Interaction design for professional virtual reality training applications

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Human Technology Relations
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Summary

Photo: Mark Wagtendonk

Summary

Virtual reality (VR) allows for embodied experiences and environments that approximate reality to a higher degree than any technology before it. The user forms conscious and unconscious expectations of an environment, and if these expectations cannot be met, the user experience will be negatively impacted. If the environment and method of interaction is in line with the user's expectations they more easily accept the environment as reality, which results in a positive experience for the user.
This project aims to create a model for optimizing the user experience in VR through the process of interaction design, and validates this model based on a training case for KLM Royal Dutch Airlines. One of the outcomes of the model is that it may be beneficial for the overall experience to deliberately choose for an environment that contains aspects that are farther from reality in order to influence the user's expectations and keep them in line with the maximum accuracy level the environment is able to achieve due to e.g. technical limitations. To validate the choices made for the case study, a prototype was developed and tested with cabin crew trainees and trainers.

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Introduction

Photo: Mark Wagtendonk

Chapter Introduction

The following introduction will give an introduction of the project's aim, and will outline the report structure.

Introduction

KLM Royal Dutch Airlines is always looking for ways to improve their services. KLM's Employees are rigorously trained in order to ensure they are capable of delivering services that adhere to KLM's standards (both in terms of safety and customer service). Those training programmes not only aim to transfer knowledge to their employees, but most importantly to allow them to experience possible real-life situations first-hand.

These real-life situations take place through simulations, ranging from fully functioning cockpit simulators to role-playing in a classroom. KLM aims to make these simulations as close to reality as possible, while keeping an eye on the cost-effectiveness curve and maintaining the safety of her employees.

Virtual reality (VR) can serve as a useful tool to positively contribute to both aspects, however there are some aspects that need to be taken into account when implementing this into the training programme in an optimal manner. This project was initiated by KLM in collaboration with the University of Twente with the aim to find ways to achieve these optima through a case study. The case study is split up in two parts, completed by T.V. Simons and J. Westenbroek, respectively. This report will elaborate on the interaction design aspect of the case, while J. Westenbroek's report **[1]** will focus on the aspect of modularity of implementing VR within KLM.

Both reports will start with an orientation of the company and current status of VR within KLM, providing a collective basis for further research. This phase was conducted by T.V. Simons and J. Westenbroek together. This report will continue with an analysis of the facets that should be considered when designing for user interaction. This will then be applied to generate a blueprint for a specific training, after which the details of this blueprint will be filled in, and a prototype will be created. A use test of the prototype will be performed, and recommendations to improve the interaction will be outlined where applicable. The report will conclude with a convergence of the results outlined in this report with the results of J. Westenbroek, as well as discussing future implementation within KLM.

VR is a broad concept, and not everyone might have the same idea as to what it does and does not include. In this report, VR will be understood to encompass the generation of certain sensory input to create a certain environment to achieve a certain experience. This includes, but is not limited to, headsets generating audio-visual input commonly referred to when discussing VR.

Definitions
This report will use certain terms to describe common features of VR and design. Throughout the report, a concise explanation will be given of these terms where necessary, as to avoid disrupting the flow of the text. A complete list of these terms can be found in the glossary.

Photo: Mark Wagtendonk

1 Orientation

Photo: Mark Wagtendonk

Chapter Introduction

The following chapter was collectively written by T.V. Simons and J. Westenbroek. The orientation is relevant as a basis for both projects, as it will provide some background information on KLM (the company for which this project was completed), their trainings, and how VR can contribute and has contributed to these trainings. Once the background of the current state of (VR-)trainig courses is established, two scopes will be defined for the project of T.V. Simons and J. Westenbroek, respectively.

Chapter 1 - Orientation

1.1 Company Context

As was mentioned in the report's introduction, this project has been initiated by KLM Royal Dutch Airlines (KLM). KLM is the oldest airline still operating under its original name. KLM and KLM Cityhopper form the core of KLM group, and together take care of the transport of 30 million passengers and 635.000 tons of cargo each year. As an airline transportation company, KLM focusses on creating a memorable experience for their customers. This is done through making them feel recognized, at ease, comfortable and touched **[2]**. In order to achieve this, the training of new personnel is done very diligently. Since all personnel acts as a "beacon" that communicate KLM's desired image, it is important that they expresses this vision in their daily work. In order to realize this, it is desirable that the personnel is trained accordingly.

For the remainder of the report, "KLM" will refer to KLM Group, meaning both KLM and her subsidiaries, unless specified otherwise.

KLM Cityhopper, also known as KLC, is a subsidiary of KLM. KLC is currently experimenting with VR, trying to find the most important use cases on their current training methods. The development is currently in an early stage, and further integration of VR technology into the training programme is one of the ambitions of the training department of KLC. One of the first experiments, which is in a try-out phase right now, is a simple 3D-scanned environment in which trainees are able to select points of interest. Once selected, information about it will be displayed. However, even though these VR applications are simple and do not contain a lot of possibilities in terms of interaction, KLC expects that more intricate VR simulations can become more common in the future, thereby allow for more intricate training methods.

Stakeholders

When discussing the implementation of VR within KLM, it is important to take all stakeholders into account relating to digital trainings. *Fig.1* visualizes the list of stakeholders for digital trainings within KLM, and how they are connected to one another. Each group is elaborated on in the following paragraphs.

Trainers

Trainers are KLM employees with several years of work experience. They completed special training that allows them to train trainees in a particular field. Their aim is to transfer knowledge to the trainees, and test it in an efficient and engaging manner. They are in charge of training multiple trainees at the same time and need to be able to observe the trainees' actions in order to provide feedback.

Trainees

Trainees are typically young people who are completing a training programme to become cabin crew. Trainees following an initial training are completely new to the aircraft layout and regulations, and the trainings serve to familiarize them with these aspects, as well as prepare them for real-life scenarios.

Recurrent trainees are personnel that has been active within the company for at least one year, and trainings serve to keep their knowledge and skills up to date. The trainees and trainers are essentially the most important stakeholders for this project with regard to the VR interactions that should be taken into account when designing a training simulation. The behaviour the trainees will exhibit through hands-on use with the simulation during development and the current trainings will mostly be used to determine the requirements for the design. Without them being satisfied with the results, the VR simulation will not have any chance of becoming an accepted alternative to a regular training. Therefore, using their input and feedback is very important during the development process.

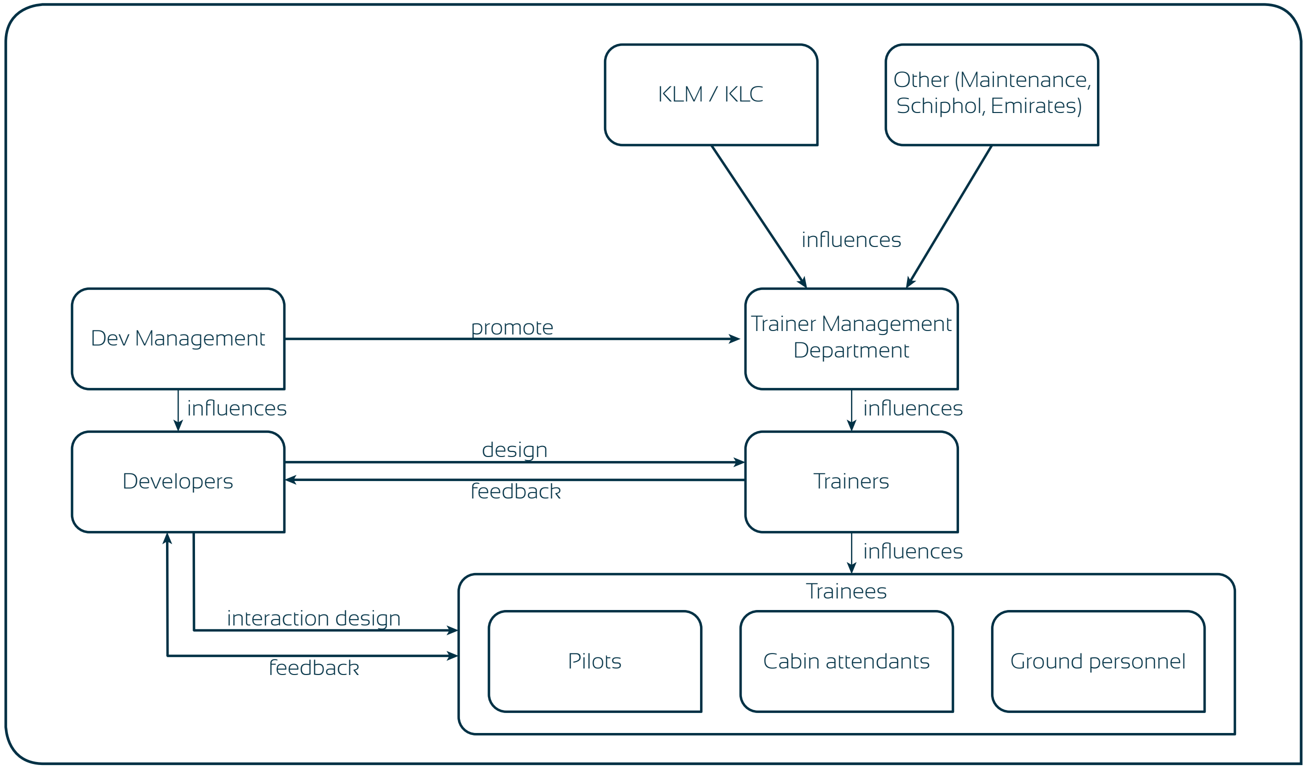


Fig.1: Stakeholders

Management

The management of KLM and KLC is in charge of making strategic company decisions.
Van der Meer **[3]** states the following as the primary reasons for implementation of VR and augmented reality (AR) technologies into the KLM business strategy:

- Less dependency on simulator suppliers
- Increased customization and control of the training methods
- Improved insight and awareness amongst the crew as a result of the teaching

.

These arguments were generally reiterated by KLC's management as reasons to explore options for the implementation of VR in the training curriculum. However, despite being generally positive about incorporating VR into the training curriculum, the techniques have currently not yet proven themselves enough to allow for large-scale investments within KLC. By demonstrating these assumptions through a proof of concept VR training, these hesitations

Where VR aims to replace the real world sensory input with computer-controlled virtual input, AR layers virtual input on top of the sensory input of the real world.

can be reduced, or eliminated entirely in the best case.

Developers
VR technologies require developers to create and maintain the training software. They possess the technical skills to create new features and are eager to develop new products for KLM. They have access to an extensive pool of trainees and trainers to test their products. They should be able to understand and translate the needs of the trainers and trainees to be able to improve the training application. "Developers" is of course a wide concept and consists of different types of developers that are needed in the development of a VR simulation. The following list serves to give an impression of the types of developers that hold important roles in projects like this one:

- Programmers
- 3D modellers
- Animators
- Interaction designers
- Sound designers
- Particle artists
- GUI designers

1.2 Technology context

As is mentioned in section 1.1, VR is being experimented with, in order to find possible implementations within the company. However, before any further substantiated choices can be made for a next step in VR trainings, a better understanding of the value of VR for these kinds of training applications should be gained. An overview of the technologies currently available will be given to give an impression of the possibilities and scale of VR within KLM.

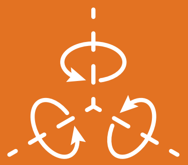
The value of VR
The aim of training KLM's personnel is not only to convey the knowledge of a certain task, but also to allow the trainees to bring this knowledge into practice. Bringing these skills into practice is an essential part of gaining insight into what it is like to be in a certain situation. This concept has been explored by Thomas Nagel in the paper "What is it like to be a bat?" **[4]**. One could posses all the knowledge about a bat, but still never be able to fully imagine the experience of what it is like to perceive the surrounding world via a system of reflected high-frequency sound signals. John Gardner coins the term "psychic distance" for this discrepancy between knowledge and experience, or between the experiences of one person and the ability of another person to imagine the experience of being in this situation **[5]**.VR allows for the psychic distance to be reduced further than any other medium before it, allowing for experiences that would otherwise be impossible **[6]**.This makes VR a useful tool to bestow the relevant skills upon personnel, however there are still many VR devices that, in varying degrees, can be used for this purpose.

VR Technologies at KLM
Different VR devices are able to reduce the psychic distance, or certain aspects of it, in different amounts. Most VR devices focus on the visual aspect, supported by audio, however there are also several solutions to emulate other senses, such as those for haptic feedback. For the scope of this research, an overview was made of the VR devices KLM has available, and what their (lack of) features are. Since KLM is experimenting with different

Haptic feedback
Feedback relating to the sense of touch; a collection of tactile (the sensation of surfaces) and kinaesthetic feedback (the sensation of forces). **[7]**

VR devices, the device with the appropriate features should be chosen for further development of the simulation. Aside from the devices KLM has available, there are other options available in the market that may have desirable features. Naming all of these devices would be too much for this project, however in case future choices require a certain feature not available in the devices KLM currently has, these devices may be individually explored. Besides these existing devices, it is a reasonable assumption to say that in the future VR will offer many more technical possibilities, and as long as the developers of VR applications can utilize these features, many different experiences can be shaped. KLM owns the following hardware, meaning these devices are available to test with.

3DOF
3 degrees of freedom. Only rotation will be tracked.



6DOF
6 degrees of freedom. Position and rotation will be tracked

Gear VR

GearVR headsets (*Fig.2*) are the devices currently used by KLC for VR trainings. These devices consist of two parts: a regular Samsung phone, and a headset where the phone is plugged into.

The general advantages of the Gear VR are its wireless capability, being a self-contained device (no pc is needed), and the concept of being able to use the phone you already own. A major downside of the gear VR is that the headset (currently) only supports 3 degrees of freedom (3DOF), meaning only the orientation, but not the position will be traked. The Gear VR supports a 3DOF controller. Currently, however, there is only support for a single controller, meaning only 1 hand can be used in VR. Even if this device would be able to track the user's position in space, it is doubtful that this information could be able to be used for room-scale solutions. A 6 degree of freedom (6DOF) device would require real time rendering of the environment dependent on the point of view, which might be too much for a mobile device.

Fig.2: Gear VR

Room-scale
The movement area of an average room. A minimum of approximately 2 x 2 meters in the context of this project.

Oculus Go

The Oculus Go is a standalone headset that allows for 3DOF movement (*Fig.3*). It is similar to the Gear VR in functionality, but due to its

Fig.3: Oculus Go

singular focus on VR, it is more optimized for this purpose. A 3DOF controller is included with the headset. Its compactness as a standalone device is one of the advantages of this device. On the downside, the restrictions in the freedom of movement limits the applicability of this device.

Lenovo Mirage Solo

The Lenovo Mirage Solo is a standalone headset that is able to track both the position and rotation of the user (6DOF) (*Fig.4*). It tracks the user's position through 2 front-facing cameras that constantly record the environment and calculate the position based on that stereoscopic input (inside-out tracking). The controller, however, only has 3DOF, limiting the positional accuracy. The 6DOF headset

Fig.4: Lenovo Mirage Solo

allows the user to pick their own point of view, but because of the limitations of the controller, interaction possibilities are still limited. There are options to select approximations for the positional movement of the user's arm based of the rotation of the controller, but these will never line up perfectly and are an unfortunate compromise due to the technical limitations at this time.

Inside-out Tracking
Positional tracking technology that is integrated in the VR device.

Outside-In tracking
Positional tracking technology that requires external devices.

HTC Vive (Pro)

KLM also owns several HTC Vive sets: 6DOF VR devices with outside-in tracking using external base stations. The sensors of the device provide motion tracking in a maximum region of approximately 5x5 meters, although a new version of the base stations were released shortly before the publication of this report to allow for tracking in a larger area. The HTC Vive

Fig.5: HTC Vive Pro set

also has a high-end variant that is marketed towards professional users (Vive pro). This headset has higher resolution screens and two front-facing cameras in a stereoscopic layout. Both the Vive and Vive Pro have two controllers that track in 6DOF, and it supports additional trackers if needed. A complete Vive Pro set is depicted in *Fig.5*. The downside is that this device requires a PC to function, and it is cabled, limiting the freedom of movement of the user. The trade-off here is that a PC is usually better equipped to perform complex graphical calculations than a mobile phone. There are however other solutions to overcome these limitations. There are dedicated VR Backpack-PCs that remove the issue of a cable to a stationary PC somewhere in the room, and shortly before publication of this report, a wireless adapter was released that would resolve this disadvantage in another way.

Manus VR

The devices mentioned before focus primarily on visual input. However, there are also VR devices that focus on emulating different sensory inputs. Manus VR makes gloves that enable a user's fingers and stance of the hand to be tracked (see *Fig.6*). It hereby allows a hand model to be generated in line with the user's proprioception. This model can then be visualized using other VR devices, such as the HTC Vive. Although the relative position and orientation of the fingers can be tracked by these gloves, a third party tracking solution is required to position the hands relative to other objects in the environment.

Fig.6: Manus VR gloves

Future

KLM is constantly investigating possibilities for new equipment to use. Development and succession of devices such as the Oculus Quest **[8]** and Vive focus **[9]** are being followed closely. Considering the rapid change and development of VR (and AR) technologies on the market, any training application made should be relatively independent of current technological possibilities. KLM management has to make a decision how much they are willing to invest in this technology. Spending more money on VR development will mostly deliver devices with better specifications, but at a certain point the improvement in the training context may not be worth the extra investment. The training application should therefore not be limited to a single device, but be a general framework that can easily be ported to several devices, or cross platform by design if possible.

Proprioception
The sense of the position of one's body parts relative to each other.

1.3 KLM Trainings

Parallel to understanding the technological background of VR devices within KLM, an understanding of trainings in general should be gained. This way the current possibilities and the (legal) requirements could be drafted. Future sections will further elaborate on these requirements. After observing existing non-VR trainings, several VR trainings were observed in order to map the current state of implementation of VR in trainings, and to establish a base for further development.

Training courses in general

KLM has extensive training programmes for their personnel and personnel of external partners, across many departments. Departments range from cabin crew and pilots to engineering crew and vehicle operators. Partners for example include Schiphol Airport. Each training aims to train a specific task for a specific group of employees. Training in this context both refers to teaching a new skill, as well as assessing the proficiency of the skill. Although there are many different trainings, a certain level of consistency between them is desirable for KLM, as this will support the intended image of the company.

At the moment, all training courses within KLM are designated either to be compliant or non-compliant. Compliant training courses are mandatory, either by law or because KLM requires their employees to possess the skills of those trainings. Non-compliant traing courses are facultative, and can be completed by employees on a voluntary basis.

Because KLM is a big company, and each training is specialized, there are too many trainings to be able to evaluate all of them, in order to determine whether or not VR can be a beneficial alternative to the implementaion of the current training at this time. In the early stages of the project, contact was established with KLC's training department in order to gain a better understanding of the trainings they offer for their cabin crew. KLC was already offering their trainees several training courses in VR, and had the intention to expand this implementation. Training courses for KLC cabin crew can be split up into two categories: service trainings and safety & security trainings.

Service trainings

KLC cabin crew is trained in how to perform a variety of service tasks on board of the aircraft. These training courses include an aircraft visit, intended to familiarize the trainees with their future work environment, and communication training courses in order to effectively communicate with passengers.

Safety & security trainings

Safety training courses aim to educate KLC cabin crew on how to deal with emergency situations. This can range from providing first aid to passengers, to putting out fires during flight. Safety trainings are highly regulated in protocols considering their legal requirements and importance. Safety and security trainings are supervised by the Human Environment and Transport Inspectorate, but are developed by the airline.

1.4 KLM VR trainings

Within the context discussed in section 1.3, there is already a subset of trainings that use some of the devices discussed in section 1.2 during training courses. In order to gain an understanding of the current stages of VR implementation in training applications, several implementations of VR trainings were observed within KLC, but also within the rest of KLM. These observations provide an impression of the current state of adoption of VR within KLC, but also provide a basis for the adoption of VR in other departments of KLM. These implementations serve as a point of reference for the integration of the devices mentioned in section 1.2 within the company.

KLC – Aircraft visit

The aircraft visit training consisted of two 360-degree videos of an aircraft visit, during which a variety of information specific to that type of aircraft was explained.

Several Samsung Gear VR devices (described in section 1.2) were setup by the trainer before the trainees arrived by loading the desired application. In order to do this, the trainer had to put on each headset individually to navigate to the appropriate application.

Although the phone is removable, inserting the phone into the headset automatically loads the Oculus home environment (the main menu of the device), and the desired application has to be selected from that menu while in VR.

Apart from this, the side of the headset has a touchpad area that is a slight indentation in the housing of the headset. Its surface is seamlessly integrated with the rest of the headset, which makes the touchpad lack the proper affordance of an input area. Since this is also the natural area where the user holds the device when putting it on, accidental inputs were frequent, and their source obscure for the user. The chance of this occurrence is amplified because the trainer takes off the headset, and the trainee puts it on again. In case this happens there is a big chance the app should be started again from the Oculus home menu. This is an unfortunate incident, as the selection interface is cluttered with ads for other apps and the interface is not intuitive, so it is easy for trainees to lose their bearing.

Affordance
The properties of an object that hint towards its intended use **[10][11]** .

“What should I do now?” was a commonly heard phrase when trainees put on their headset for the first time. The trainer then had to help each trainee individually, which negated the effort the trainer put in beforehand by preloading the headsets. This can also be a problem in the future, as it cancels out part of the scalability of VR compared to regular training approaches. Often, the trainer had to do the setup again (by taking the headset, putting it on, selecting the app, and returning the headset to the trainee).

All together, the setup before the trainees entered took around 45 minutes. Once the trainees entered and all had their headset, the trainer was still helping trainees start the training session for around 15 minutes. This while the actual training itself only lasted 10 minutes. See *Fig.7* for an impression of the training. Because the trainer could not see what the trainees were seeing, the trainer and trainees were constantly verbally confirming whether or not the training had started and if the trainees were seeing the correct menus. This discrepancy in the time spent setting up the technology and actually spending time training is an undesirable scenario for both trainers and trainees.

Fig.7: Trainees attending the VR aircraft visit training

The training itself consisted of 2 360-degree videos (lasting 4 and 6 minutes, respectively) where an aircraft visit was simulated. In the videos, someone gave a tour at different points of interest in the aircraft, and trainees could look around by moving their head (see *Fig.8*).

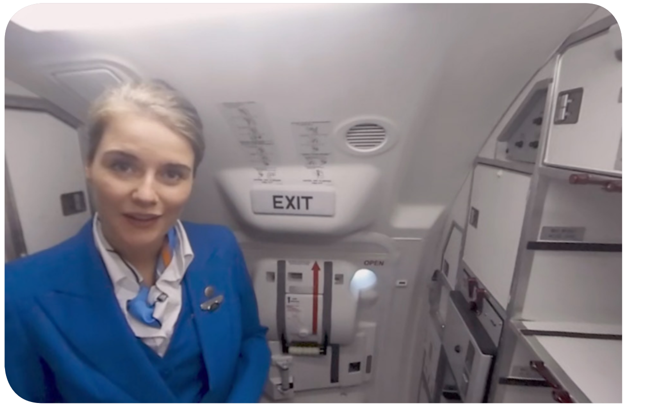


Fig.8: Screenshot of the KLC aircraft visit training.

After observing the current implementation of the GearVR, it became clear some of the advantages of this device were not relevant for the current implementation. The trainings were held in a classroom and the phones were stored in the training department and only used as VR screen, they were not the students' own devices.

