searches for a video in the video library. Therefore we need to know how different interfaces impact the search task. We can use three criteria for the search tasks to determine if an interface is viable for use. The first is that it should be possible to complete the search task. Next, the user should be able to find the correct item(s). And finally, a search task should not take too long. These three criteria can be measured with three statistics, completion rate, error rate (How many wrong items are selected), and completion time. The completion rate should, in all cases, be hundred percent. The only exception is if a user is physically unable to complete the task, for example, due to heavy symptoms of cybersickness.

D.4.7   Cybersickness

As stated before, the user interface should not adversely impact the search process. This means that we also need to look into cybersickness. Cybersickness is a group of symptoms that look like motion sicknesses. These symptoms occur when users use immersive extended reality (XR) systems like VR. Cybersickness symptoms include headache, nausea, and disorientation. As most signs of cybersickness are not/less visible from the outside, one way to test for cybersickness is by self-report via a questionnaire. One such questionnaire was developed by Hyun et al. in 2018 [28]. The Virtual Reality Sickness Questionnaire (VRSQ) is a revised version of the widely used Simulator Sickness Questionnaire (SSQ) released in 1993 by Kennedy et al. [27]. The SSQ could be separated into three categories: nausea, oculomotor, and disorientation. However, the VRSQ only consists of the oculomotor and disorientation categories. This is because both Drexler [16], and the case study done by Kennedy et al.[27] show a trend of the nausea component contributing less to motion sickness in comparison to the other two categories in VR systems.

A psychometric evaluation of the VRSQ was done by Volkan and Berkman[49] between the SSQ, VRSQ, Cybersickness Questionnaire (CSQ), and the FSSQ (a variant based on a French translation of the SSQ). This evaluation found that the CSQ and VRSQ had better psychometric qualities than the SSQ and FSSQ when assessing HMD VR applications. Furthermore, Volkan and Berkman show that there is evidence for the validity of all measures.

D.5   Design considerations

The developers of the oculus ecosystem have released an in-depth guide on the best practices for immersive VR applications[2]. This guide covers everything from vision and audio to hand tracking and health and safety guidelines. The guide states a couple of items that need to be considered concerning the user experience. One such thing is that the application should be optimized for a short loading time. The reason is that while users may experience longer loading times outside the virtual environment, they have ample opportunities to do something else in the meantime. For example, look at their phone, which is much harder to do in VR with an HMD. To help with cybersickness the guide states that ideally, the render time of a frame should be below 20ms. Above 20ms, users start reporting being less immersed and comfortable. When the render time exceeds 60ms, the disjunction between the head movement in real life and VR starts to cause discomfort and disorientation. Furthermore, having a slightly higher render time is not as bad as having a highly variable render time. Besides Oculus, other major developers have released best practice guides for designing VR environments, such as Unreal Engine [3]. One notable statement from Unreal Engine is that "the scale of objects in a VR environment should mimic reality as closely as possible," as the difference between the real world and the VR environment could lead to confusion and cybersickness.

D.6   Dataset

For this study, we need a 360° video library. To acquire said library, we looked at multiple studies concerning the creation of data around 360° videos and VR with HMDs to see if they contain usable 360° videos. When looking for a suitable library, we consider the following for the separate videos:

- Duration of the video

- Quality of the video

- Subject of the video

Looking at the use cases described in Section D.4.1 again, we can narrow down how we need to handle these items. First, the subject of the videos. When performing a search task, the user should be able to easily identify if a video is about the subject the user is searching for. This is because manipulating the timeline of the videos is not part of this study. Take the search task "Look for a red car" as an example. Once the user interacts with the thumbnail, the red car should not appear after 10 minutes, as this would influence the completion time in a non-desirable manner. Therefore, it is also necessary for the search tasks to be unambiguous. The same applies to the video subject. This consideration also ties into the duration of the videos. It does not matter how long the video is as long as the subject of the video is clear from the start of the video until the end. As for the quality of the videos, Hosseini [23] states that for 360° video, the functional minimal resolution is 4K, and 8K is desired. However, as Vermast states [53], the thumbnails are smaller in size compared to the sphere surrounding users when playing 360° videos. This means that we are not bound to the functional minimal resolution of 4K and can use 360° videos of a lower resolution. This also has the added benefit of needing a lower bandwidth when streaming the 360° videos.

D.6.1   Available Datasets

There are a lot of available datasets containing 360° videos. Table 31 shows an overview of some available datasets. In this table, N/A in the column "# of categories" indicates that the publishing paper did not categorize the videos. For the datasets from Vermast[53], Lo et al.[36], and Li et al.[33], not all the videos are available at the time of writing.

Many datasets contain data besides the video, such as Head Movement (HM) and Eye Movement (EM). With this data, it is possible to create a heat map of a video where the user is looking (saliency maps). However, for this study, HM and EM data are not needed. What could be interesting is if a dataset already contains a categorization of its videos. Vermast[53], Jun et al.[26], and David et al.[12] divide the videos based on high-level attributes of a video such as Animal, City/Urban, Indoor/Outdoor, and Underwater. On the other hand, Lo et al.[36] categorize the videos based on the pace of the videos.

Dataset	Release year	Dataset Size	# of categories	Used video length	Resolution
Vermast[53]	2022	90	6	30 seconds	1080p
Chakareski et al.[10]	2021	15	N/A	10 or 36 seconds	8K
Jun et al. [26]	2020	80	5	20 seconds	1080p to 4K
Li et al.[34]	2018	60	N/A	10 to 23 seconds	4K to 8K
David et al.[12]	2018	19	6	20 seconds	4K
Lo et al.[36]	2017	20	3	60 seconds	4K
Li et al.[33]	2017	73	N/A	37 to 668 seconds	1080p to 4K

Table 31: Overview of some of the available 360° video datasets

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