The wirelessness was also not used, as the students sat down on still standing chairs to watch the training videos. There were also no controllers present, so all interaction had to take place with gazing at a menu item for a certain amount of time. The problem with the lack of motion tracking is that it interferes with the wirelessness of the device. You are technically able to move around in space, but this is undesirable since the motion is not tracked in the virtual world.

After the training had concluded, some trainees had to leave the room because they felt nauseated. Some trainees also reported a headache. When asked if this is a frequent occurrence among trainees, the trainer said that there are always some people in the group that experience these symptoms. Section 2.2 in T.V. Simons' report further examines the phenomenon of VR sickness.

Trainees were asked whether or not they thought the virtual tour to be useful for their education. The trainees at this time already had visited the aircraft in question, so the training was only repeating what they had already heard. They noted it was useful to refresh their memory, but doubted it would be clear enough if they had this training instead of the aircraft visit, due to the limited point of view the training offered. One trainee noted he preferred the real visit, because you would be able to look up closer, freely move, change viewing angle and interact with the environment (such as opening cabinets, etc.).

They also noted that they were constantly reminded although the videos were 360 degrees, they were not stereoscopic, so no depth could be perceived. Besides this, only looking horizontally would give the correct height perception, looking up or down would make you seem very small or large, respectively.

Evacuation training

Another implementation of VR for training purposes is an evacuation exercise for the engineering department that takes place in a hangar (see *Fig.9*). This training is more interactive than the aircraft visit: it allows the

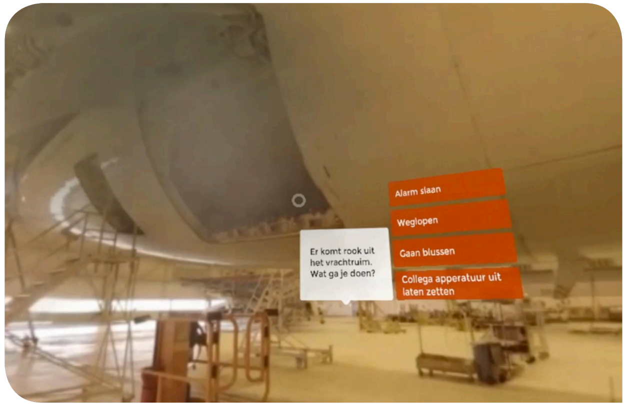


Fig.9: Screenshot of the evacuation training

user to choose one of several multiple-choice options throughout different moments in the training as to where to go, what to do, etc. The choices the user makes influences the outcome of the training. The user is however not able to move in space, but only able to look around in the 360 degree video environment. The VR environment allows users to feel more present in the environment, as they have to physically look around to find options as to what to do; if there are two doors on opposite sides of the hangar, the user has to physically look both ways and make a choice to go through one of them. This gives an increased sense of actually being in the hangar, but this sense of presence is still limited since positional movement of the user will not translate to movement in the virtual space, and inputs are given by selecting textbox options representing the trainees' actions.

Pre-flight safety checklist

The department of Crew Safety and Security Training of KLM (CSST) has developed a VR version of the pre flight checklist training (see *Fig.10*). Cabin crew must complete a pre flight checklist before a flight to ensure all equipment is present and usable, and no foreign objects are present in the cabin. During the training, the trainee must navigate towards the backside of the aircraft and complete the checklist by locating the item on the list, and selecting via a menu option whether is flight ready as prescribed by the protocol. This training makes use of a 6DOF room scale VR solution, meaning the user has positional freedom, as well as rotational freedom (see section 1.2 for more details). This as opposed to the two trainings mentioned before, where the trainee only has rotational freedom (3DOF).

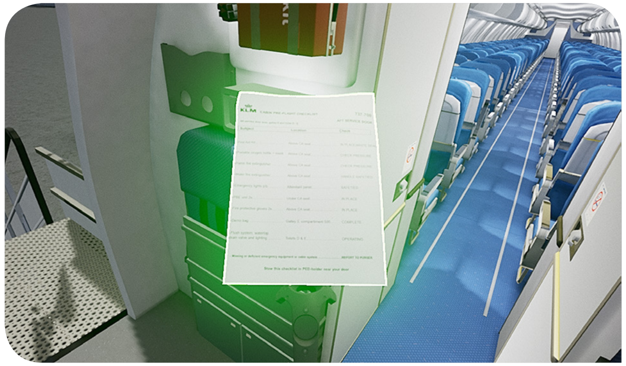


Fig.10: Screenshot of the pre-flight safety checklist

The trainers of this training mentioned several concerns for this training, one of which was that trainees often performed unwanted actions, such as teleporting themselves across the aircraft when trying to pick up items. Besides this, the training used a virtual controller model to represent the actual controller position and orientation, and although this was an accurate representation of reality, it did not aid the user in determining how to perform certain actions with the controller.

Teleporting
Instantaneously transporting one's point of view to a different position in the virtual environment. This allows for movement within areas larger than the physically available space.

1.5 SWOT analysis

In order to assess the potential of VR for trainings for KLM group, a SWOT analysis was performed in order to see what asepects to leverage, and what issues to take into account when using VR instead of a regular training at KLM. *Fig.11* on the next page visualizes the summary of the SWOT analysis.

Strengths

If implemented correctly, virtual reality environments can provide an immersive experience. This experience can fully absorb the user into the virtual environment and tasks. This form of immersive experience is the greatest strength of VR as it allows for a significant reduction in the psychic distance by inhabiting a certain point of view, as described in section 1.2. Besides this, utilizing VR, developers of trainings will be able to rapidly implement their ideas in an immersive environment. This improves the development

SWOT analysis
Analysis of the strengths (S), weaknesses(W), opportunities (O) and threats (T) of a project or choice.

process greatly, as developers are able to more easily test their ideas and make improvements early on in the project's development phases, compared to regular trainings. On the other hand, VR simulations allows trainers to easily configure trainings to their needs, if implemented in a scalable manner.

Weaknesses

Of course, virtual reality technologies have their weaknesses as well. One of the most important weaknesses is the fact that current VR hardware is still limited in emulating all senses accurately. Haptic feedback, for example, is still limited to an approximation, mostly only on certain areas of the body. This limits the immersive properties of VR and is an aspect that needs to be dealt with. Furthermore, current hardware limits users to move freely in a large area. The current hardware only allows people to move within a small area. However this functionality of the hardware is quickly improving and might be interesting to look at in future scenarios.

Like most technology, interaction in VR takes place through an interface. This can be a controller of some sort, or more natural feeling interfaces, such as hand tracked solutions. Because VR aims to simulate reality by

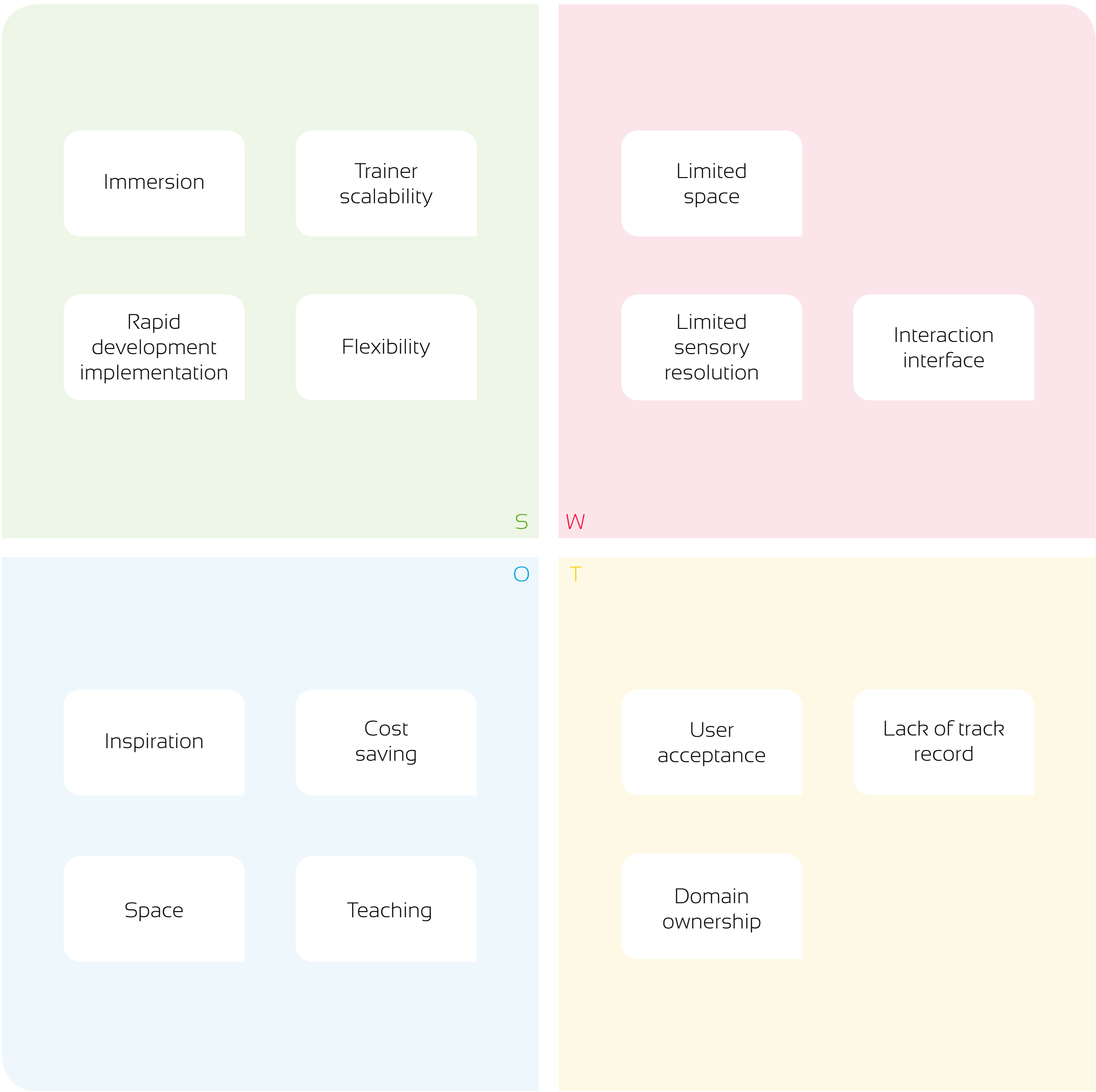


Fig.11: SWOT analysis of VR for KLM trainings

removing and replacing the sensory input of the real environment with that of the virtual environment, an appropriate interaction interface should be found to facilitate the user's natural interaction intent.

Opportunities

Virtual reality provides many opportunities. It can be used in many scenarios for different purposes, all enabling the user to either learn through it, get trained by it, enjoy it and have new experiences in it. All these possibilities arise once VR is implemented effectively. With that being said, it is clear for companies like KLM that VR offers several opportunities. At the moment, virtual reality is an emerging technology within KLM, and in some cases, VR can offer a fairly cheap alternative to current training equipment. For trainings that require a specific environment such as cockpit simulators or airplane cabins, it is not necessary to build these complete environments since it is possible to shape any room to a virtual environment of choice.

Apart from being cost saving in the right circumstances, the technology also enables trainers to provide more realism to their trainings, in order for them to be more effective. Virtual reality has been proven to be very effective for educational purposes, allowing trainees to more quickly absorb and retain the provided information **[12]**.

The configurability of a single space into multiple different training areas is also a a great opportunity of implementing VR into the training curriculum. In the current situation, KLM has an entire hangar full with dedicated flight simulators. This space is not able to be used for any other purpose. VR offers the possibility to create many kinds of environment in a single space, meaning the space will be able to be used more flexibly.

VR is a novel technology for KLM. This novelty instigates inspiration and interest, as many people see the value VR can have. This serves as a simulant to acquire investments for the development of VR within KLM.

Threats

The novelty of VR can also translate to a threat, because it has a lack of track record within the company. Virtual development still needs a lot of research and in order to create VR environments that appropriately suit the needs of each use case. Developers need time and much in depth knowledge to accommodate for these needs. This threat will subside in the future, once the best practices of VR are more generally established. Therefore, at the moment it is of great importance to stay aware of the progression of the technology, as this knowledge will be of great value to KLM.

User acceptance is another threat that needs to be addressed. Both trainers and trainees will have to work with the technology. In case they fail to see the added value, or interacting with the technology is too complex or in another way uncomfortable, end users will be reluctant to change their working method to include VR. Keeping the usage accessible to as many people as possible should be a high priority.

Implementation of VR requires many different disciplines to converge in a single training. Due to the novelty of the technology within KLM, it is currently still ambiguous as to which department is responsible for the creation of these trainings. The IT department may feel responsible for the technical implementation of a training, while the Learning and Development department cares more about the training's content. This domain ownership is a threat, as it can create confusion and leads to similar projects being started parallel to each other. Some departments may also feel that others are invading their domain because of this.

1.6 Training scope

As the SWOT analysis outlines, there are many strengths and opportunities that would positivley contribute to the further implementation of VR for trainings within KLM. There are however several weaknesses and threats that need to be addressed to ensure this implementation happens smoothly, For this purpose, a case study will be outlined to serve as an example and blueprint for furter development. A brief discussion was held with the head of KLC's training department to determine the best training option to implement for this case. It was stated that there are extensive plans to incorporate VR into the training programme, but the implementation is still in its infancy. Providing a fitting case as example, this implementation can be aided.

Plans range from simple aircraft visits in VR to complete passenger interaction in VR. From a standpoint of the current implementation the next logical step is to include simple interactions in the VR trainings. This way a stronger sense of presence in the virtual environment can be created as the trainees are no longer merely observer of the virtual world, but are able to manipulate it as well.

KLM's safety trainings in particular will be able to emulate real life effects more accurately in VR. If the trainee makes mistakes, the consequences can be simulated and experienced by them without endangering their safety. There is also more variation possible, forcing the trainees to apply their training in a dynamic environment. If these safety trainings prove successful, expansions can possibly be made to service trainings, with less need for actors for role-playing. The next step would therefore be to introduce more natural, embodied interaction, but still defined enough not to require advanced AI at this stage.

For these purposes the implementation, a safety training, specifically a fire fighting exercise, is a suitable option. This has several reasons:

- Safety trainings are highly protocolled, and therefore have more defined interaction. This means the interaction possibilities are more easily programmable.
- Safety trainings allow for sufficient interaction, giving the trainees the freedom to make their own choices.
- No complex human artificial intelligence (AI) needs to be programmed.
- Applying a fire-safety training in VR will be inherently safer than a real fire training.
- VR allows for a more realistic implementation of the fire-safety training compared to the current training environment.
- It is possible to let trainees fail the exercise and experience the consequences of wrongful actions without endangering their safety.
- The fire-safety protocol is varied enough to not be predictable, which will force trainees to think for themselves instead of relying too much on the execution of a set of predetermined actions.
- For further application of other trainings, VR allows for extension of this variability. The same virtual environment can be reused for multiple types of trainings, whereby trainees may not even be informed of the scenario that they will encounter. This will even further reduce the anticipation of a certain event.

During the discussions with KLC, it became clear that the integration of a training as a compliant training would have many conditions, which all would have their own forms of intricacies. The realism of such a VR fire-safety training has to be of a certain level in order for the training to be sanctioned by the Human Environment and Transport Inspectorate.

With this knowledge, the choice was made to go into depth on one of the training protocols of this training. KLC saw the most benefit in the oven fire protocol (one scenario of the fire-safety protocol), due to it being a protocol that uses many of the most important interactions in the aircraft cabin.

To gain understanding in the actions the trainee should be able to take in order to deal with a fire-safety event, the manual of a fire-safety training was obtained and a real-life training was observed and participated in.

The manual outlines the procedures the cabin crew should follow in case of a fire on board. This includes different locations of the fires, different fuel sources, and different protocols to handle those fires.

The current fire-safety training itself took place in a specialized cabin (see *Fig.12* and *Fig.13*). This cabin consisted of a steel construction resembling part of an aircraft cabin. One side of the aisle had several steel chairs, and the other side had a glass wall behind which the non-participating trainees could observe.

One trainer was inside the cabin assisting trainees in reminding them which actions to take, while the other trainer was outside the cabin and could control where the fire would originate through a simple wall panel. The cabin could fill with smoke if this setting was selected on the panel. The fire origin points had sensors to notice extinguishing and some places would reignite if the proper procedures were not followed. For example, the laptop dummy would reignite if water was not thrown on the laptop after extinguishing, and the oven would reignite if the galley power wasn't turned off (as dictated by the protocol).

Fig.12: Current fire-safety training (image source: [3])

Fig.13: Current fire-safety training (image source: [3])

There was a fake intercom to communicate with the cockpit (a role assumed by the trainers), and an alarm light above the lavatory that would turn on in case of a fire. No audible alarm would go off, however, unlike in a real aircraft.

The extinguisher was similar though not exactly the same as a real halon extinguisher used on board, and had little recoil when used. Although the fire was real, little to no heat could be felt even when standing in close proximity. The trainees would put on safety gloves and a PBE mask before entering the cabin. Although optional according to the protocol, this was done to familiarize trainees with the feeling of wearing this equipment.

The fire extinguisher used was filled with water instead of halon, and lasted around 10 seconds, just like real extinguishers. The safety pin was not inserted during the trainings. Some lacked a safety pin altogether. The laptop dummy was fixed to the tray table, so it could not be removed and submersed in water, like would be done in a real situation.

Halon
Chemical fire extinguishing agent used on board of aircrafts.

PBE mask
Protective breathing equipment mask (smoke hood)

Trainees were at ease and thought the training was fun to do, which is not the same state as would be felt in a real situation. One of the trainers also told us that she would probably act different in a real situation than the calm response in the training environment, indicating even the current training fell short in terms of realism.

If the training could take place in a more realistic setting, more accurate behaviour might be evoked, and KLM will be able to increase the preparedness of cabin crew for a real-life emergency. VR can be a very useful tool in this context as to provide a more realistic setting while not endangering the trainees' safety.

1.7 Problem statement and goal definition

KLM currently has the ambition to implement VR into its training curriculum. The current possibilities are however only utilizing limited functionality of the VR technology. Improvements can be gained in the areas of interactivity and user experience for the trainee. The flexible nature of VR environments will allow trainers to easily adapt their training setup to their ever-changing needs. In order to allow this, a modular setup of the VR application is essential.

Specifically KLC's fire-safety training shall be used as focus for a next step in implementating VR in the training curriculum. If implemented accurately, this training can allow for more variation and possibilities to experience the consequences of ones actions than a real-life fire safety training in a controlled environment.

T.V. Simons will focus on the trainee interaction aspect of the training. Because interaction in VR is only possible through an interface, the interaction must be intuitive enough not to hinder the user in their experience. Although KLC currently has several Gear VR headsets, the HTC Vive is more suited for the primary development, due to the native support for 6 degrees of freedom and access to a 6-DOF controller for each hand. The final training should allow trainees to complete the training without having to spend much time and effort on learning a new VR interaction interface.

J. Westenbroek will focus on the modularity of the VR training configuration. In future processes, the VR environment is to be developed and created more efficiently while changes are easily applied if necessary. These changes concern both trainers and developers, meaning that they play a significant role in future development. Developers are concerned with the back-end components, while trainers want a clear front-end modular experience. Either way, they both require the ability to access certain configurations. KLM has recently started development on a virtual platform, from which trainers will be able to obtain and control their virtual training. The results from the project act as a blueprint for this platform, as this project analyses the requirements for configurability.

In the next chapters of this report, the focus of T.V. Simons will be discussed in detail. In section 6.4 a common reflection will be held based on the results of both projects.

2 Analysis

Chapter Introduction

The focus of this project will be on the trainee side of the training, specifically how trainees will interact with the virtual environment in order to provide a smooth user experience. The following chapter will dive into the details of providing an optimal user experience in VR in general, and will conclude by applying these concepts to the fire-safety training.

Chapter 2 - Analysis

2.1 Trainee Experience

Providing the trainee with a good user experience is essential to ensure trainees feel comfortable in using VR devices and to achieve the optimal effect of the training. In order to allow for an optimal user experience for the trainees, it should be taken into account that the main focus of the training should not be how to interact with the VR environment, but to achieve the goal of the training as it is defined by KLM. In case of the fire-safety training, the goal is to train the procedures of extinguishing different types of fires in the aircraft cabin.

Although the concept of VR has existed quite a while now, it has not yet become as ubiquitous as e.g. personal computers. Input mechanisms for computers, such as mice and keyboards, have settled in through decades and could be considered mainstream. On the other hand, VR devices have had less opportunity for this mainstream adoption, due to their relatively recent availability to the general public. Additionally, the embodied experience of VR can lead to a quickened expectation of a natural form of interaction, rather than the more abstract interfaces of personal computers. With this in mind, one of the goals of this project is to allow trainees to go through a training course with minimal barrier in the interaction method. The training itself aims to educate trainees in certain areas, and the interaction should facilitate that, without them needing to spend much time on learning the controls of the application.

In order to gain a better understanding of how interaction methods can best be chosen for this goal, a better understanding should be gained in the factors that contribute to the user experience in VR.

2.2 VR Sickness

A large threat to a proper user experience is the existence of VR sickness. VR sickness is the uncomfortable feeling that can arise when a person is a VR environment. The symptoms include nausea and headache, and are sometimes comparable to motion sickness.

Only limited studies have been carried out on the subject of VR sickness. There are however some studies that can help gain a better understanding of the phenomenon.

Akiduki et al. **[13]** researched as to how conflicts in the visual and vestibular input caused motion sickness symptoms by using VR, and found that a mismatch between the two caused significantly higher subjective symptoms than when the inputs matched. This mismatch is also stated by Kolasinski **[14]** as an often-cited cause for the symptoms. Kolasinski also mentions other issues such as a low refresh rate or a different distance between the 2 image inputs and the user’s pupils.

All of these factors could explain why trainees became nauseous in the VR environment during the observerd training mentioned in section 1.4. While factors relating to the hardware are difficult to influence directly, designing the environment with this issue in mind is important to avoid trainees rejecting the technology as a whole.

2.3 Use experience model

When talking about VR, “immersion” is a commonly used word, but it is often used as a catch-all term to describe a desirable mental state that needs to be maximized. There is however a big distinction between this ideal mental state and the formal definition of “immersion”. In the following sections, the meaning of “immersion” will be discussed and how it, along with other aspects, relates to this mental state, which will be dubbed “user experience” (UX). Besides immersion, 4 other aspects will be defined, as they too contribute to the overall user experience. These aspects are based on talks from (VR-)developers, as well as literature studies.

Immersion

As stated before, immersion is often used as an interchangeable term for user experience, where a common notion is that increased immersion results in a better user experience. However, according to Slater, immersion “refers to the objective level of sensory fidelity a VR system provides” **[15]**. In other words, to which level can a simulation mimic real-life sensory inputs, and substitute those for the sensory input generated by the real world **[16]**. For VR this means that higher immersion can be achieved through, for example: a higher pixel density, a greater field of view (FOV), but also by adding real world props such as physical buttons or simulating these props, e.g. with specialized gloves that can give haptic feedback (see *Fig.14*). Slater not only refers to immersion in the context of VR, but also applies this definition to other simulations in the broadest sense of the word, including VR, AR, but also films, traditional games and even books (a “technology” that provides very low

Fild of View (FOV)
The extent to which a user can see the visible environment. Usually expressed in a horizontal and vertical angle.

Fig.14: HaptX gloves provide simulated haptic feedback [i]

immersion). Aside from the devices already described in this report, examples of immersive (VR) devices include a moving/vibrating floor to emulate e.g. the feeling of a car's movement, flight simulators, but also 4D cinemas, where effects such as smell are added (see *Fig.15*). Slater's definition will be used throughout this project when referring to immersion.

Fig.15: 4D cinemas add practical effects [ii]

Fidelity

Immersion in the content is distinct from the content itself; a movie played in a cinema on a big screen with surround sound is more immersive than the same movie played on a phone screen while on the train. This means that there has to be another aspect of the simulation that contributes to the user experience aside from just immersion. This aspect that defines the content itself can be referred to as fidelity. In the context of books for example, this refers the level of detail to which a writer is able to create and express a world and its characters.

The level of fidelity is a choice of the creators, and maximizing fidelity is not always the goal. When viewed from the perspective of films, different levels of fidelity can be found when looking at a traditionally animated film such as The Lion King, a CGI animated film such as Toy story, and a live action film such as The Dark Knight (see *Fig.16*). In the context of (VR-) games, a game like Superhot **[17]** has a low fidelity on purpose (the game takes place in a stylized environment), whereas a game like Call of Duty aims for more lifelike graphics (see *Fig.17*).

Expectation

Both Immersion and Fidelity are aspects of the environment that is presented to the user by the developer. The user has some pre-existing expectations, but the environment also allows shaping the expectations of the user to a certain extent for example through affordances. Gibson defines affordances as what the environment affords to the individual **[10]**. The term was popularized by Norman for application in the field of design to describe the properties of an object that hint towards its intended use **[11]**. If these affordances conflict with each other, products with limited usability can emerge, such as the teapot in *Fig.18*. Taking the concept of affordances into account is especially important in VR, where every possible interactable object has to be

Fig.16: Three films with different levels of fidelity. Left: The Lion King [iii]; middle: Toy Story [iv]; right: The Dark Knight [v].

Fig.17: A comparison of the fidelity of "Superhot" (left [vi]) and "Call of Duty: Modern Warfare 3" (right [vii])

preprogramed. For example: when providing the user with a VR environment with a table with certain objects on it, these objects will provide the affordances of being able to be picked up to the user. If this is possible, the user's expectations will be met (such as the black objects affording to be picked up in

Fig.18: Affordances of this teapot impede intended use [viii].

Fig.19: The black objects in "Superhot" provide the affordance of being picked up [vi]

Superhot, see *Fig.19*), but if this is not possible (or only certain objects allow this), the user will feel shorted, disrupting the experience **[18]**. An example of this is a door that is intended as a background element but is not able to be

Fig.20: The doorknob in Rick and Morty: Virtual Rick-ality is removable as it is a "real fake door", a joke from the show.

opened. The VR game Rick and Morty Virtual Rickality **[19]** solves this problem by making the doorknob interactable, but instead of opening the door, the user removes the doorknob from the door, which reveals a reference to the show on which the game is based (shown in *Fig.20*) **[21]**.

Besides these affordances, aspects of the VR environment can provoke other expectations that should be taken into account when designing the environment. It is important to realize that when the VR environment becomes more lifelike (higher immersion and fidelity), the user will also have higher expectations of that environment. Examples of this are detailed movement of leaves on trees, or accurate behaviour of simulated liquids. Giving an environment a lot of detail relating to the real world (high fidelity), will provide the user with conscious and unconscious cues, and will therefore expect the environment to behave in a realistic manner.

Presence

In the context of VR, presence is also a frequently used term. Slater describes presence as a user's subjective psychological response to a certain level of immersion **[15]**. Presence is the feeling of actually being in the virtual world, in other words, the brain should accept the world as reality. However, this does not mean that this is only possible by providing an environment with the same fidelity and immersion as the real world. In fact, increasing these two aspects will also increase the user's expectations, and tiny shortcomings will become more noticeable, which can have a negative effect on the user's presence. A game like Job simulator **[20]** uses stylized (low fidelity) hand avatars (see *Fig.21*), and when the user picks up an object, the hand avatar disappears and is replaced by only the object (dubbed "tomato presence" by the developers **[22]**). While the level of fidelity is quite low in this case, this lower fidelity results in lower expectations: no hand avatars means there is no expectation for the hand to accurately form around whatever object is being picked up **[18]**. By doing this inaccurately, the user will notice the mismatch and the presence will be decreased. However, when the object's movements are still synchronized with the user's hand's movements, presence will be maintained.

Fig.21: Hand avatar in Job Simulator [ix]

Engagement

The fifth aspect to take into account when designing for optimal user experience is engagement. This is the aspect of keeping the user's mental state focused on the provided stimuli **[23]**. It encompasses involvement and interest as mentioned by Slater **[15]**. In the context of film or a book, engagement is the difference between whether a film or book is good or boring; the good film or book will keep the viewer engaged for hours on end, while during a boring film or book the user will get distracted by other stimuli (looking at their phone, changing the channel). This almost seamlessly translates to the context of (VR-) experiences, a good experience is not primarily defined by the quality of its graphics, but by whether or not the user kan keep interest. A proper narrative is a great tool to provide the brain with a framework to order all the stimuli into an engaging experience **[23]**.

Relation to each other

The aspects discussed above are not independent of each other, nor are they linearly connected; instead they all have a complex relationship to each other (*Fig.22*). Immersion and fidelity can be grouped together as aspects of the external VR-environment, while engagement and presence are cognitive processes experienced by the user internally. At the same time, fidelity and engagement refer to the content of the experience, while immersion and presence refer to the form **[15]**. Expectations can be seen as a barrier that connects the internal and external sides together. Although the user is the one who has expectations, they can be shaped by the virtual environment, as a person's expectations

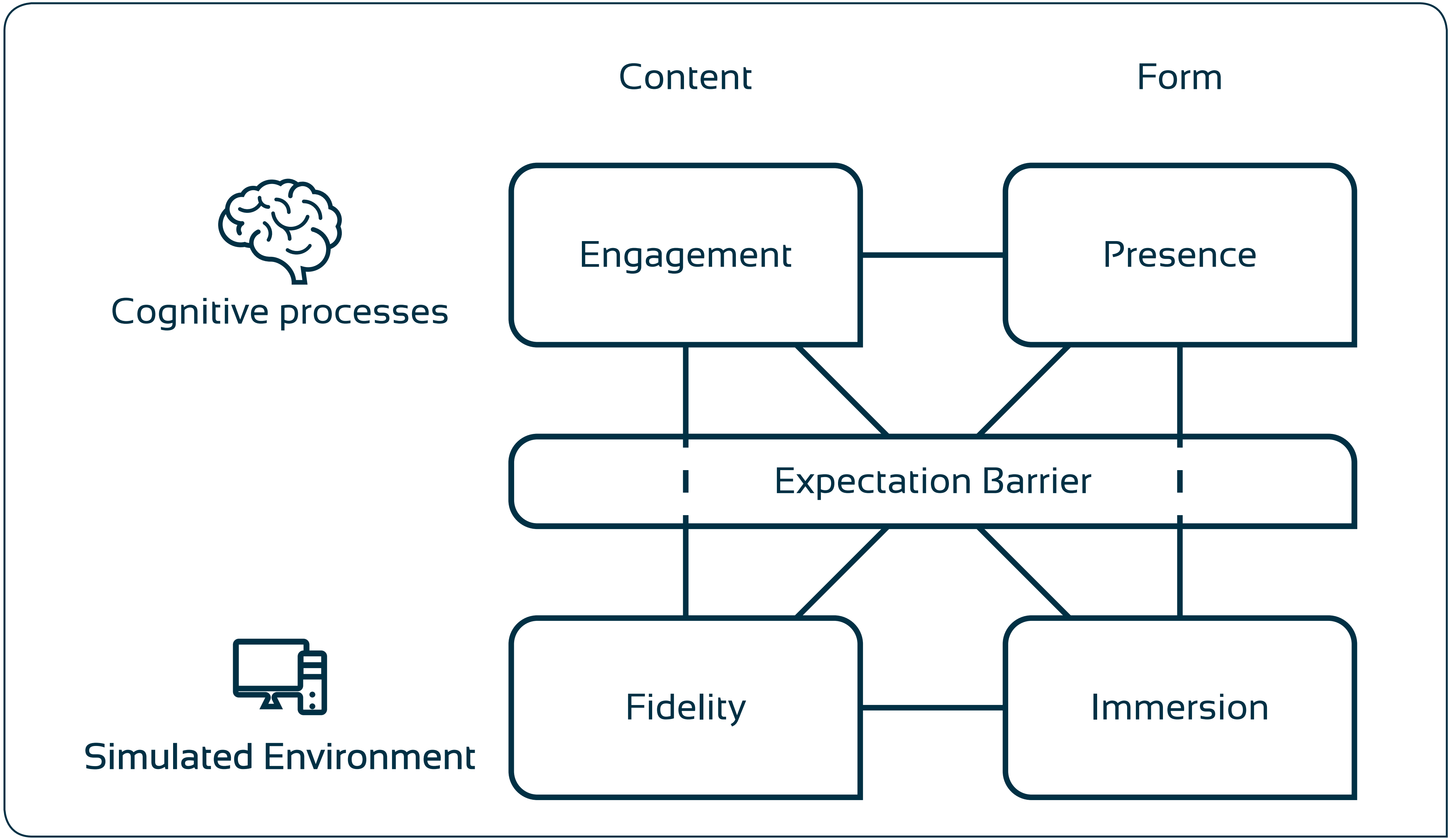


Fig.22: Proposed user experience model. All aspects on should be coherent with each other in order to optimize the overall experience.

in the real world are shaped by the interaction with the world. Adequately managing and conforming to the user's expectations is crucial for the user to achieve and maintain a high quality of user experience. It should not be the aim to maximize any of these aspects independent of each other, nor to maximize all of them together. Instead they should all be balanced in relation to each other depending on what kind of experience is intended. When properly balanced, the application will be able to achieve the highest quality experience for the user. *Fig.22* depicts this proposed user experience model (UX model) with the relation of the discussed aspects and to each other.

2.4 Current VR experiences

Using the proposed UX model as a basis for further analysis, current KLM VR experiences were evaluated. These experiences were however not enough to provide a decent understanding of the problems and opportunities that arise when designing a VR experience. To broaden this base, other existing VR experiences were tested and their developer commentary was reviewed where possible.

KLM experiences

When analysing the current 3DOF VR applications of KLM (described in section 1.4) according to this UX-model, a misbalance can be found between the fidelity and immersion. The fidelity is high, since the content is real-life footage, but the immersion is low (only 3 degrees of freedom). This limits the user in their movement and their natural interaction tendencies (moving and looking around), whereby their presence and engagement is limited.

The pre-flight safety checklist does offer a 6-DOF environment, and its visual fidelity is high, with most virtual objects matching real life objects' scale as close as possible. This is where some issues arise. Several objects, such as the seal on the first aid kit, are very tiny, and due to the limited resolution of the VR headset, this level of detail is difficult to see, yet assessing if the seal is still intact is a task of the training (see *Fig.23*). Aside of this conflict between resolution (part of immersion) and the size (part of fidelity), the virtual controllers were a 1 to 1 representation of the physical controllers, as mentioned in section 1.4, (see *Fig.23*). Although high fidelity, the unfamiliarity and abstractness of these devices did not provide the right affordances in order for the user to determine how to perform actions in the environment.

Other existing VR experiences

There are already many 6DOF-VR applications, specifically VR games, which aim to provide an optimal experience for their users. They leverage the possibilities of the VR device to try and make the users feel present and engaged in their environment. All of them have their own solutions for interacting with objects and handling the restrictions of limited freedom of movement in the real world. Although a lot of games are still relatively low fidelity because of performance limitations, by translating natural spatial cues to the user, such as accurately translating the user's position, rotation, and scale, the user's natural expectations are met. The downside of this is that the user is limited in his/her movement within the confines of the play area. As stated before the controller interface is also an issue that needs to be addressed in order to create an optimal interaction method.

Play area:
The virtual boundaries of the play area defined by the physical space and range of the base stations.

Fig.23: The seal of the first-aid kit (circled) in the pre-flight safety checklist VR-training. The screen door effect caused by limitations in the resolution of the VR headset makes it difficult to destinguish. A close up of the seal is shown on the right.

Several VR experiences were tested on the HTC Vive and Oculus Rift to analyse their interaction, controls, and ability to create a smooth experience. These experiences served as reference material when designing the interaction for the fire-safety training. The most noteworthy aspects of these experiences that are relevant for the fire-safety training will be mentioned in upcoming sections.

Most notable of the experiences that were tested are:
- Superhot **[17]**
- Rick and Morty: Virtual Rick-ality **[19]**
- Job simulator **[20]**
- Google earth VR **[24]**
- Accounting **[25]**
- Beat Saber **[26]**

General observations

When entering the virtual world, a sense of presence is not immediately established. The users have to orient themselves after the abrupt change of environment, might need to adjust the lenses, etc. To overcome this, most VR applications observed use a 'lobby' (equivalent to a main menu) with limited stimuli other than the virtual environment. There is then usually a certain action the user has to take to start the game. This action usually also serves to familiarize the user with the controls. By default the Vive renders a visualisation of the Vive controllers in the virtual environment with accurate position and orientation, however most games have their own virtual model for the controller, with varying degrees of fidelity. There is a spectrum of models resembling the controllers and/or the user's hands, several of which are depicted in *Fig.24*.

Out of all experiences that were tested, Beat Saber and Superhot stand out in terms of engagement. Beat Saber is a game where blocks fly in the user's direction, and he/she has to cut them away to the beat of the music. Superhot is a shooter, where time only moves if the user moves. Both games are relatively low fidelity, which allows the user's attention to be focused on the events in the game. Intriguingly, the events in Beat Saber are quick, frequent and directional, while those in Superhot are omnidirectional and purely dependent on the physical speed of the user. This indicates that there is no ironclad paradigm to ensure high engagement of an experience.

Locomotion

The applications have several ways of dealing with the limited play area of the HTC Vive. Some of them ensure the confounds of the virtual world match those of the real world. For some applications this is however too limited. These applications make use of artificial locomotion.

Locomotion is the act of moving in the environment. 6DOF VR headsets with outside-in tracking allow for the user to physically move in space (natural locomotion), but mostly within certain limits. These limits arise due to constraints in the sensors or available physical space. To overcome these limitations, there are a variety of artificial locomotion solutions available. Several examples include instantaneous teleporting, allowing users to swing their arms to emulate a walking motion, and allowing users to drag the world around them.

The most forms of artificial locomotion have severe drawbacks, most notably the frequent occurrence of VR sickness. Teleportation mostly avoids this issue, since the change in position is instantaneous. With instantaneous teleporting, the user points to a location and then instantly appears at this location. The advantage of this way of moving is that there is no motion sickness induced, as there is no disconnect between the visual and vestibular input. The downside is that it is not an intuitive way of moving, so the user needs a moment for reorientation after teleporting, which decreases the user's presence. Some try to counteract this loss of presence by incorporating teleportation into the storyline, and/or by previewing the user's avatar at the new location, but the temporary disorientation is hard to prevent. Another disadvantage that emerges with experiences that allow teleporting is that unrestricted teleportation causes users to stop physically moving within their play space, and instead teleport around the environment. This compromises the experience, since moving around in space is one of the advantages of VR. Rick and Morty Virtual Rickality solves this by only allowing teleportation to another 'zone'. The user's position within the target zone stays the same relative to the position in the departing zone, increasing the amount of virtual content offered, but maintaining the need for the user to move around to complete tasks **[21]**.

One of the methods of reducing the disorientation effect is by gradually transitioning towards the selected teleport location. The downside of this effect is that the user's visual system perceives the motion, but the vestibular system does not, resulting in VR sickness in most users.

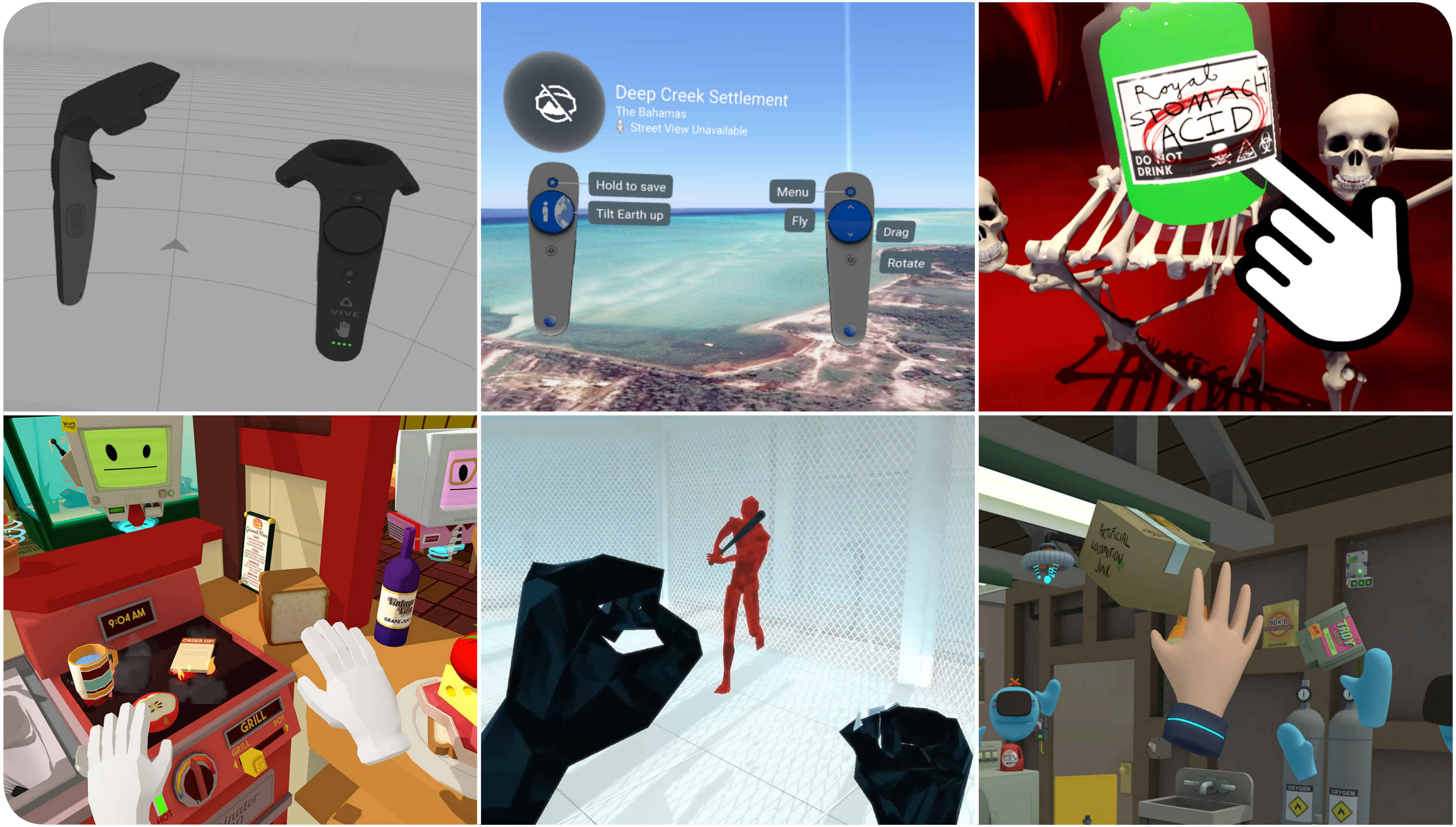


Fig.24: Virtual controller representations from different VR experiences. Top-left to bottom-right: Steam VR default, Google Earth VR, Accounting [xi], Job Simulator [ix], Superhot [xii], Rick and Morty: Virtual Rick-ality [xiii]

On the other side of the spectrum is the possibility to move the virtual world around the player. This can be done by approximating a walking movement where the user moves their arms in a walking manner, or by pointing the controller to a point on the ground and dragging that point around such as with Google Earth VR. To prevent VR-sickness, Google Earth VR restricts the FOV and projects a grid on the floor when the user does this (depicted in *Fig.25*). As stated by Fernandes & Feiner **[27]**, restricting the FOV in VR will generally allow people to remain in VR without becoming nauseous. The Google Earth VR team describe this in their developer talk **[29]** as watching motion on a TV screen; where the user remains visually stationary in their peripheral vision. The VOF extends again once the movement has completed. This solution does compromise immersion, but the developers state this solution is an optimum between the two for their purposes.

For the purposes of this project, a careful consideration should be made when deciding whether or not the user should be able to move around beyond the confines of the play area, and which method should be chosen to provide the user with this possibility. This question will be further addressed in section 3.5.

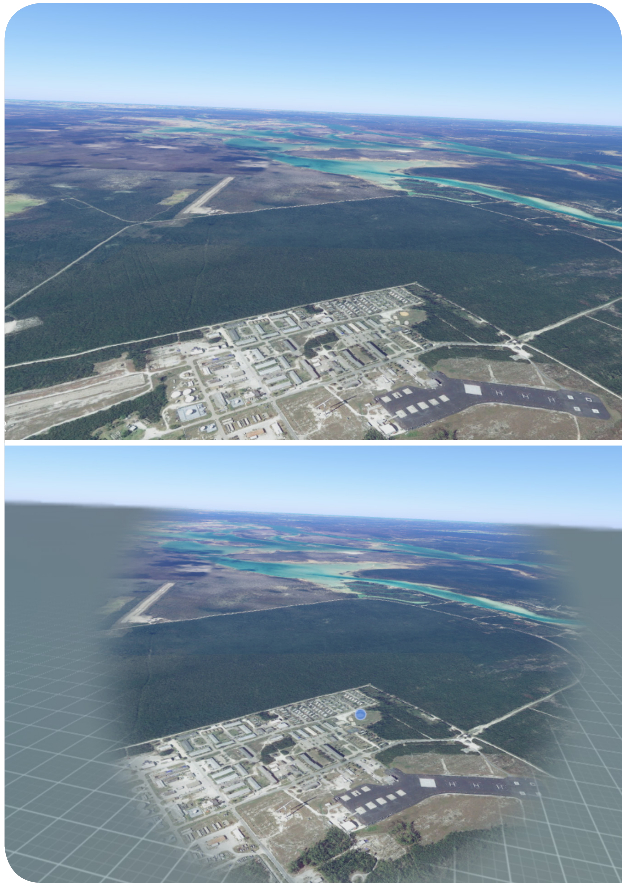


Fig.25: Google Earth VR. Top: normal FOV; bottom: FOV limited with a grid on the floor.

Object manipulation

Most VR experiences incorporate some form of manipulation of virtual objects, mostly grabbing objects, moving them around in space, and occasionally using them. There are different methods for inputting this action, and each existing VR experience makes its own choices to enable this. Aside from out-of-the-box controllers, there are other input methods possible, such as tracking the user’s hands. Since this is a very broad question that needs careful thought specific to the requirements of the fire-safety training, this topic will be further explored in section 3.4.

2.5 Requirements

Based on this analysis, the following requirements were formulated. Since many future choices depend on previous choices, the requirements are still abstract at this point. After each choice in chapter 3 and 4, the consequences and additional requirements of the choice for future steps will be discussed.

Fire-safety training

The fire-safety training was chosen as a case to develop in the form of a VR training. Considering the trainee has to complete actions in a practical way, a 6DOF VR device is necessary to allow users to move around in space. The training aims to familiarize trainees with the procedures of extinguishing fires on board of an aircraft. With this in mind, the focus of the VR experience should be to allow trainees to complete the steps prescribed by the procedure, rather than focussing on how to interact with the objects involved in the training. This provides some freedom in deciding the method of interaction (which will be further explored in section 3.4), as the focus will not be on emulating the detailed operation of the equipment within the aircraft.

Entering and leaving the environment

- The user should be able to orient themselves when entering the environment
- The simulation should provide adequate feedback to the trainee at the right times.
- The trainee should be notified when the simulation has concluded

Interaction method

- The training must allow for a 6-DOF experience.
- The user needs to be able to input actions with as little learning curve as possible.
- The user should be able to complete the steps of the procedure with as little impediment from the interaction system as possible.
- An appropriate method of locomotion should be decided on, if needed at all.

Balancing the experience:

- Fidelity of the environment and equipment should be adjusted to suit the needs of the training and interaction method.

3

Concept Generation

Photo: Mark Wagtendonk

Chapter Introduction

With the previous analysis in mind, several choices can be made as a basis for the fire-safety training. Occasionally, some additional research is required to adequately substantiate certain choices and thier consequences. This chapter will provide a basic blueprint for the interaction of the fire-safety training.

Chapter 3 - Concept Generation

3.1 Training flow

The first thing to define for the new fire-safety training is the flow of the entire training. The flow will define the steps the users take during the training from start to finish, and will serve as a basis to design the different steps of the training on an abstract level.

As described in the previous chapter, entering and leaving the environment require special attention to allow the trainee to feel comfortable in the virtual environment. This sense of comfort can be split up into two parts: being comfortable with being present in the environment, and being comfortable with interacting with the environment. The first aspect relates to the lobby for orientation as described in section 2.4; trainees have to be able to orient themselves in the new environment. The second aspect establishes interaction rules for the user, which the user will then be able to apply throughout the entire training. This can be thought of as a tutorial.

Once the user completes these stages, the actual training can begin. The trainer initiates a training event, and the trainee reacts to this event by performing actions. These actions ideally allow the trainee to perform the actions with minimal additional cognitive load generated by the interface.

After the training scenario is completed or reached an unrecoverable failure state, the user should receive some kind of feedback. The results will then be discussed with the trainer after exiting the training environment. This order was determined to be preferable by J. Westenbroek over having trainers provide feedback in the virtual environment, because the feedback session could then be detached from the simulation itself **[1]**.

A visualisation of the entire training timeline can be seen in *Fig.26*. Note that there is no fixed time step in the scale and steps may overlap more or less depending on future choices.

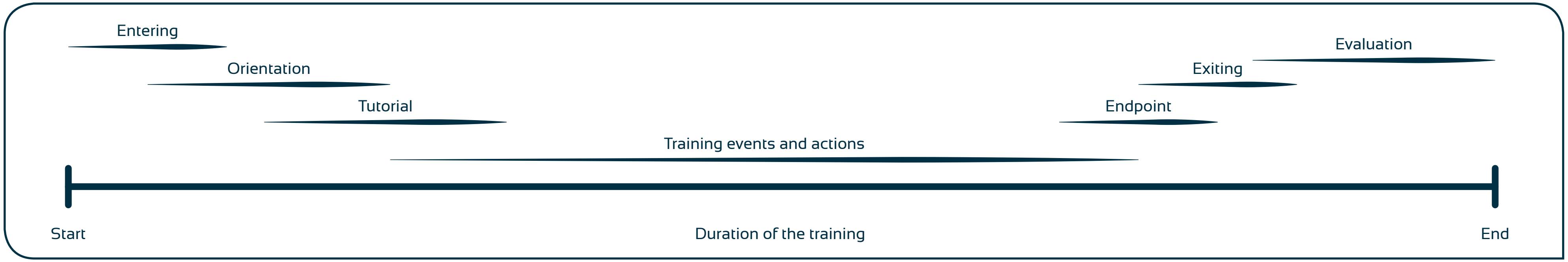


Fig.26: Training flow timeline

3.2 Transitioning into the virtual environment

When starting a (VR) experience, the user needs to mentally transition from the real world to the new experience. For VR, full immersion of the senses (most notably the audio-visual senses) is an aspect that allows for a high degree of presence to be created. In the ideal situation for the fire-safety training, the user completely forgets about the real world and fully feels present in the virtual world (see *Fig.27*), however this is difficult, if not impossible, to achieve. Additionally, presence is a subjective response, and it can be a difficult feeling to express, making it unquantifiable. Even if a mehtod of quantification can be devised, this would have no practical purpose for the implementation in this project. Instead, use tests have to indicate whether or not sufficient presence is achieved for the aims of this project.

The idea of a lobby (main menu) is used by most existing experiences to allow users to transition into the virtual world. This is usually an area with minimal interaction possibilities and stimuli, to allow the user to get used to the new environment. Once the user is ready, the environment changes to the main area and the main experience starts. This agency over their own starting time gives the user a sense of comfort and control, which is a desirable effect on the user experience.

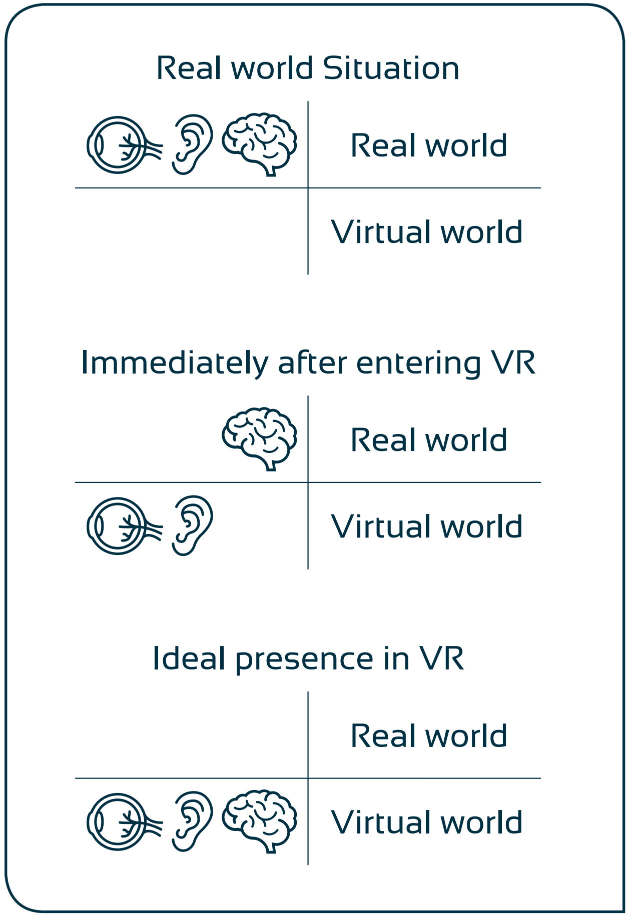


Fig.27: Immersing the senses in the virtual world is not enough; the user needs to be able to achieve presence. The eye and ear represent the senses, the brain represents the user's mental state.

There are several ways in which such a transition can be added into the fire-safety training. One essential part in selling the experience is that this stage of the simulation has to match the narrative of the intended target environment. This will further the acceptance of the target environment. In the case of the fire safety training, the target environment is the airplane cabin, so the transition should fit this theme.

Ideation

The following ideas were explored as possible solutions of this problem.

- Starting in the aircraft, but in a different section than the cabin. This solution has the advantage that no artificial locomotion (described in section 2.4) is required, and the user can physically walk from one section to another. The disadvantage is that there are few separate sections in the aircraft, and these areas may require substantial extra resources to create (such as 3D modelling). The two options that come to mind are the cockpit and a section of

the aisle directly before the galley, possibly behind an area-dividing curtain to separate the lobby area from the main area.
- Starting in the gate, then transitioning to the cabin through teleporting or another form of artificial locomotion. The gate is a familiar waiting area, so it fits the narrative of the transition part of the simulation. The disadvantages are that it requires a separate area to be modelled and that after teleportation reorientation is required.
- Starting outside the aircraft then using artificial locomotion (from the tarmac) or possibly walking in (from the jet bridge). The advantages of these options are that they also fit the narrative, emphasising on entering the plane. The second option is preferable, since it requires less additional modelling and the user will be able to walk into the next area instead of through artificial locomotion. The downside of this option is that it requires a dedicated area of the trackable space that cannot be reused.
- Instead of using a separate area for orientation and then physically moving into the new area, the real world can be used as this primary area. The user then walks through a doorway to the training area. The advantage of this is that users do not need to reorient at all, since they can maintain their natural orientation in the world and move into the new area while maintaining this orientation. The downside is that the real world area might not fit the environmental narrative as well as the previously described lobby areas, but it still fits the procedural narrative of entering an area to perform a training exercise.

Testing and choice

The lobbies of most tested VR experiences are comparable to one of the first three ideas described above, so these ideas were not prototyped. The last idea, starting in an AR environment and transitioning to VR, was prototyped, since no comparable solution was readily available.

The Vive pro was used since this headset has two front facing cameras built in that can be used to live stream the environment through the headset. For the test, a simple door was used to mimic the sensation of opening and walking through a door into a new room. During this test, there were no 3D models of the cabin ready yet, so a rudimentary placeholder cabin was used as test environment. The test setup can be found in the TestObjects application found in the Appendix. An image of the test setup is displayed in *Fig.28*.

The results of the test were very promising. Many users reported they felt more at ease in the virtual environment after entering it this way, partly because they liked the fact that they could choose themselves when to enter the virtual environment, as opposed to being teleported to an unknown new environment. These reports matched the observed behaviour, as in general, users weren't looking around in the environment as much after entering the virtual world, and they were notably less hesitant in moving around the environment from the start.

One test subject started at the front of the room and had to walk towards the back to get to the door opening. Once he entered the virtual environment he continued in the same brisk pace through the aisle of the virtual environment (back to the front of the room). The virtual environment was however bigger than the real environment, and we had to stop him from walking into tables that he had just seen a moment ago.

Based on the results of this test and observations of users in regular virtual lobby environments, this AR solution was selected to be used as a transition phase in the simulation.

Consequences of this choice

This choice has limited impact on future design phases, one of the consequences is that the VR headset has to be able to live stream or in another way give the user a view of the real world environment. A dedicated starting area on the side of the play area should be available where the VR headset is still trackable, but which limits a part of the play area. In most cases this is not a substantial problem, since it only concerns a small area. For future implementation of VR within KLM, these factors can be considered trivial requirements, since they can easily be taken into account when implementing the simulation in the training curriculum, and do not limit the course of the simulation itself. One positive consequence is that teleporting is not needed for this part of the simulation. For an extended discussion on whether or not teleporting is needed in the rest of the simulation, see section 3.5.

Further requirements

- The VR headset has to be able to live stream the user's environment
- A dedicated starting section needs to be available at the edge of the play area.

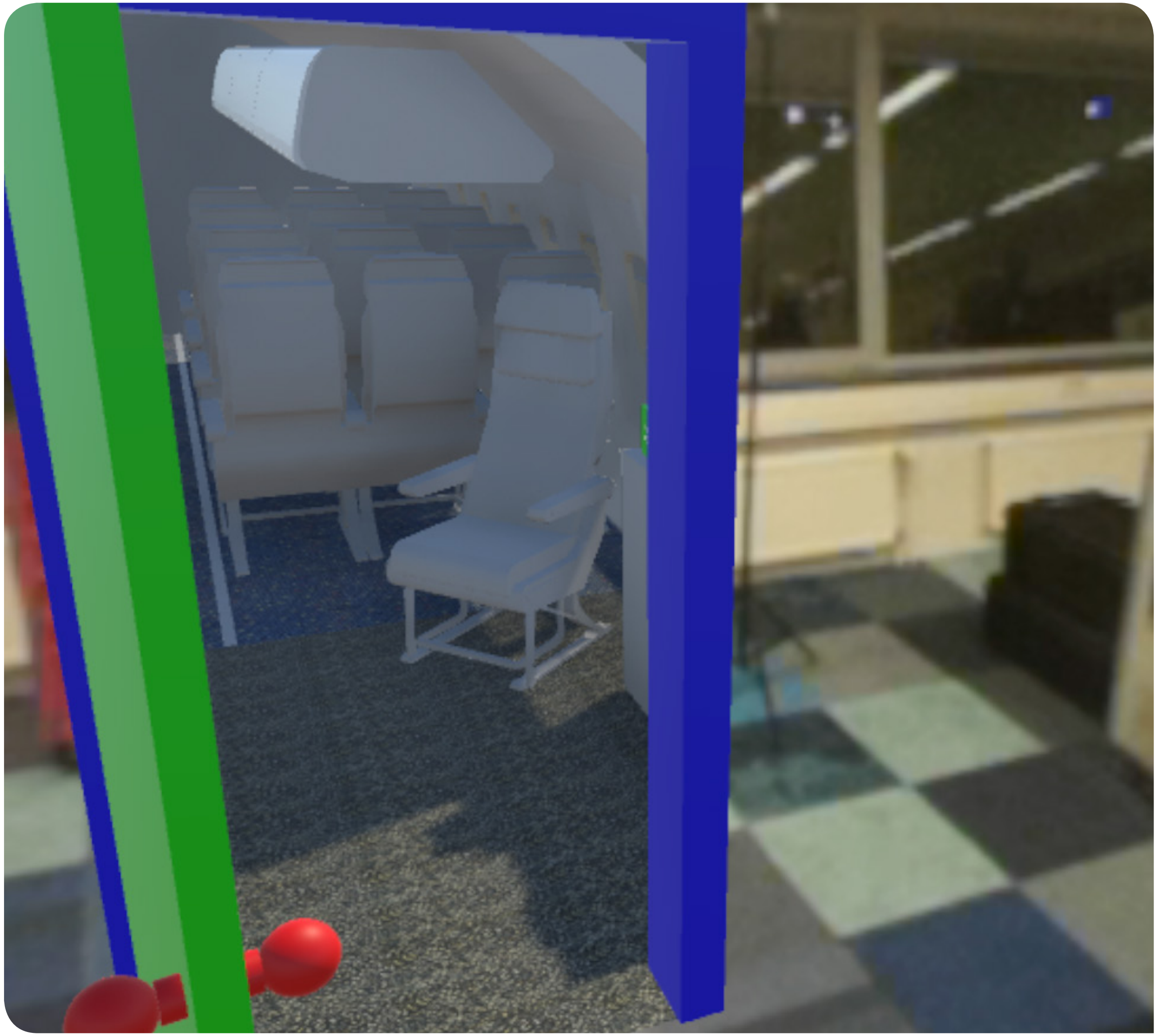


Fig.28: AR transition test setup. The virtual environment can be seen through the doorway..

3.3 Training events and actions

Once the trainees have entered the virtual environment, the actual training can start. The trainer issues an event, and the trainees will have to respond by performing actions. As a first case study, the procedure of an oven fire will be used. This type of fire has the most actions a trainee has to perform according to the protocol. The protocol is split between the 2 cabin attendants (CAs) that are normally present on all flights of KLC. The cabin attendant that spots the fire automatically assumes the role of CA-a, while the second cabin attendant assumes the role of CA-b. The actions the two cabin attendants should then perform, and how they translate to interactinos are depicted in *Fig.29* (taken from J. Westenbroek's report **[1]**).

Event
Passive occurrence in the simulation.

Action
Active deed performed by the user.

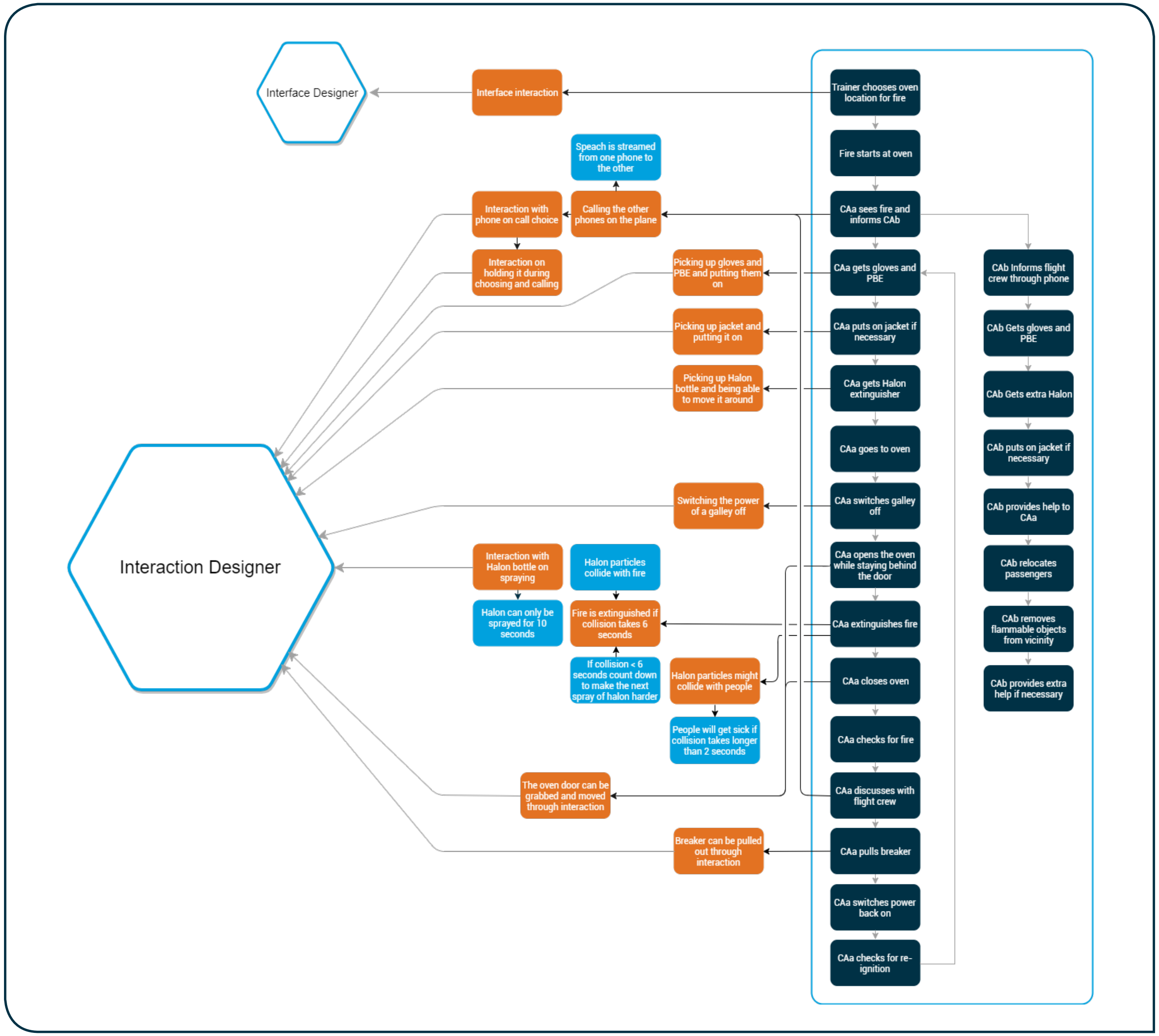


Fig.29: Architecture with relevant actions as described by J. Westenbroek.

Although prescribed by the protocol, grabbing gloves, a PBE, and jacket is considered optional by trainers, since this can cost a lot of valuable time that can be used to get the fire under control. These steps will therefore be omitted in the first prototype of the training.

For CA-a the remaining steps are to:
- Inform CA-b
- Get the halon extinguisher
- Turn off the galley power
- Open the door while not standing in front of the oven
- Extinguish the fire with the halon
- Close the oven
- Consult the cockpit about pulling the circuit breaker
- Pull the circuit breaker if the cockpit agrees

At the same time, once informed by CA-a, CA-b will perform the following actions:
- Inform the rest of the flight crew via the phone
- Grab additional halon
- Remove flammable objects from the vicinity of the fire
- Provide CA-a with other assistance if necessary

After these steps, when the fire has been extinguished, and there is no more threat to the aircraft, the regular operations are to be resumed. These steps will not be included in this simulation.

Translated to actions in the VR environment, these actions can be split up into several categories:
1. Communication
2. Moving objects
3. Using objects

Communication
Communication is an essential part of the fire-safety training, both between the two trainees assuming the roles of CA-a and CA-b, and with cockpit crew, a role that will be assumed by the trainers. To allow for communication between the trainees when using different play areas, some form of voice transmission should be used from one headset to another. When using the same play areas, voice transmission between trainees is not strictly necessary. However, having the virtual environment emit sounds requires some kind of audio output device (see section 4.3 for more details on the role of audio). It is therefore recommended to have the voice transmission between trainees anyway, and to have two separate play areas to avoid one trainee hearing the other trainee double. Section 4.6 will outline another reason why separate play areas are preferable.

The same voice transmission issues apply when examining communication between trainee and trainer. Besides this, it is desirable to have a stricter separation between the trainer and the trainees, so the trainer can comment on actions for potential viewers (such as other trainees), and because on a real flight, the pilot talks to the flight crew through an on-board phone system, and therefore can only be heard by the cabin attendant that has the phone.

Moving and using objects
The other actions relate to the manipulation of virtual objects, both moving them and using them. There are many different methods to allow users to interact with virtual objects, and an appropriate and consistent choice is necessary to make the experience as smooth as possible. The focus of the next section shall be solely on addressing this problem. Section 4.1 will further evaluate the behaviour of objects in these categories individually.

Consequences of the choices

Most actions described in this section are direct requirements following from the protocol. As for the communication, this requires a microphone for the trainer and trainees. The need for communication also emphasises the benefit of separate play areas for the two trainees.

Further requirements

- A microphone and sound output system is required for each user.

3.4 Interacting with the virtual environment

There are several possibilities for handling interactions in the VR environment. Which will be able to provide a range of immersion and fidelity. The question then becomes what level of immersion and fidelity is needed to provide an adequate balance for the purposes of the fire-safety training. First, general interaction methods will be discussed for the manipulation of virtual objects. The section will conclude with a choice for an interaction method. Upcoming sections will then address several other obstacles that need to be dealt with.

Manipulating virtual objects

The main method of interaction with the virtual world is the manipulation of objects. This mainly consists of moving objects around in the environment and sometimes having the object perform a useful action. In further sections these actions will be referred to as grabbing and using, respectively. There are several input methods and devices that allow for users to grab and use objects; the next sections will elaborate on several options and their pros and cons.

Hand tracking

Hand tracking provides possibilities (and affordances) for natural mapping of hand movement and fine motor skills. On the down side, fine motoric tasks also require more development capacity to respond to the different gestures. For example: opening a soda can is a delicate movement, and having full finger tracking will prime the user to use their fingers to open the can, as they would also do in the real world (depicted in *Fig.30*). For VR, the reaction to this gesture needs to be specifically programmed each object individually, as picking up a heavy object such as a fire extinguisher with the same gesture will not align with the user's expectation and will interfere with the experience.

Fig.30: Grabbing a heavy fire extinguisher with this motion will feel unnatural.

This also points out the second obstacle on the side of immersion when using full hand tracking: haptic feedback. Haptic feedback is an umbrella term for two types of feedback: tactile and kinaesthetic feedback. Tactile feedback refers to the type of sensation that can be felt on the surface of the skin, for example texture or vibration. Kinaesthetic feedback refers to the sensation generated from the proprioceptive sensors in the muscles, joints, etc. These sensors give information about the approximate size, weight and position relative to the body of an object **[7]**. Tactile feedback, in the form of vibration, is a well-known solution used in a variety of digital devices to give feedback to the user, however, kinaesthetic feedback is much harder to mimic.

One option is to omit kinaesthetic feedback entirely, resulting in the user only having to perform the hand gesture of picking up/using an object (and possibly providing a rumble to give some tactile feedback). This way the user grabs in space, making a fist or other gesture on the location of the virtual object, thereby picking it up. A setup for this approach was created with Manus VR gloves. The advantage of this method that the gesture is quite natural, reducing the learning curve. The drawback is that the balance is shifted to fidelity without providing a similar increase in immersion, whereby the user's presence is compromised.

There are however solutions to compensate for the lack of immersion. Through the use of additional VR hardware like HaptX gloves (shown before in *Fig.14*) the kinaesthetic feedback of touching a virtual object can be simulated to a certain extent. This allows for less compromise when feeling the shape of certain objects, but still limits the resistance that is felt when e.g. trying to push through a solid wall. This level of kinaesthetic feedback might then set a certain level of expectations, which will then be broken because they are incomplete. Besides the expectation barrier, the extra setup time and having to wear all the extra gear might actually diminish the experience. A different proposed solution could be to have an external robot arm move around the user's play area in anticipation of virtual objects being touched. This robot arm would then places physical surfaces at the locations where the user touches the virtual object, and provides resistance to the user's movement to provide kinaesthetic feedback. However, the sheer complexity and additional hardware of this solution are, at least at this point in time, considered to be too excessive for the implementation of the fire-safety training.

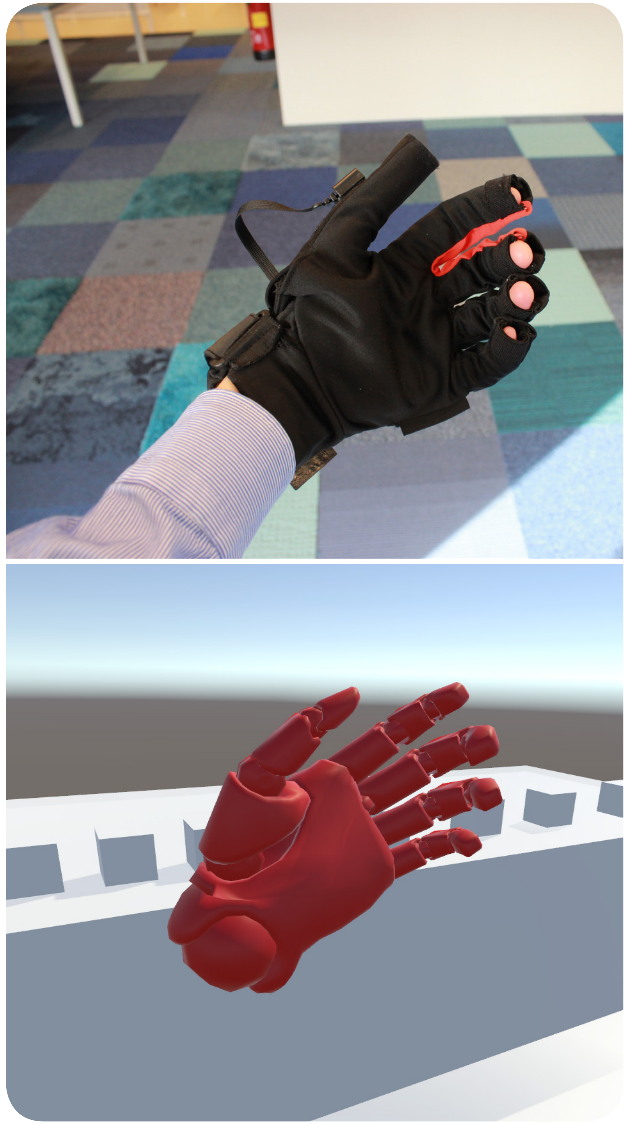


Fig.31: Manus VR test setup. Top: real life hand pose; Bottom: virtual hand pose

In order to circumvent the issues caused by the option above, and to provide more natural and accurate immersion, tracked props can be used to provide physicality to the virtual objects. The advantage of this solution is that it allows for real haptic feedback as accurate as the props are matched to the virtual props. The downside of this solution in general is that the virtual environment becomes constrained to the same physical limitations of the real world, and the available virtual area becomes directly proportionate to the physical space. Another issue with this solution is that once some intractable props become physical, others must also be physical in order to match the achieved expectations for this level of immersion.

In case of the fire-safety training, this solution is undesirable, since it would require having a complete physical mock-up of a cabin, as well as a virtual skin to overlay over the physical mock-up. If such a solution is considered to recreate a part of the real world, it may be worthwhile to look at AR as a solution instead of overlaying an entire virtual world over a similar physical environment.

This does not mean that this method would be undesirable in all cases. Section 6.2 briefly discusses a different training where a physical interface could significantly benefit the experience without having to manufacture an entire physical environment.

Controller interface

Opposed to full hand tracking, devices like controllers provide a more abstract interface for interaction. Using controllers will allow for an out of the box, low cost solution. Keeping immersion and fidelity lower allows for more leeway in focussing the user's presence and engagement on the training due to lower expectations.

Reducing the level of fidelity for the hands also allows for a reduction in the amount of immersive equipment needed. For the tracking of individual fingers some kind of extra hardware is needed, such as the previously mentioned Manus VR gloves, or a device like the leap motion **[28]**. This increased immersion might actually be distracting from the goal of the simulation.

Although a reduced fidelity and immersion might allow for an experience based on lower expectations, it also creates obstacles for itself. Without the possibility for fine motor skills, the simulation should naturally ensure that those kind of actions are not needed in the environment. To ensure this is the case, a stricter management of the affordances of the virtual objects would be required. This might mean parts of the simulation would have to be carefully redesigned, reducing fidelity of the environment to match the level allowed by the controllers, but thereby providing proper affordances that will align with the user's expectation.

Controllers are more limited in interaction possibilities, and require, at least in part, to depend on their designs for usability. Especially the current Vive controllers (depicted in *Fig.32*) offer limited possibilities without being confusing. Experiences like Job simulator and several others go out of their way to redesign the entire environment to be interactable with the use of only one button (see *Fig.33*). This might be an interesting option for our case, since the operation of the props is not essential to be translated one to one.

By choosing this route, the affordances of the virtual objects should be designed in such a way that would allow for more coarse movements, and should be able to be picked up with one hand, and operated with the second if the object should be usable as well as grabbable.

A second method could be to use one controller button/interaction for grabbing an object, and a second button to use that object. Considering there are different designs of VR controllers, the most natural control binding can only be determined by testing several controller designs.

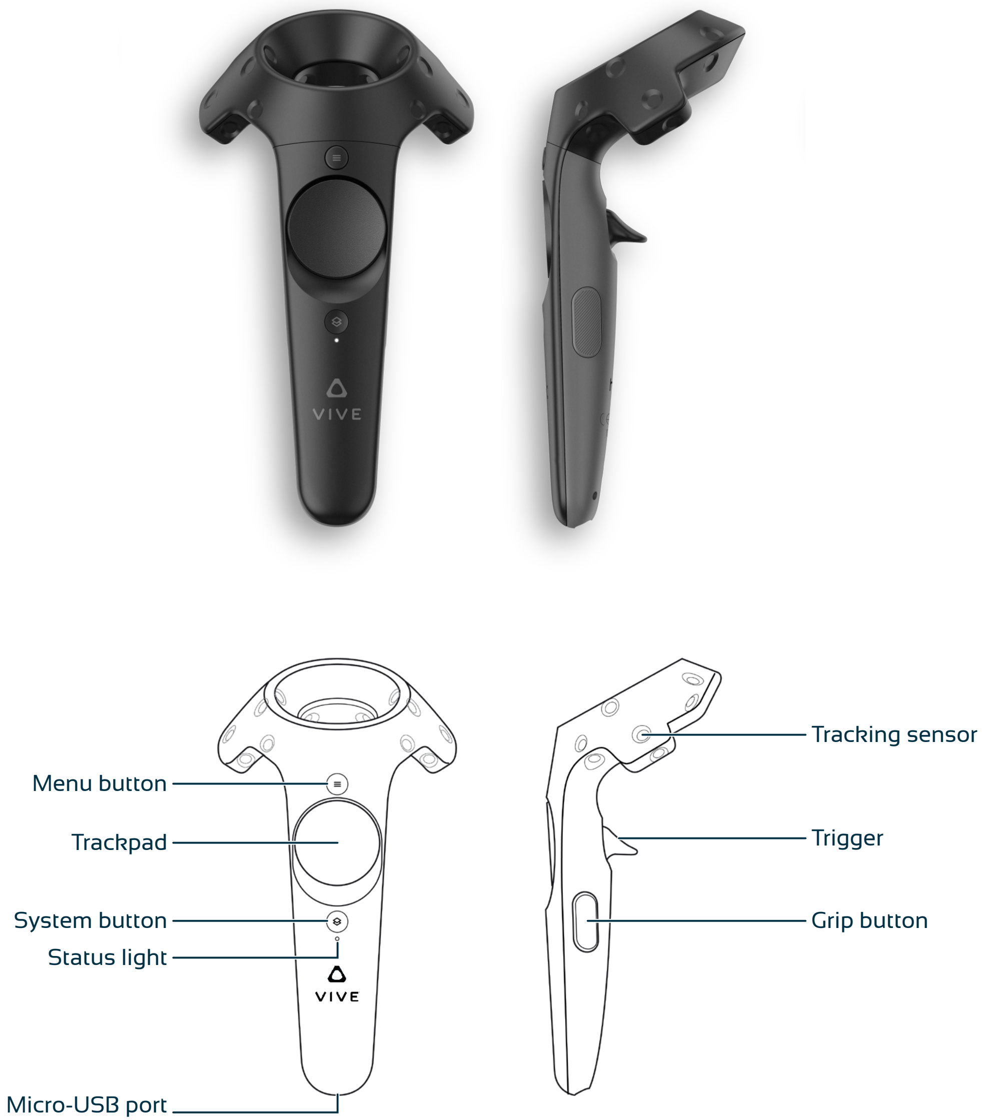


Fig.32: The Vive Controller [xv] [xvi].

Fig.33: Job Simulator removes the regular need for fine motor skills when operating a keyboard, by replacing the dozens of buttons of a keyboard with 2 huge, easily distinguishable buttons [xiv].

Different Controllers

Initially, only Vive Controllers were available for testing. A gripping action could be used to emulate the sensation of grabbing an object, and another button could then be used to use that object. The way the vive controller is designed, however, does not allow for an actual gripping motion, but only to use a squeeze as an input. This is not a natural input to grab objects, and feels awkward. This method of interaction can be tested by grabbing the yellow cube in the TestObjects application found in the Appendix.

In order to try and trick users to accept this action as a more natural input, a test setup was made where the virtual hand avatar snaps to a certain position around the object, with the hand half closed. The idea being that the user then sees the half closed hand, and priming them to finish the grabbing motion, thereby squeezing the controller. The issue with this method was that either the hand avatar, had to snap to a certain position, or the object should. In the first case, the hand presence is lost, since the virtual hand no longer corresponds to the user's real hand position (see *Fig.34*). This setup can be tested by picking up the blue bar in the TestObjects application found in the Appendix. The second option would require the objects to move without an actual input being provided to snap to a certain position, which is also undesirable, as it can become confusing for users if objects move (seemingly) randomly.

Knuckles Controllers are a different type of VR controller that are strapped to the users' hand palms instead of being held (see *Fig.35* and *Fig.36*). These controllers might allow for this type of interaction to feel more natural, since an actual grip movement is required. Unfortunately, these controllers were not available at time of writing. However, Oculus Touch controllers (depicted in *Fig.37*), whose

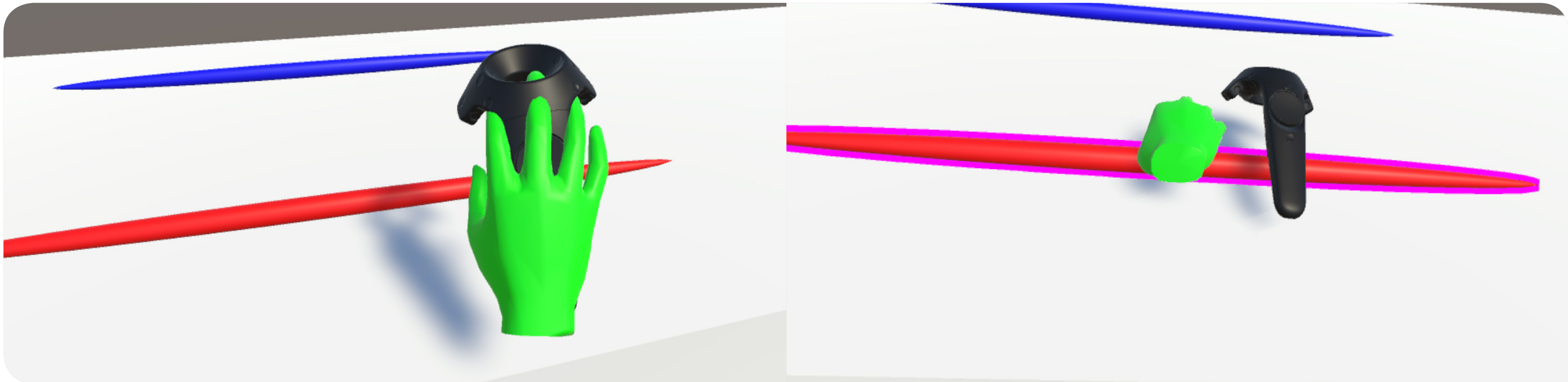


Fig.34: Test setup where the virtual hand snaps to the object.
The controller model serves to illustrate the position of the controller and was not visible to the user. Left: base position; right: snapped position

Fig.35: Knuckles controllers [xviii]

Fig.37: Oculus Touch controllers [xix]

Fig.36: Knuckles controller strapped to a hand [xvii]

grip buttons require a similar gesture (see Fig.38), were tested.

The feel of these controllers was tested in the game “Oculus First Contact”. This game offers an introduction into the Oculus Touch controllers and makes the user accustomed to its interactions. Although the controller does not track the exact position of the fingers like ManusVR or similar technologies, it does an adequate job at tracking different stances of the hand, as depicted in Fig.39.

Fig.38: Grip button of the Oculus Touch controller, under the .user’s middle finger [xx].

Fig.39: The Oculus Touch Controllers are able to approximate the stance of the user's hand [xxi]

There are three sensors involved in simulating the stances: the grip button, trigger, and capacitive touch sensors in the top plate and buttons.

The trigger works similar to the Vive controller's trigger, the only difference being reduced resistance when pressing it. The top panel works in a similar capacitive manner as the Vive controllers, but has physical buttons (the panel both has capacitive sensors on the panel itself and on the buttons). The biggest difference between the two controllers is the grip button and the way the controller sits in the user's hand. The Vive controller must be held completely, and the grip button can be pressed by squeezing the controller. This button gives a digital click as feedback, indicating it was pressed. The Oculus Touch, however, has a trigger-like grip button with minimal resistance, pressed when the user closes his/her hand (mostly the middle, ring and little fingers) around the handle. The shape of the controller also allows the user to open his hand completely in many different hand orientations, without the controller falling out of the user's hand. This allows the user to hold their hand in an open position where the grip button is released, and grabbing the handle where the grip button is automatically pressed.

The difference, although seemingly minimal when judging the motion of the fingers, results in a drastic difference in experience; picking up objects with the Vive's grip feels like trying to pick up objects with a closed fist and squeezing, while the Oculus controller actually gives the impression of closing ones hand around the object. This motion felt natural and intuitive, even when first using it in First Contact to pick up items. This freed up the trigger to use the object, e.g. shooting a gun. But although this is a more natural interaction, especially with a gun, it still takes the user a while to familiarize with the controls, since the user has to actively keep their index finger from pressing the trigger. Additionally, most people use their index finger and thumb when picking up objects (supported by the other fingers). This could also be seen during a demonstration of the Vive equipment to trainers, where they pressed both their thumb and index finger when interacting with the VR world. Therefore, although highly intuitive, grabbing this way still requires people to learn a new way of interacting.

Training goals
With these methods of interaction in mind, the main goal of the fire-safety training should be supported by the interaction method. The main question being if, besides practicing the procedures, it is also required having accurate equipment representation in the training. KLC’s response was that the main purpose for the fire-safety training would be to train the procedures. There are already separate trainings where the operation of the different equipment and parts of the plane are trained. This opens up the freedom to choose an interaction method that might be more abstract, and/or requires redesign of certain objects to accommodate for simpler interaction and easier development.

Conclusion
There are two viable possibilities for controlling interaction in the simulation. The first is to redesign the environment to be interactable with a single button. This lower level of immersion allows for more general controllers to be used for the trainings. The downside of this is that a lot of thought should be put into the design of the interactable objects in the virtual environment to provide the right affordances to manage the user’s expectation, while maintaining the desired level of fidelity.

The second option is to use a dual button interaction, where the grip acts as a higher immersive input gesture. This method removes the need for extensive redesign for the affordance of grabbing, since grabbing is no longer the only interaction possible. The downside however is that the simulation will be limited to certain types of controllers that allow for this level of immersion, and there will inevitably be a steeper learning curve, since the use of the object will be more abstracted to a button press, instead of a redesigned affordance in line with a grabbing motion.

Considering the target group, trainees with a broad background as opposed to e.g. gamers, a simpler interaction is preferable. Where gamers will want to spend time in the simulation/game and expect (and therefore are open to learning) more complex interactions to complete more complex tasks, the goal of this project is to provide a tool for students to train their theoretical knowledge of the procedures. Requiring them to learn a new interaction, however simple, will only add to their study pressure and will get in the way of the actual goal of the trainings as stated above. The fact that the focus of the trainings is the procedures, and not the operation of the equipment is something that allows for the redesign of certain equipment to be operable in VR using single-button interaction. The best choice for this case is therefore to design for single-button interaction.

Consequences of this choice
This choice has many consequences, some of which are already stated above. The most demanding will be to redesign many aspects of the cabin to allow for a single-button interaction method. Objects that are usable are require the most attention in this regard. There is also a lack of accurate haptic feedback due to controllers being used in the simulation. The controllers are able to vibrate, but it is yet to be determined whether or not this is enough, or if some extra feedback is required. All of these aspects will be discussed in chapter 4.

Further requirement:
- Controllers will be used as primary interaction interface.
- All interactions should be possible through the use of one button on this controller at most.
- All intreractable virtual objects need to be evaluated based on this interaction method, and redesigned if needed.
- The lack of haptic feedback needs to be addressed. In case this is a problem, a

suitable alternative solution should be found.
- If locomotion is needed beyond the bounds of the play area, it will require an activation method that complies with the single-button interaction requirement.

3.5 Artificial locomotion

As stated in section 2.4, play area restrictions are an issue many VR experiences encounter, and deal with in a variety of ways. Artificial locomotion has many drawbacks and is ideally avoided. In the context of the fire-safety training, the core of the experience takes place in an aircraft cabin. This has the advantage that the width of the aircraft fits within the play area. The types of aircraft used by KLC (Embraer 175 and Embraer 190) do not have a second floor, so vertical movement is also not needed. The only issue when it comes to this training is the length of the environment. The length of the aircraft is too much to fit within the play area. Although new VR solutions would allow for multiple sensors to be chained together to allow for a larger trackable area, this would still require a lot of physical space to be available.

In case of the fire-safety training, the entire aisle is not needed to perform the training. In the current training chamber the aisle is shortened. This is possible since most of the aisle is a repetition, so for training purposes there is little physical difference between a row in the front and a row in the back. The only point of compromise is that walking through the aisle takes a certain amount of time, which cannot be emulated when the aisle is shortened. However this is a small sacrifice to make compared to requiring a play area length of over 30 meters, or introducing an artificial locomotion technique. Especially the (arguably) most popular artificial locomotion technique, unbounded teleporting, will not solve this time issue, as users will be able to traverse the length of the plane with the press of a button. It is therefore preferable that locomotion beyond the play area is not needed, and that the play area is not extended beyond the standard area that the base stations can track (approximately 5x5 meters, see *Fig.40*). A natural boundary is preferable, since this will ensure users will automatically stay within the play area **[18]**.

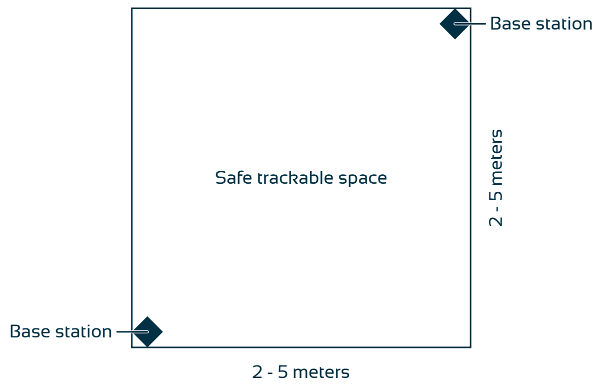


Fig.40: Play area setup

Consequences of this choice

This choice is based on many practical considerations. The consequences are therefore that the play area remains compact. A very positive consequence is that no solution will have to be found on how to include the possibility of locomotion that complies with the single-button interaction requirement stipulated in the previous section. A slight downside is that therefore the entire aircraft cannot be included in the training, and a choice needs to be made on how to deal with this limited space. An elaboration on how this will be done can be found in section 4.4.

Further requirements

- No artificial locomotion is to be used in the training
- A natural bounding area should delimit the aisle at the edge of the play area

3.6 Tutorial phase

Although the aim is to create an interaction method that is the most natural for the user, it is unavoidable that users will need to familiarize themselves with the interaction. This is partly due to the novelty and diversity of VR technologies, due to which some people might not know what to expect when using this simulation for the first time. Trainees' expectations may be based on a 3DOF VR system, or they may have seen different interaction methods. Both are possibilities considering the current state of VR within KLM, as explored in section 1.4). The aim in this project is to provide an interaction method with as little a learning curve as possible, so the tutorial phase won't need a dedicated separate section. Ideally the tutorial is integrated with the transition phase, so the user not only transitions into the VR environment, but also learns how to interact with it simultaneously. The previous section has established that no artificial locomotion is necessary to traverse the virtual environment. This leaves the single button interaction to be introduced to the user.

The transition phase requires the user to walk through a door to enter the virtual environment. Since the virtual environment is an aircraft cabin, it is a logical decision to make the door an aircraft door to fit the narrative. There are many different aircraft doors, each with a unique manner of operation (at least unlocking and opening).This makes the operation of the door an ideal candidate to serve as a tutorial for the user, as the operation consists of several distinct acts that the user needs to perform consciously. A current Embraer door training model is depicted in *Fig.41*.

Fig.41: Embrear training door (inside)

In case there are still problems with the interaction, users are not stuck in the virtual environment yet, and the trainer can give some instructions if necessary. Once users are able to open the door and enter the virtual environment, it can be safely assumed they know how to interact with the virtual world, and no further intervention of the trainer should be required.

Consequences of this choice

This choice fits seamlessly in the transition phase and has little impact on future steps. Some attention is required to ensure the door operation is complex enough to allow users to go through several steps to familiarize themselves with the interaction method, but it should be simple enough so they do not get stuck in this stage for too long. An elaboration on how this will be achieved can be found in section 4.4.

Further requirements

- The door operation should be calibrated to serve as a suitable tutorial phase.

3.7 Training endpoints

The actions of the trainees can have three types of results, the main being the correct result after a correct action. In case the trainees make a mistake, however, the results can be split up in two separate categories: recoverable mistakes, and unrecoverable mistakes.

Recoverable mistakes are minor mistakes that have little impact on the training status and can be corrected by the trainees, possibly with assistance of a trainer. An example includes grabbing the halon before switching off the galley main power (as prescribed by the protocol). In cases like this the simulation should not stop.

Contrary to recoverable mistakes, unrecoverable mistakes are severe mistakes that are too severe to be corrected by the trainees themselves (with or without assistance from the trainers). One example is emptying the halon canisters without extinguishing the fire. These kind of endpoints will be referred to as fatal endpoints. In this case the simulation must be stopped and the trainer should discuss the results with the trainees.

Unrecoverable mistakes and the correct outcome result in endpoints of the simulation, but recoverable mistakes do not. In case an action results in an endpoint, the simulation should communicate this state to the trainee, so they know they can now leave the training environment to receive feedback from the trainer.

For the fire-safety training, a fatal endpoint should alleviate the stress that the simulation might have caused, while also communicating why this outcome has been reached. One idea is to freeze the simulation and displaying the fatal error in colour, while the rest of the environment becomes greyscale. The freezing will halt the possible overload of sensory input, and the attention will be drawn to the issue that resulted in the fatal endpoint.

The correct endpoint is reached when the trainees successfully executed the protocol. This is an endpoint where the stress level is probably less than a fatal endpoint, since the trainees gained control over the situation. The trainees however should not assume this endpoint has been reached while in reality the simulation is still ongoing. This can happen when, for example, the trainees successfully extinguish the fire in the oven, but forget to close the oven. If this happens, the fire can reignite. This is a recoverable mistake, but a lack of actions will result in a fatal endpoint. Trainees should therefore actively decide that they have completed the simulation. One possibility is to instruct trainees to leave the virtual environment the same way they entered after they have decided that they have finished the protocol. It may still happen that they exit the environment prematurely, but they will have to think about they protocol more actively, reducing the chances of this scenario. This idea will also smoothen the transition between the virtual and real world in a similar manner as entering the virtual world does.

Unfortunately, due to time constraints, and because this is more the area of expertise of someone with an educational background, these concepts for endpoints were not incorporated in the prototype. It is recommended that this becomes a priority when continuing the development of this training.

Fatal endpoint
Endpoint reached due to an unrecoverable mistake

Correct endpoint
Endpoint reached due to the correct execution of the prescribed protocol

Consequences of this choice

Since trainees can theoretically reach an infinite amount of different outcomes in the simulation, a finite list of unrecoverable mistakes should be drafted to be implemented as endpoint in the simulation. Since this is out of the scope of this project, this will not be discussed further, and will be a recommendation for future work. As for the correct endpoint, the choice to give trainees their own agency to determine when this endpoint has been reached will require some instructions to be given to the trainee before starting the training.

Further requirements

- Instructions should be given to the trainees to exit the environment once they have finished the protocol.
- A list of fatal endpoints should be drafted and implemented. (out of scope for this project)

3.8 Evaluation of the training results

Once the simulation has been completed, the trainees will exit the VR environment, and discuss the results with the trainer. Although this is an essential aspect of the training, the initiative of this step lies with the trainer, and the content is out of scope for this project. J. Westenbroek will elaborate more on this step of the training in his report.

Concept Detailing

4

Chapter Introduction

Now that the general blueprint has been established for the fire-safety training, several new questions have emerged due to the consequences of previous choices. This chapter will discuss those consequences, and how these consequences can be dealt with in an agreeable way. Several other points of attention will also be briefly touched on, however not all of them will be able to be thouroughly elaborated within the scope of this project. In these cases, a recommendation will be given to include these aspects in future work.

Chapter 4 - Concept Detailing

4.1 Moving object behaviour

As noted in section 3.3, the manipulation of virtual objects can be split up into several categories, and section 3.4 explored the method of interaction best suited for the fire-safety training. Even with these decisions defined, some questions still remain relating to the behaviour of the interactable objects.

Moving constrained objects

There are two types of movable objects in the virtual environment: constrained objects and unconstrained objects. Constrained objects are objects that only have a limited amount of degrees of freedom (usually only one or two). Usually these objects can only move within certain limits on their free axis, such as doors (which can rotate around one axis) and buttons (which can translate along one axis). For the fire safety training there are at least three types of constrained objects to take into account: hinged objects (objects with rotational freedom around one axis, such as doors, armrests, the crew chair seat), buttons (objects with one degree of freedom, and a pressed/released or on/off state) and a circuit breaker (similar to a button, but moving outward). These objects should react to other objects colliding with them, similar to how they would react in real life, but stay within their constraints. An example of this behaviour can be found in *Fig.42*. When colliding with virtual hands, they should normally behave similar to a physical hand moving into them (i.e. pushing a hand into a door should close the door if possible), but since the hands (controllers) are not restricted by the same objects in the physical environment as in the virtual environment, some solutions for unsolvable hand positions should be devised. Section 4.2 further elaborates on how the behaviour of the virtual hands was designed.

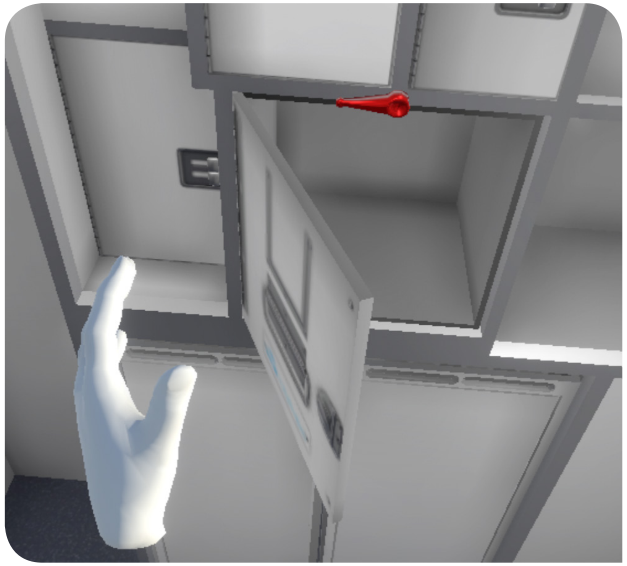


Fig.42: Slapping this door should result in the door closing

Moving unconstrained objects

Unconstrained objects are objects that are freely movable through space, such as the halon canister. They have 6 degrees of freedom in a vacuum (i.e. when no other objects are taken into account). These objects should behave similar to physical objects when not grabbed, but when grabbed they should follow the controller's position. The simulation is however not a single object in a vacuum, but any unconstrained object can come in contact with other objects in the environment, which would limit their degrees of freedom in real life. In VR as applied in this project, however, the physical constraints do not apply for the input controllers, as these can move through, for example, virtual walls (illustrated in *Fig.43*).

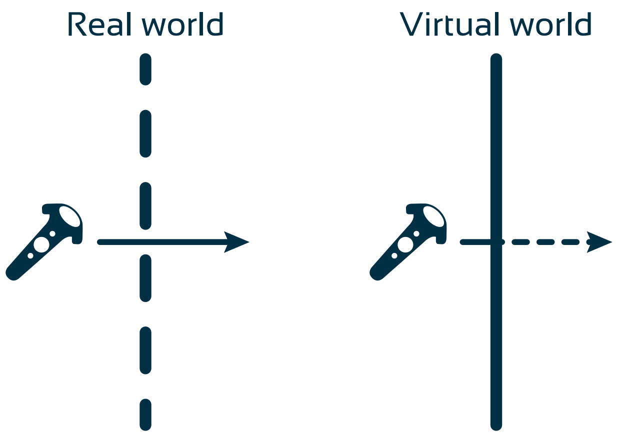


Fig.43: The user is able to move his/her hands through a virtual wall, as there is no physical wall to prevent this.

There are several ways to solve cases where a grabbed object attempts to move through an object that is supposed to be solid. Three tested methods will be described here, and can be tested in the TestObjects application found in appendix A. The first and simplest option is to prioritize the controller's position over the constraints of the virtual physics when an object is grabbed. This would mean that any grabbed, unconstrained object would be able to move through other objects when grabbed. The disadvantage of this solution is that the moved object can be moved in ways a real object cannot, for example grabbing an extinguisher through a cabinet door, instead of having to open the cabinet. When released halfway through a solid object, the unconstrained objects can also end up in otherwise impossible locations, such as halfway through a wall. The blue cube (see *Fig.44*) in the TestObjects application behaves in this manner.

A different method of moving an unconstrained object is by prioritizing the virtual physics over the controller position. This can be done by moving it towards the controller using velocities. This method tracks the direction the controller is moving in, and applies velocities to the grabbed object to move it towards that position. The advantage is that there is no actual connection between the controller and the grabbed object, meaning the object's virtual physics constraints are prioritized and the object will not move through other objects.

The disadvantage of this method is that the grabbed object sticks to the last valid position, and constantly tries to move to the controller's position. This can have some undesirable effects, such as the grabbed object flying through space at high velocity towards the controller once its path is no longer obstructed. The Green cube (see *Fig.44*) in the TestObjects application behaves in this manner.

A third method is to add a threshold to the second option where the object disconnects from the controller when it attempts to move through a wall. This behaviour can be simulated by utilizing the joint system of the physics engine. Joints in this context are virtual connections that comply with the physics engine. Using joints will result in a similar

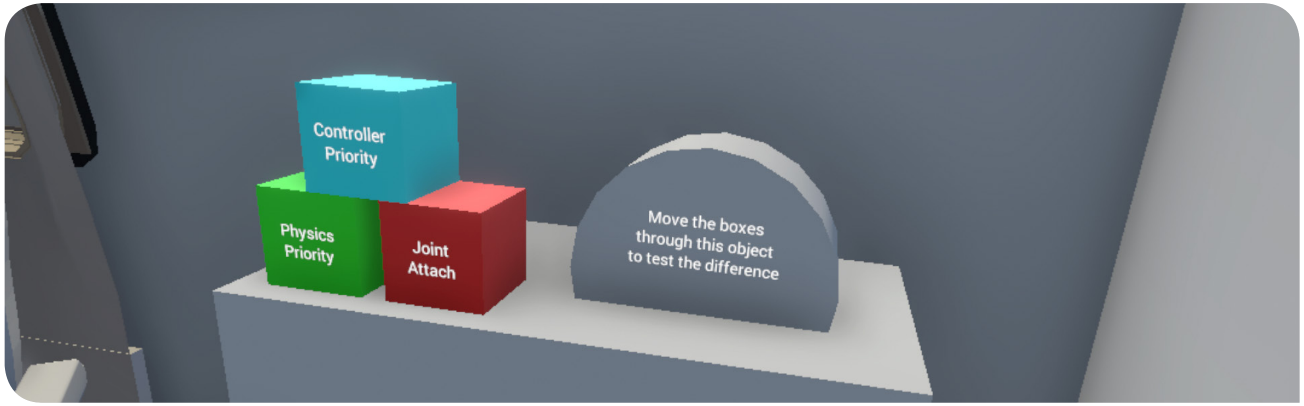


Fig.44: The three cubes in the TestObjects application behave in three different manners when colliding with a solid object.

behaviour as using velocities, however they can have a break force threshold. The virtual forces on the joint are constantly calculated, and if the force is higher than the break force threshold, the joint will break, and the object will no longer be attached to the controller. This will have the effect that when the user attempts to move a grabbed object through a wall, this object will fall as if it were released at that point. The break force threshold is in place to allow for some margin of error, since there is no physical wall stopping the user from moving their hand, and having the object fall immediately once it collides can be very tedious. The break force also allows users to use objects to push other movable objects without the grabbed object releasing on impact. The Red cube (see *Fig.44*) in the TestObjects application behaves in this manner.

There is no magic number for determining the break force threshold (as also discussed by Newport **[30]**), and it should be determined by for each project individually. Considering this method has the most natural feel out of the three options, and it requires trainees of the fire-safety training to accurately move the objects throughout the environment, this attach mechanic was chosen for this project.

For the objects required by the protocol, this solution works well, however these objects are relatively light, so the absence of the feeling the object's weight is not a big problem. This changes however when also trying to incorporate heavy unconstrained objects, such as the trolleys. Using this method of grabbing for these kinds of heavy objects will feel superhuman, as the user will be able to pick up and freely move the trolley with one hand without much effort. Section 4.4 will elaborate on this problem.

4.2 Virtual Hands

One of the most important aspects of interacting with the virtual environment is how the controllers translate the user's intentions to actions in the virtual world. Section 4.1 already detailed the behaviour of the objects within the virtual environment. This section will elaborate on how the user's hands and/or controllers will be represented..

Controller avatars

Section 3.4 explained the choice to use controllers as primary input device to interact with the virtual environment. There are many ways to visually represent these controllers in the virtual environment. The simplest is to have a 1:1 representation of the controller in the virtual environment. Although high fidelity, the appearance of the controller usually has no significance, as it is a more abstract shape intended to have an ergonomic feel and is intended for avariety of applications. Choosing to keep this shape in the simulation will require more familiarity and explanation of the purpose of the controllers and their buttons.

To make the controllers feel less abstract, but still retain their fidelity, some deviations can be made to hint to the purpose of the controllers.

Examples include creating a grip like extension on the controller model to provide visual feedback when a button is pressed, and to provide the affordance of grabbing objects. A solution like this was implemented in the VR game Fantastic Contraption, where the flower closes if the trigger is pressed **[23]** (*Fig.45*).

Another possibility is to abandon the controller shape altogether, and move more towards a representation relating more to the actions that can be performed by the controllers. Like many VR applications, the fire-safety training allows for grabbing of objects as a main action. This action is performed with the hands in real life, so a logical step would be to represent the hands visually as well. Choosing this route will also allow for visual feedback (closing of the hand) of the possible action (grabbing) to be coupled to the real-life action of pressing the trigger button. Considering much attention has been given to make the real-life action of pressing the trigger button match the virtual action of grabbing objects as close as possible, choosing hands as visual models will support this interaction method and will further compensate for the abstractness of the controllers as interaction interface. Not only will this initially provide affordances towards the method of interaction, but it will also serve as a constant reminder that the user will have to perform the procedures with his/her hands in real life.

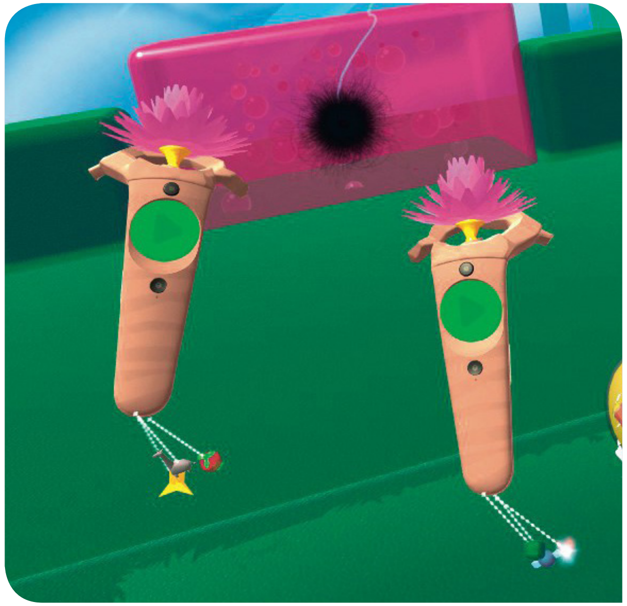


Fig.45: The controllers of Fantastic Contraption [xxii]

One concern that arises from this solution is what stance the hands should take. Shaping the virtual hands to have the same stance as the user's hands when holding the controller results in hand models that feels awkward and do not provide the affordance of being able to grab objects. Luckily people's proprioception allows for some leeway, and a hand stance can be chosen that is more inviting to interact with objects (see *Fig.46*). However, a narrow margin is present as to the position and orientation of these virtual hands relative to the controller, and great care should be taken to accurately choose these variables. The choice was made not to include arms in the avatars, as this would require the arm avatars to be in the correct orientation to match the user's proprioception. Since the controllers do not provide any tracking data for the user's arms, it would be impossible to align the orientation of the virtual arms with that of the user's arms.

As the user presses the trigger button, the virtual fingers close as well, resulting in concrete feedback as to what the more abstract action of pressing a button on the controller is able to do. A small detail that was added to help with the acceptance of the hand avatars was that movement of the thumb. The virtual thumb moves down when the user touches touchpad on the controller, and moves up when the user does not the touchpad. These virtual poses roughly match the user's thumb position when holding the controller as intended. Although it has no function beyond a visual cue as to maintain the single-button interaction, it helps improve the user's presence.

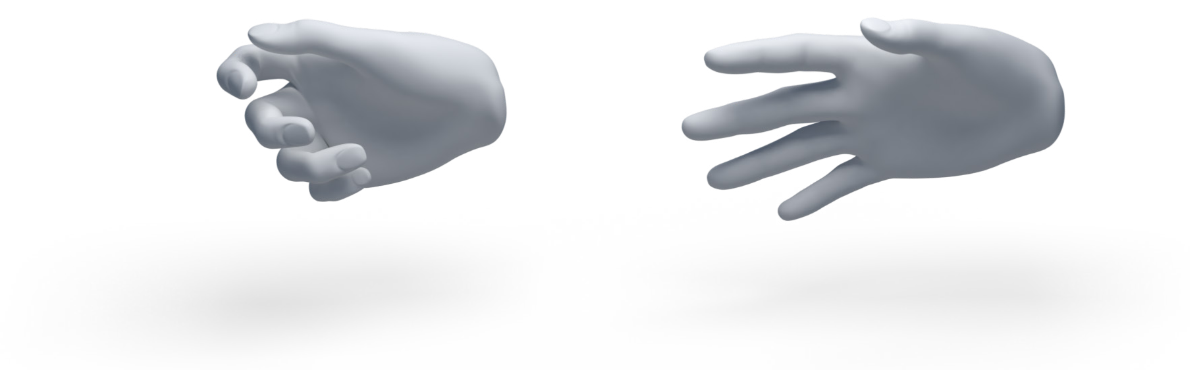


Fig.46: The stance of the user's hand when holding the controller (left) and in a stance more inviting to grab objects (right).

Hand behaviour

Besides deciding on the visual representation of the user's hands and controllers, several aspects of the hand avatars' behaviour should still be decided. The first is a similar problem as the unconstrained objects have, as described in section 4.1. This is the question whether the position of the object, its virtual physics or a combination of the two should be prioritized. The difference between the hand avatars and other unconstrained objects is that the hand avatars have a connection with real-world objects at all times, and unconstrained objects in the virtual world only have this connection when the user interacts with them. This makes the solution mapped out for the unconstrained objects less viable in this case, since the break force threshold effectively forces the controller to stop interacting with the unconstrained object, allowing the object to be controlled by the virtual physics.

There was another issue that has been encountered when iterating on different interaction interfaces and also briefly mentioned in the previous section. This issue is that moving the hand avatar to a position that no longer corresponds to the user's actual hand position breaks the user's presence, which is undesirable. The best solution is therefore to always keep the hand avatars fixed to the location of the controllers, and therefore the user's hands. The disadvantage of this solution is that the hands will be able to move through other objects, however this is an acceptable compromise considering other options have more downsides.

To compensate for this downside, some kind of feedback could be given to the user, to inform them they were performing an illegal movement. This could be done for example by giving off a tactile pulse with the controller while the user's hand is within another object. After some deliberation, it was decided not to choose for this feedback, as it was considered to be distracting. The tactile pulse emulates the initial touch of a surface within a reasonable degree, but it does not approximate kinaesthetic feedback (the missing kind of feedback) in any way. It also interferes with the intended effect of the vibration for the fire-safety training that will be described in more detail in section 4.3.

Another way to negate this downside as much as possible, and simultaneously reduce the barrier between real world and virtual world, the hand avatars should be able to interact with movable objects without the need to press a button. More specifically, objects should be able to be pushed around if their constraints allow for it. Not only does this make it less noticeable that the hands can move through objects, it also increases the fidelity of the environment, and the presence of the user. It does this by meeting the user's expectation that for example cabinet doors can be pushed close without grabbing them. This is also a useful mechanic for the fire-safety training. Consider the manner in which a microwave door is closed. This is not done through grabbing the door and closing it, but by merely pushing against the door's surface. This mechanic therefore allows for a quicker and more natural action of e.g. closing the oven door.

One unresolved topic is how a virtual hand and/or object should react when they interact with one another. The simplest solution is to have no additional step after an object is grabbed. The hand avatar can simply be present at the location where it should be, and the object will then follow the controller as well. This is an inelegant solution, as there is a high chance the hand will be in an unnatural position in relation to the virtual object. Many VR applications have also reached this conclusion, and a variety of solutions have been devised in response. Some of these have already been briefly mentioned in previous sections.

Among these previously mentioned options is to have the hand or object snap to a certain matching position and orientation. As discussed before, moving the hands separate from the controller is undesirable, so moving the object remains as an option. This solution leads to several problems. Firstly, most objects can be held in a variety of orientations, and every orientation has to be pre-programmed. The developers may not always account for the intent of the user, causing the simulation to behave in a way the user does not expect. See *Fig.47* for an example of one object being held in three different orientations, requiring three different hand-object poses. Secondly, this requires the object to move to this predefined position. This can be done either instantaneously, or through interpolation. Either option is not ideal, as it interferes with the desired fidelity and the user's expectation. Lastly, constrained movable objects will be unable to snap to a position outside of their constraints, allowing this concept to only provide a valid solution if the controller is held in one specific orientation. These problems make this solution a less viable option for the fire-safety training.

Another solution mentioned before is to have the controller avatar disappear when grabbing an object (tomato presence). This solution has

Fig.47: One object being held in three different orientations

the advantage that a limited amount of fidelity is sacrificed for several big advantages. Firstly, it is an easy solution to develop, as no separate hand poses have to be modelled, and no predefined orientation for different objects has to be defined. Secondly, not having any solution in place will also negatively influence fidelity and expectations, and this solution provides better management of the user's expectations. Considering existing VR applications have proven the merits of this method, and it has the least disadvantages for the fire-safety training, this method is the most viable option for this project. One detail that should be taken into account when implementing this solution is that the grabbed object should maintain its pivot at the position of the controller to ensure the movement complies with the user's proprioception.

4.3 Grounding the experience

The previous section already explored some additions that will further improve the user experience, such as the movement of the thumb. There are several other additions that provide the user with cues to ground them in the virtual environment, which are also present in the real world.

Sound

One of the most important aspects that will drastically improve immersion and presence is adding sound effects. Foley (named after sound-effects artist Jack Foley **[31]**) is the reproduction and addition of ambient sound effects to various media, most commonly films. These effects are usually exaggerated versions of certain sounds that would not be heard in real life, such as footsteps or the movement of clothing. Although these sounds are exaggerated, and the user doesn't actively notice them if they are present, the user will certainly notice if they are absent, making the film feel unnaturally quiet. This concept can be translated to the VR environment, as it helps to compensate the lack of accurate haptic feedback. Considering Foley artist is a profession in and of itself, and as of yet is mostly applied to film, an entire study could be carried out to how this aspect translates to a VR environment. A reasonable assumption would be that the sounds in a VR environment would also require a certain level of exaggeration, as it will help compensate for the lack of certain sensory input, such as haptic feedback.

For this project this aspect will be placed out of scope due to time constraints. Some basic sounds were added to the prototype in order to help enhance the experience. Sound design should be considered a high priority when continuing the work done for this project.

Compensating for lack of haptic feedback

As mentioned several times before, the choice of controllers as interaction interface has a lack of haptic feedback as a consequence. This lack of haptic feedback, specifically kinaesthetic feedback can cause some problems, since in the real world these senses provide a lot of information to determine for example if an object is touched, and if it is movable or (relatively) immobile. Without compensation for this feedback, users are to rely only on visual or auditive cues to differentiate between objects in the virtual environment that are and are not interactable. To add a sense of tactile feedback, a slight vibration was used to emulate touching an interactable object. A relatively wide area was used around the visual hand avatar to pre-emptively provide feedback to the user about the interactability of the object. As already stated in the previous section, the choice was made not to add a vibration when the user's hands move through solid objects. The vibration aims to communicate interactability to the user, so adding the communication of exactly the opposite would cause undesirable ambiguity.

An extra element that was added to compensate for the lack of haptic feedback is to highlight the touched object. Highlighting is a method commonly used in computing interfaces to indicate selection, and can therefore be considered to be a familiar occurrence. There are several ways to indicate selection, e.g. outlining or changing the colour of the touched object. For this project an outline in KLM blue was added due to aesthetic preferences (*Fig.48*). After some experimentation with the duration of the vibration and thickness of the outline a combination of the two was found that was considered an acceptable compensation for the lack of full haptic feedback.

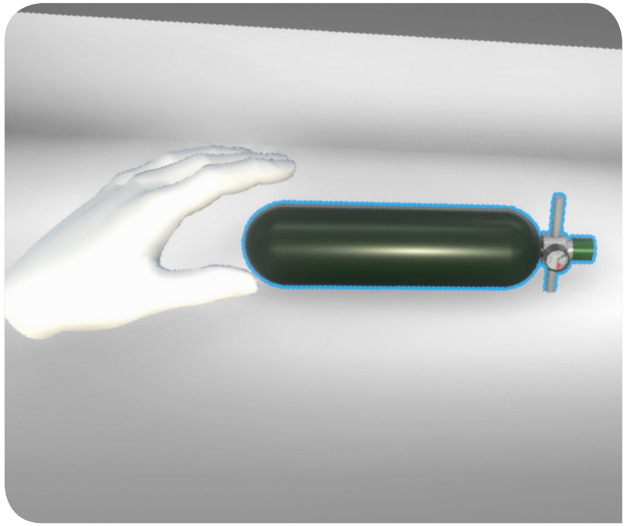


Fig.48: Outline of a touched object (an oxygen canister).

4.4 Redesign with appropriate affordances

The choice of only using single-button interaction to allow users to interact with the virtual environment has the consequence that some virtual objects should be redesigned to accommodate this method of interaction. Especially objects that can be used require attention in this regard.

Door tutorial

Before the trainees can enter the virtual training environment, they have to complete the tutorial stage as described in section 3.6. This tutorial consists of opening an airplane door. There are a wide variety of door variants, each with their own operation method. The KLC fleet consists of two aircraft types: the Embraer 175, and the Embraer 190. For this project, the Embraer 190 was chosen, because more information was available on this type of aircraft. The operation of the door was slightly simplified to remove both tiny gestures that would become too finicky for the controllers, such as the mechanism to release the door from its open position. The actions that remained were pulling the lever and pulling the door open to the side. A handle was added in the area on the right side of the door to provide an affordance

Fig.49: The redesigned door

for grabbing. This concept was tested and validated during development, however it should be noted that the test subjects were KLM employees who may or may not have been aware of the exact procedure of opening an Embraer door. Chapter 5 will elaborate on how the end users reacted to this simplified door opening procedure. An image of the redesigned door can be found in *Fig.49*.

Fire extinguisher

Arguably the most essential usable object for the fire-safety training is the fire extinguisher. Fire extinguishers know many different variants, ranging from big to small, but they mostly have a similar method of operation. After the safety pin is removed, at least one hand is used to squeeze the lever, while the other hand is used as support if necessary. The support hand aims the attached hose or nozzle, or it can support the canister by providing stability during use.

Fig.50: Real-life fire extinguishers. Left: Larger commonly found extinguisher; Right: KLC halon extinguisher

Most extinguishers are designed so that the lever both acts as a handle for carrying, and as a method of activation. For the purposes of the fire-safety training with single-button interaction, performing two actions with one hand is undesirable, and those functions need to be separated.

On board of KLC aircrafts, a smaller extinguisher is used. This extinguisher fits into one hand, as opposed to the bigger commonly found fire extinguisher (both are depicted in *Fig.50*). For the translation to the VR environment, this smaller size is ideal, as it will feel more natural to pick a hand-sized extinguisher with one hand, than a big extinguisher that is normally too big and heavy for one hand. Another advantage of only using one hand to grab the extinguisher is that the user's second hand is free to perform a using action. The smaller fire extinguisher found on board does not have a movable nozzle or hose, but a small rigid nozzle. This is also convenient, as the hand that grabs the canister can simultaneously aim the nozzle.

Several concepts were generated and tested to remove the grab function from the lever. These concepts are displayed in *Fig.51* and explained in *Fig.52*.

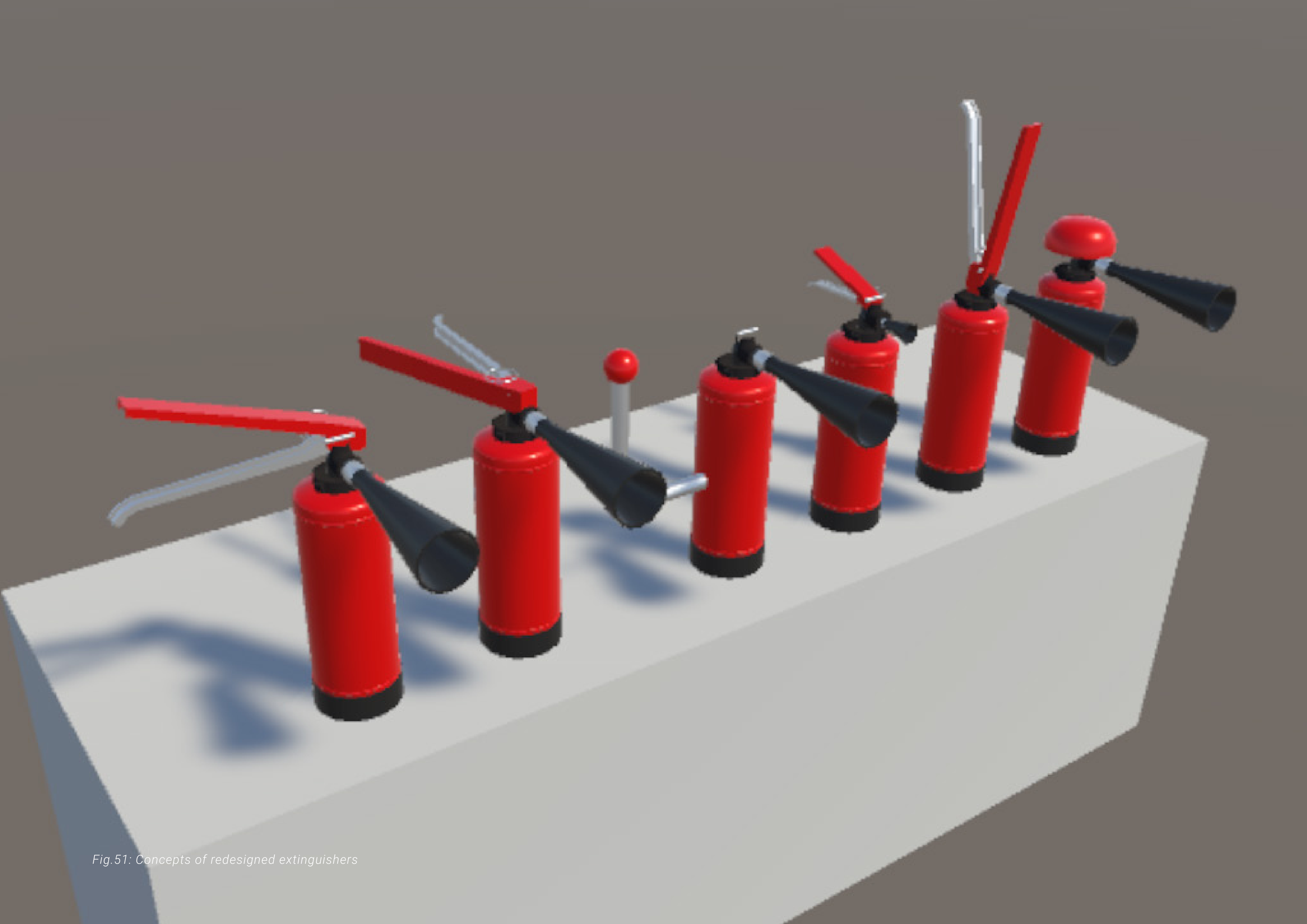


Fig.51: Concepts of redesigned extinguishers

Regular extinguisher

As a control specimen, an extinguisher that closely resembles the real-life extinguisher was used. Users behaved as expected and tried to grab the extinguisher at the handles, activating the extinguisher. Conversely, after users had managed to grab the extinguisher by the canister, it was difficult to use, due to the small size of the handles.

Twisted handle

To remove the affordance of grabbing the handles, but keep the directionality of the handles and nozzle, the handles were twisted. The handles were also increased in size, to compensate for the small area to allow them to be used. This caused issues since now the handles came too close to the user, and although there is no physicality to the handles, users were still trying to keep the handles out of the space their body occupied.

Sideways Extinguisher

This concept aims to remove the affordance of aiming using the handles. The nozzle's size was increased to assume this responsibility. The idea was that if users manage to grab the extinguisher's canister, the handles would be in an inviting position to squeeze, at least when grabbing the canister with your left hand. This handedness caused problems, as well as users that still attempted to grab the handles, and were confused as to why the nozzle pointed the wrong way.

Fig.52: Detailed description of the redesigned extinguisher concepts.

Bunny ears handles

This extinguisher achieves the best result to remove the carrying affordance from the handles, and simultaneously keeps the parts out of the user's personal space. The way in which the handles are placed also invite a grabbing motion that can be provided by the hand avatars.

Top button concept

One of two concepts made that allow for the removal of the handles completely. A big red button was placed on top to convey the affordance of activation, without also reintroducing the affordance of grabbing. This concept was based on the fire extinguisher used in the game Job Simulator. A downside of this concept is that it deviates more from the intended fidelity level of the simulation.

Lever activation concept

This concept also allows for the complete removal of the handles. The downside is that it becomes even more cartoonlike, which makes it a less suitable candidate for the fire-safety training.

The previously mentioned concepts can be tested in the TestObjects application found in the Appendix. The functionality of the safety pin was omitted in these concepts, since its removal would require a precise movement, which is an undesirable action with the controllers. The pin could be made bigger to allow proper interaction in conjunction with the controllers, but it was chosen not to do this as the equipment operation was considered to be dispensable aspect of the simulation. Additionally, the safety pin was also not present in the current fire-safety training, as it was also considered to be a part of the separate equipment operation training.

The test consisted of placing one variant of the extinguisher in a room with a fire. Test subjects were then asked to extinguish the fire without any further information on how to operate the extinguisher. The test subjects were the same people that tested the redesigned door from the previous section immediately before this test, so it could be assumed they were familiar with the controls by the time of this test.

The variant that had the users perform the desired actions with the least hesitation was chosen as a suitable solution (*Fig.53*). The idea of this concept was that the handles were upright, removing the affordance of carrying, but maintaining the affordance of squeezing. The gripping motion provided by the virtual hands was still communicated by the handles, but since their orientation communicated that there was no way for them to rest on top of the user's hand, this affordance was removed.

Fig.53: The cosen fire extinguisher concept.

Buttons and knobs

The cabin has several small buttons and knobs that would be too small to be comfortably pressed and moved with the controllers if they remained their actual size.

Buttons were given a bright colour and a uniform look throughout the cabin (*Fig.54*, *Fig.55* and *Fig.56*). The main purpose of this change was to communicate interactability and similarity in their method of interaction. The buttons were also made bigger than normal and made visibly movable. This was done to negate the undesirable need for high accuracy movements for interaction, and to provide the user with visual feedback in response to their action (as kinaesthetic feedback would normally communicate this small movement). When the user's hand would come close to a button, the hand would automatically animate to a pointing stance, providing the affordance of pushing the button (as seen in *Fig.56*). As there is no set paradigm for deciding to what extent the appearance can be changed without losing the connection to reality, these changes were made on intuition and validated by other KLM employees.

Fig.54: Top: real-life crew control panel, bottom: the redesigned galley master button.

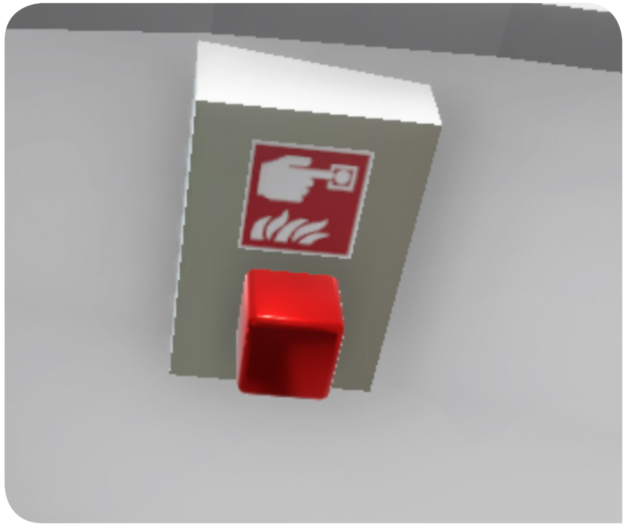


Fig.55: The lavatory smoke alarm button.

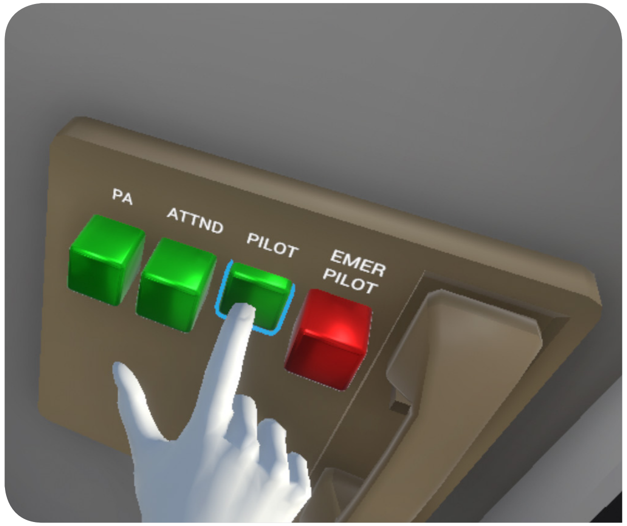


Fig.56: The phone buttons and the hand in a pointing stance.

The phone was given a bigger panel where the four buttons were placed to accommodate for this larger size, while maintaining the layout of the buttons relative to each other. The cabin crew panel (where the galley master power is located) was removed and replaced with a single button. This was done because programming functionality for all the panel's buttons was unfeasible in the allotted time span of the project, and having buttons that communicate interactivity without delivering a response would not align with the users' expectations. The button was placed in the same area as the panel would be to ensure users would still be able to rely on their knowledge of the aircraft layout. One final button was placed on the smoke detector in the lavatory. Normally this would be a very small button to reset the alarm, requiring a pinprick tool, however for the same reasons as stated before, the choice was made to align the interaction method with the controller as interaction interface.

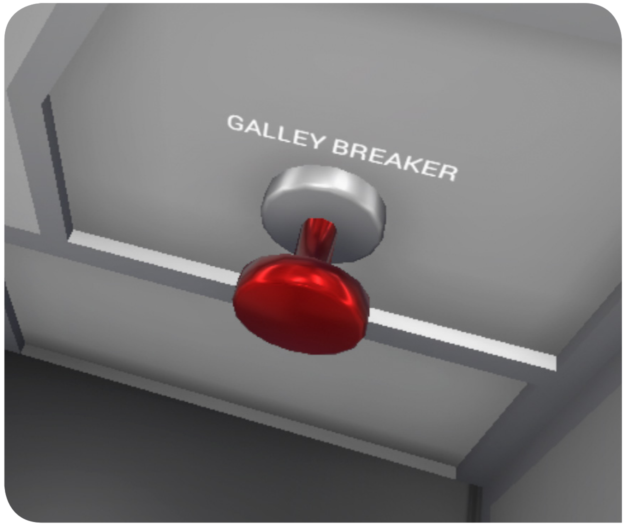


Fig.57: The redesigned galley circuit breaker

A similar change was made to the galley circuit breaker as was made to the buttons: it was made slightly larger and given a bright colour (*Fig.57*). The movement was kept the same as the real circuit breaker, but also amplified (pulling the breaker out ceveral centimeters).

The galley locks were also modified slightly. Besides making them a bit larger, two locks were collapsed into one at locations where there were two locks close to each other (*Fig.58*). This was done due to constraints in space, but also to prevent users from having to perform a similar trivial action repeatedly.

Fig.58: Two galley locks were collapsed into one. Top: real-life galley, middle 1:1 virtual model, bottom: two locks collapsed into one.

The choice was made to not make the trolleys interactable. They are not required for the protocol, and making them interactable could create the undesirable expectation of being able to move them around the cabin, which would then, among other things, demand a solution would be found for the superhuman strength problem, as described in section 4.1. To remove any possible affordance of interactivity, the galley locks were also removed where they would normally guard the trolleys (*Fig.59*).

Fig.59: The locks guarding the trolleys were removed. Top: Real-life galley, middle: 1:1 virtual model, bottom: trolley locks removed

4.5 Environment boundary

One aspect of the environment that needs to be addressed is a way to limit the virtual environment as to fit the physical play space (a consequence of the choice made in section 3.5).

An option already briefly mentioned was the shortening of the aisle to fit within the physical space. this would reduce fidelity, but allow for the environment to become an enclosed space. However, lowering fidelity in this case might not be necessary. considering the aisle is the only way to move to the back of the aircraft, blocking the aisle will provide a natural boundary of the environment. The aisle could be blocked off by a trolley, however this might prompt trainees to remove the blockade as prescribed by their training, so a more acceptable blockade is preferable. KLC employs a curtain to partition the aircraft in an economy and a buisiness class section. The amount of rows in the buisiness class can be variable, and hence the curtain's position is variable. This makes for an ideal candidate to shield off the back rows of the plane, as their presence in the walkway will not automatically prompt removal by the cabin crew. If this solution is chosen to delimit the play area, the testing phase should point out that these curtains do not prime trainees to try and open them and walk through the rest of the aircraft. For the fire-safety training, the main events mostly take place in the galley area, and possibly on the first few rows, so the curtains will possibly not have this effect.

All things considered, the curtains were chosen as a boundary of the environment, as depicted in *Fig.60* on the next page.

Buisiness class is in the front of the plane, economy class is behind buisiness class.

Fig.60: Top: real-life curtain divider; bottom: the curtains as implemented in the final prototype.
note: the top image is taken from a spherical image, so the perspective is heavily distorted.

4.6 Multiplayer avatar

The fire-safety training is performed by two trainees simultaneously. One of the unanswered questions of having two people present in the same environment at the same time is how they will perceive each other. There are many social VR experiences, that all have their own view on how a multiplayer avatar should look like.

During a developer talk about the subject, Booth, Creative Director of Social VR at Facebook, outlined the challenges of designing a social experience in VR **[32]**. Although the fire-safety training is not intended to be a social experience per se, some of the lessons outlined by Booth can be applied to the context of trainings to enhance the experience. Several topics that should be taken into account are the value of eye contact, being able to see where the other person is looking, emotions of the other person, sip sync, and how the other person's body avatar looks. These topics are not trivial, and can make or break the multiplayer experience, however due to their complexity, developing a suitable multiplayer avatar was placed outside of scope for this project, and is recommended as a topic for further research. For the prototype of this project, a simple, neutral head model was used to represent the location of the head of the other trainee, and hands were used to represent the controller (hand) locations of the other trainee (*Fig.61*). KLM Blue was chosen as a friendly colour, however, due to a glitch in the final build, the colour reverted to red (default). This was not noticed until the test, and was left like this during the next test day for consistency.

Because there are essentially only three tracking points for the user, and because the choice was made to deviate from the maximum fidelity possible, it is recommended to have two users in two separate play areas. This will prevent one user from colliding with parts of the second user's body or equipment that are not tracked, or not taken into account in the avatars (e.g. the protruding parts of the headset and controllers). This is complementary to the recommendation given in section 3.3.

Fig.61: The multiplayer avatar in the final build

4.7 Final Prototype

With the previously mentioned aspects redesigned, a final prototype was created. This prototype was included in the appendix B (trainee application, requires a Vive Pro) and appendix C (trainer application, for desktop to monitor trainees and issue training events). Several screenshots of the prototype (trainee application) can be found in *Fig.62*,and *Fig.63*.

Fig.62: Screenshot of the cabin filled with smoke from the final prototype.

Fig.63: Screenshot of the fire being extinguished in the final prototype.

5 Testing

Photo: Mark Wagtendonk

Chapter Introduction

Once the final details of the concept were designed and developed in the prototype, a use test was planned with KLC trainees and trainers. The test was carried out in collaboration with J. Westenbroek, who designed and tested the trainer side of the prototype.

Chapter 5 - Testing

5.1 Test setup

The prototype test was conducted during two days at KLC's training department. 10 groups were asked to use the VR fire-safety training prototype. A group consisted of 2 trainees and one trainer, so in total 20 trainees were test subjects for the prototype. The rest of this chapter will elaborate on the trainee side of the test. See J. Westenbroek's report for details on the trainer side of the test.

The aim of the test was to validate the choices made in earlier stages and to identify shortcomings that have to be addressed in a future iteration. The instructions given to trainees were that they would undergo a fire-safety simulation where they would have to follow the protocol. They were informed that they could interact with the environment by using the trigger button on the controllers, but no further specifics were given.

Throughout the course of the training, the behaviour and actions of the trainees were passively observed. Screen recordings were made of their viewpoint to be able to go through interesting sections with the trainees after they had finished. Once the trainees had completed the training, their general feedback was asked, and noteworthy behaviour and actions were discussed with the test subjects, using the screen recordings if necessary.

The following sections will discuss the most important design choices of the project and how trainees reacted to them. Recommendations will be given to further improve the VR training, and to preserve aspects that had the intended effect. *Fig.64* displays the test setup during the second day.

5.2 General notes

During the testing on the first day, there were many issues with the internet connection, which caused the three instances of the application (two trainee instances, one trainer instance) to lose synchronization. This was problematic in some cases where, for example one trainee was holding the fire extinguisher, but the other two test subjects observed the fire extinguisher on the ground. The desynchronisation was unfortunate, but after informing the trainees the issues were due to technical issues that would be worked out at a later time, most groups were able to complete the scenario.

On the second day, and attempt was made to curtail these issues by connecting through a 4G hotspot. The issues unfortunately persisted, meaning the prototype will have to be developed further to allow for a smooth multiplayer experience. During the second training day the choice was made to remove the multiplayer aspect and only have one trainee execute the procedure in the simulation. This

Fig.64: Test setup

was possible since the tasks of the second cabin attendant (CA-b) are mostly supportive and can be handled by CA-a as well.

Some test subjects noted the multiplayer avatar made them feel uncomfortable, since it consisted of a floating head and hands. Although unfortunate, this outcome was a consequence of placing the design of a suitable multiplayer avatar out of scope.

The curtains performed well in their function of providing a natural boundary of the virtual environment. However it should be noted that the implemented protocol mostly takes place in the galley (in the front of the aircraft). It should be re-evaluated when a scenario is implemented that takes place in the aisle (closer to the curtain)

One noteworthy action that many trainees wanted to perform was to grab the PBE and gloves once they noticed the fire in the oven. These items were omitted from the simulation since the protocol considered this step optional. When asked why trainees wanted to include this step in the execution of the protocol, the majority of the test subjects stated this was to protect themselves from the halon that would bounce back towards their face when they would spray it in the oven. This reaction was unforeseen, but several conclusions could be drawn from this observation. Firstly this intention implies the expectation management of the simulation falls short. This is an issue that should be addressed with high priority, as falling short of the user's developed expectations severely inhibits a positive experience. Both allowing trainees to grab and wear the PBE and having the halon bounce off surfaces are relevant additions to address this matter. On a more positive note, these expectations do suggest the simulation is of an appropriate level of fidelity that the users expect this kind of realistic behaviour. This is a legal requirement for the training as prescribed by the Human Environment and Transport Inspectorate, meaning it could serve as an argument in a future endeavour to include this training as a compliant training in the curriculum.

If these actions can be implemented in the simulation, this behaviour can also result in a valuable lesson for the trainees as to the behaviour of the halon. When users would not use the PBE for protection, and they would haphazardly spray halon, it could for example blur their view, or have other purposefully negative effects on the sensory input created by the VR devices. In a real fire-safety training it would be impossible to have trainees experience this kind of effect, due to the health risks it would pose.

When setting up the equipment during the second day, the floor level of the simulation was accidentally set too low during the first two tests. This caused users to be unable to pick up objects dropped on the floor, as they were physically unable to move the controller close enough to the object to interact with it. This was corrected after the second test where the user was unable to complete the training due to the fire extinguishers having been dropped out of reach. This is a difficult problem to address in a structural way, and should be less of an issue when the base stations were placed in a more permanent, fixed location in the room.

At the root of this problem was another point that requires further attention: Users frequently dropped the objects they were holding. Some test subjects were causing this because they were using the controller in an unintended way, an occurrence that will be discussed in section 5.4. However, the majority of test subjects that were facing this predicament were using the controllers correctly. They experienced this problem due to the break force threshold being too low, causing objects to disconnect from the controller too easily.

One of the choices made during development was to require the halon to collide for at least 6 seconds. This was based on instructions from the real fire-safety training where trainees had to discharge the entire content of the extinguisher (around 10 seconds) onto the fire. During testing, however, several trainees attempted to smother the fire by discharging quickly into the oven and closing the oven door. This would be a viable method in reality, but the simulation does not recognise this as a valid extinguishing method. Adding this possibility would be preferable to enhance the fidelity of the training and align with the users' expectations. Aside of this possibility, even trainees that extinguished the fire with an open oven door noted the fire reacted too slowly to the halon. Reducing the extinguishing time, or adding more feedback to the extinguishing action would also improve the fidelity to align more with the users' expectations.

Aside from the design recommendations, a distinction can be made between technical issues that can be resolved by further development (such as the desynchronisation issue) and technical issues that can occur due to issues that are mostly out of the developers' hands (such as the floor issue). After a certain point, staff will be needed for issues due to e.g. hardware failure, or resetting of the base station calibration, as developers cannot account for every possible scenario. This is unfortunate, but not exclusive to VR, as for example flight simulators, or other training equipment face the same problem.

5.3 Training flow

Having the trainees start in the real world setting was mostly experienced as positive. Due to the size of the room that was available for the test, the virtual entry door had to be placed close to a wall, resulting in limited space to unlock and open the door. The possibility of such a scenario was described in the consequences of the choice for this transition concept, and in final implementation the room should be big enough to prevent this problem.

The door itself was useful as a tutorial, but it did not react to the users' intended actions in all circumstances. A handle was added on the right side of the door to hint the user to grab there, however this handle went unnoticed by many trainees. In these cases the trainees attempted to grab the side of the door to pull it open, which was not possible in the prototype. Trainees also noted the door did not behave like an actual door, for example because of the omission of the vent flaps. The door had these kinds of simplifications on purpose to allow trainees to complete this stage with more simple interaction. Since cabin crew trainees are drilled in door operation procedures, it is recommended to have more accurate representation of these procedures in the tutorial stage of the simulation to align more with their expectations. This increase in complexity can also be positive, as it can serve to increase the trainees' familiarization with the controls.

Once the trainees had entered the virtual environment, most of them left the door open. This caused the outside world to be visible through the door opening throughout the course of the training (as seen in *Fig.65*). This is an undesirable situation, since the visibility of the real world only serves as a transition phase. It is recommended to find a suitable solution for this problem, for example by having the door automatically close behind the user if they fail to close the door themselves.

It was also unclear to most trainees when the training had concluded. The endpoint concepts were not implemented in the prototype due to time constraints, and it is recommended to review this part of the training flow after these endpoints are part of the simulation.

Fig.65: The outside world was still visible during some tests

5.4 Intuitiveness of controls

One of the main goals of this project is to design an interaction method that is intuitive enough to allow for a minimal learning curve of the controls to be able to complete the training scenario. One of the main design choices to achieve this was to implement the training through single-button interaction.

This method of interaction was a good choice, since almost all trainees were able to handle the controls immediately, or after a short period of trial and error at most. There was one trainee who had more difficulty, as it took her a while to get used to the fact that the trigger had to be held down to keep holding an object. She thought one press would grab an object, and a second press would release that object.

The interaction method was supported by the animation of the hands, which were noted by some trainees to feel realistic and comfortable. Several trainees noted during the door operation that the hands disappearing when grabbing an object (tomato presence) could have resulted in some kind of additional feedback, however once they had entered the cabin, this was no longer an impediment for interaction. This was possible caused due to the fact that the trainees were still present in the real world, and the disappearance of their hands conflicted with their expectations in this environment.

One often unused interaction possibility was the option to transfer a grabbed object from one hand to another. This was possible in the simulation and could for example aid trainees to reorient the fire extinguisher to face the correct way. What trainees did instead was either place the extinguisher on the galley counter and pick it up from a different angle (often accidentally pushing it off the counter), or rotate their hand and controller until the desired orientation was reached. In order to inform users of the possibility of the action of transfering objects between hands, it should be included in the tutorial stage of the simulation. An alternative option could be to revisit the choice to not automatically orient the grabbed object in a predefined pose, so the described problems are no longer an issue.

5.5 Redesigned affordances

Several virtual objects were redesigned to provide the right affordances for the chosen interaction method (described in section 4.4). Out of these objects, the fire extinguisher is the most central to the fire-safety training. Most people were using the fire extinguisher as intended, however some people did not notice the difference between the handles (the usable part) and the body (the grabable part), at least at first. A possible improvement to the fire extinguisher could be that it is unusable if it is not grabbed. This way accidental use could be reduced.

Many users also exhibited noteworthy behaviour when trying to press buttons in the simulation. They attempted to activate the button by pressing the trigger on the controller once they were in the buttons vicinity (see *Fig.66*). The intended manner of operation was to physically press the button, similar to real buttons. This seemed like a more natural way of interaction than connecting the button to the controller trigger, as this is more a pulling motion than a pushing motion. The tests however showed that this argument does not cover most users' expectation, and a different

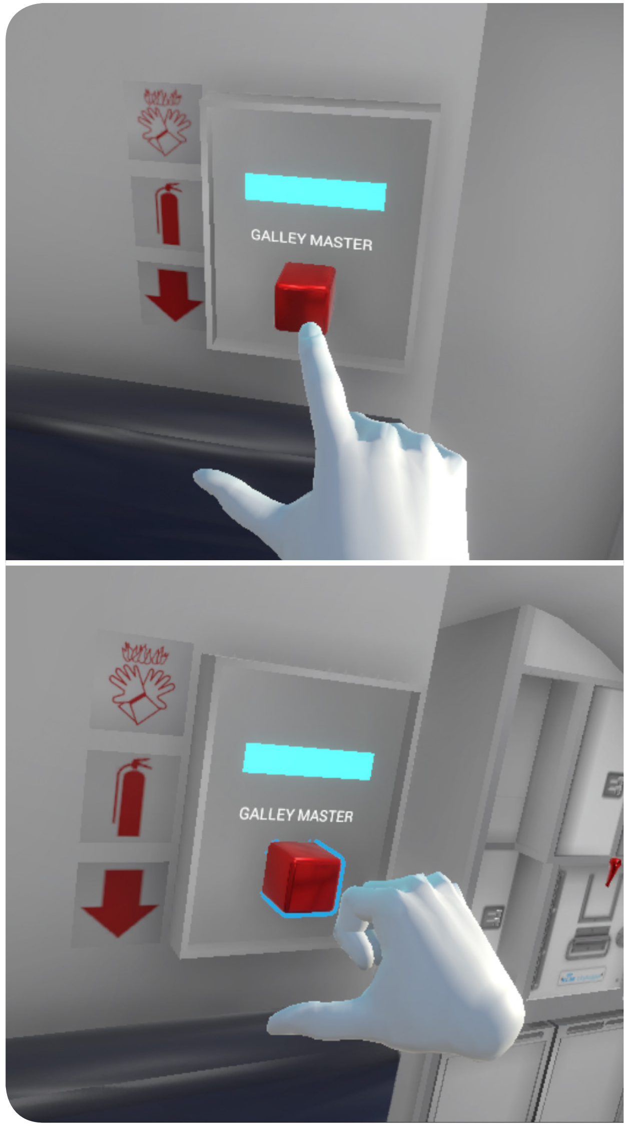


Fig.66: Most users pressed the trigger button when trying to press a button, resulting in a different action than intended.

implementation is recommended in future iterations. One option would be to use rocker switches, as the operation of these switches better matches the movement of the finger when the trigger is pressed in proximity to a button (see *Fig.67*).

Fig.67: A rocker switch would align with the users' observed behaviour and move in a similar manner [xxiii].

Interestingly, some of the same users that wanted to activate buttons by pressing the trigger also moved the galley locks without pressing any buttons. This debunked the hypothesis that these users only expect objects to react to actions when a controller button is pressed. These trainees were also unable to give an explanation for this behaviour when asked, and further research into this behaviour and how to design for it is recommended.

Another interesting development during the simulation was that many trainees forgot to disable the galley main power. This is a mandatory step in the protocol, so trainees should be aware of its importance. When trainees did remember or were reminded by the trainer to turn of the galley power, they often had trouble locating the main power switch. This could be the result of the omission of the entire crew control panel, and its replacement being the single relevant button. The next iteration of the training should include a closer analysis of this step of the protocol and its most fitting implementation within the restrictions of the chosen interaction method.

One object that had also been simplified was the oven door. In the simulation, the knob normally used to (un)lock the door was only a visual animation, and did not respond to a twisting motion (*Fig.68*). Some trainees however attempted to twist the knob and were confused as to why it did not work as expected. Implementing this twisting action should therefore be considered and tested to further enhance the simulation.

The removal of the galley locks above the trolleys had the desired effect, as only one trainee attempted to grab a trolley once, and quickly moved on without much hesitation once the simulation did not react to this action. This can be considered acceptable, since the trainee did not seem distracted by the lack of reaction.

Fig.68: The oven knob only visually turns 90 degrees when the trigger is pressed. Left: oven knob just before grabbing; Right: oven knob when grabbed (tomato presence removes the hand).

Future Implementation

6

Photo: Mark Wagtendonk

Chapter Introduction

This chapter will give a recap of the results of the case study, and will discuss the broader applicability of the results of this prototype to several other training simulations, and reflect on the achieved outcomes. A shared conclusion written together with J. Westenbroek will link the results of this report with the results of his report.

Chapter 6 - Future Implementation

6.1 Recap of prototype results

The results of the prototype test reveal several aspects that can be improved for this training specifically, however these improvements show no serious shortcomings relating to the bigger design choices made in chapter 3. The choices made can serve as a solid foundation for further iterations, to eventually allow the simulation to be integrated in the training curriculum.

The main choices made during the development of the fire-safety training were based on the UX model posited in chapter 2. Throughout the project, this model served as a useful framework to base choices on for a coherent and pleasant user experience. Single-button interaction with controllers was chosen to allow for as much freedom as possible, while still keeping the interaction feel as natural as possible. As a consequence, many virtual objects had to be simplified and redesigned. Although the current prototype solved several of this challenges in a satisfying manner, further development and testing is required to fully allow for the benefits of single-button interaction to flourish for this training.

For this project, the UX model was applied to provide a basis for the fire-safety training. The model should however be more generally applicable. The following section will discuss several possible changes in outcomes when applying the model to different circumstances, to further illustrate the value of the model.

6.2 Discussion

One of the main choices made for this project was the interaction interface. The choice was made to use out-of-the-box controllers and single-button interaction. These choices were possible due to the aim of the training. In case the training had a different goal, a different interaction interface might have been a more logical choice.

In case the operation of the equipment had to be taken into account in the training, this would result in other aspects, such as fine motor skills and haptic feedback, having to play a bigger role in the simulation. One option would be to invest a significant amount of resources in hardware that could accurately emulate these sensory aspects. Another, conclusion could be to step away from a strictly VR solution, and move more towards an AR solution, where strictly natural interaction with the equipment would be possible. A solution tending towards this direction would obviously also come with its own problems and limitations, requiring exhaustive analysis and iteration to overcome.

When briefly attempting to apply the UX model to a different training, different conclusions can be drawn. One of the trainings developed parallel to the fire-safety training at KLM is a jet bridge training. The goal of this training was to train personnel to connect a jet bridge to an aircraft. The jet bridge is operated through a control panel (as seen in *Fig.69*), with joysticks and buttons to control the speed and direction of the jet bridge. Assuming the interaction with the control panel occurs similar to operating the controls when driving a car, kinaesthetic feedback plays a big part in operation. Normally a driver is able to shift gears almost entirely based on the resistance the gearshift gives. This frees up the visual system for digesting other information. In this case, immersion needs to be increased to incorporate this kind of feedback to fulfil the user's expactations.

Fig.69: Jet-bridge operation panel

With this solution, a fully physical environment is not needed, as the interactions are confined to the control panel. The rest of the simulation could be mostly audiovisual feedback as VR would allow the trainee to see the entire tarmac (a large environment) within a training room (a small environment).

6.3 Important lessons

One of the main lessons of this project is that blindly striving to maximise immersion and fidelity is not enough to provide a pleasant user experience. Current VR devices and software are technologically not yet in a stage where they can sufficiently emulate the real world, so balanced compromises have to be made in the areas where they lack. These compromises should always be made with the goal of the simulation in mind.

Referring to the proposed solutions as virtual reality should also be reconsidered, as it may be too restricting. For this project the solution to smooth the transition between real world and virtual world should technically be classified as augmented reality. The term Extended reality (XR) encompasses a more broad definition that may be a better fit for future expansion.

Finally, although the UX model provides a framework for making design choices, a lot of testing is still required to validate the assumptions made about the user's expectations. The test results can then be used to iterate on the simulation and maximize the overall experience.

6.4 Shared conclusions

This section will discuss how the results of this project relate to the results of Jasper Westenbroek's project. It is a common conclusion written by both parties together.

One of the main conclusions of J. Westenbroek's project is that the code and assets should be built in a reusable manner. One of T.V. Simons' main conclusions is that the interaction design should be re-evaluated per training. These two results conflict with each other, considering the fact that J. Westenbroek recommends the re-use of components for future training applications, while T.V. Simons suggests redesigning important components of the simulation completely.

However, considering that this conflict has already occurred throughout the course of the fire-safety project, it is possible to find compromises that can overcome this conflict in a satisfactory manner. In the current prototype, a code library (VRTK **[33]**) was used that served as a base to develop specific interactions in the form of modular assets. In case a different interaction design concept would have to be applied in future development, such libraries allow developers to regress to a more abstract version of the asset and continue from there, without having to rebuild it from scratch. Conversely, trainings which have a similar goal to the fire safety training, i.e. practicing protocols, can easily reuse the assets built for this training.

This section was written in collaboration with J. Westenbroek

A second conclusion of T.V. Simons is that in order to maximize the user experience of a VR simulation, it may be beneficial to purposefully reduce realism in order to allow for more natural interaction in line with users' expectations. This is complementary to J. Westenbroek's conclusion on modularity, as a simpler implementation of interactions is able to be applied in a more generic way across the simulation.

An example of this is the choice for tomato presence to solve the problem of hand-object orientation. This concept removes the need for the reorientation of the hand or object when grabbing. In the latter case, pairs of hand-object poses (as were seen in *Fig.47*) should be incorporated in the simulation, while tomato presence removes this need by hiding the hand model. This way generic grab behaviour can be applied to all interactable objects, making the entire simulation more modular.

Conclusion & Recommendations

Photo: Mark Wagtendonk

Conclusion

VR can serve as a useful tool for professional training applications. One of the most important aspects to keep in mind when designing VR experiences is the manner in which users interact with the simulation. If users are not comfortable in using the simulation, they will be hesitant to use the simulation, and possibly even reject the entire technology as a result. The UX model proposed in this report provides a useful framework in determining which aspects to take into account and how they relate to each other. The fire-safety training served as a useful case study to test the UX model. The finalized prototype provides a effective first iteration to further develop this simulation for future utilization in the training curriculum. More broadly, it serves as an example of the capabilities of VR for future implementation within KLM.

Recommendations

Fire-safety Recommendations

The following recommendations were mentioned in the report as (possible) improvements for the fire-safety training:

Apects placed out of scope:

It is recommended to include the conceptualized endpoints in the simulation. These endpoints need use testing to validate their effectiveness.

Further research is recommended on the addition of sound (Foley) to the simulation, and its impact on the experience due to the increased immersion.

It is recommended to do further research on what the impact is of different multiplayer avatars on the experience.

Technical issues:

The synchronisation issues encountered during the use test should be addressed and resolved within the application if possible.

Aside from the space for the virtual environment, space should be allocated for the area where trainees can freely open the door without having to worry about physical obstacles such as walls.

Simulation events:

The break force of grabbed objects should be fine-tuned to avoid the accidental release of grabbed objects.

During the test, it became apparent that the extinguishing of the fire lasted too long, did not give enough feedback, or otherwise did not meet the test subjects' expectations. This should be addressed in a future iteration.

Tutorial phase:

The test subjects were actual KLC cabin crew trainees. They therefore already had had certain knowledge about the door operation. This resulted in the simplifications made to the door being too severe for the target group. Acceptable middle ground should be found in this regard.

A suitable solution should also be found for the cases where trainees leave the door open, as to avoid the real world being visible through the door opening.

During most tests, users were unaware they could transfer a grabbed object to their other hand. It is recommended to include this possibility in the tutorial section, so users will be able to rotate grabbed objects more easily.

Expectation management:

To fulfil the expectations the trainees exhibited during testing, the inclusion of PBE masks and gloves is recommended. It may also be worthwhile to increase the fidelity of the halon behaviour to include bouncing off surfaces to work in conjunction with the virtual PBE.

Although the redesigned extinguisher is a step in the right direction, some fine-tuning of the fire extinguisher is needed to prevent accidental use. This could be done by making the fire extinguisher unusable if it is not grabbed, but testing is needed to validate this idea.

Many users pressed the trigger button when attempting to press a button in the virtual environment, instead of moving their hand in the direction of the button. A solution should be found either by reworking the buttons to function with this action, or by removing the incentive in users to press the trigger button. One possibility is to replace the switches with rocker switches to keep the visual feedback of the switch moving, while simultaneously aligning the movement with the trigger press.

As an extension of this, the crew control panel (where the galley main power switch is located) needs to be reworked to be more in line with the real control panel.

On a more general note, research as to why users pressed the trigger button when they wished to press the virtual buttons, but also moved the locks without pressing any buttons can contribute to a further understanding of users' expectations.

The fidelity of the knob to open the oven door should be increased to align with the users' expectations that this knob should and can be turned.

General recommendations

Besides the previous recommendations for the fire safety training, some general recommendations can be outlined for further development of VR for training purposes within KLM.

One of the most important steps is to determine the goal of the training, as this goal should be the primary drive behind finding an interaction interface that allows for the optimal balance in costs and effectiveness. As mentioned earlier, blindly striving towards maximum fidelity will most probably result in a simulation that looks good, but without the proper immersion to back it up, it will not achieve its intended goal. Similarly, striving for maximum immersion will result in a lot of expensive equipment, but without content to offer through that equipment, it will be of limited use. These two aspects relate to the externally offered environment, making them the easiest to influence, but taking the user's internal processes into account can also compensate for lower immersion or fidelity. It is recommended to test each design choice to the UX model to ensure the overall experience is maximized.

Throughout the course of this project, KLM's personnel was always willing to assist in testing concepts or (parts of) the simulation. This not only provided valuable input for design choices, but also allowed them to see and experience VR, which is a whole new exciting experience for many people at this point. Spreading enthusiasm for the technology can aid and accelerate its adoption within KLM, so continuing these tests at every step highly recommended.

Glossary

Photo: Mark Wagtendonk

Glossary

The following section will list frequently used terms and their definitions that appear throughout this report.

Glossary

3DOF
3 Degrees of freedom. Referring to VR headsets that only track rotational movement. The user is fixed positionally in space, but is able to look around in 360 degrees from that fixed point.

6DOF
6 Degrees of freedom. Referring to VR headsets that track both rotational and positional movement. These devices can be split up into two categories: devices with inside-out tracking, and devices with outside-in tracking.

Affordance
What the environment affords to the individual; the properties of an object that hint towards its intended use.

AR
Augmented reality. AR layers virtual input on top of the sensory input of the real world.

Base stations
Devices that allow the inside out tracking with the HTC Vive. The base stations are usually set up on either end of the play area to allow them to have an unobstructed view of the Vive devices from most angles.

Embraer 175 / Embraer 190
The two aircraft types in the KLC fleet At the time of writing KLC operates 17 Embraer 170 models, and 32 Embraer 190 models.

Endpoint
Final state of the simulation. Either an unrecoverable failure state (fatal endpoint), or the proper outcome of performing the correct actions.

Engagement
In the context of the user experience model: the level to which a user's mental state can be kept focussed on the provided stimuli.

Expectations
In the context of the user experience model: conscious and unconscious assumptions made about how the virtual world will react to certain actions.

Fidelity
In the context of the user experience model: the level of realism and detail of the environment of the simulation.

FOV
Field of view. The extent to which a user can see the visible environment. Usually expressed in a horizontal and vertical angle.

Galley
The “kitchen” of an aircraft.

Halon
Chemical fire extinguishing agent used on board of aircrafts.

Haptic feedback
Feedback relating to the sense of touch; a collection of tactile and kinaesthetic feedback.

Immersion
In the context of the user experience model: the objective level of sensory fidelity a VR system provides.

Inside-out tracking
Positional tracking technology that is integrated in the VR device.

Kinaesthetic feedback
A type of haptic feedback relating to the sensation generated by the tension in muscles, joints and tendons. Kinaesthetic feedback includes the sensation of an object's weight, position relative to the body, etc.

KLC
KLM Cityhopper, subsidiary of KLM and main client for whom the fire-safety training was developed.

KLM
KLM Royal Dutch Airlines.

Locomotion
The act of moving in the environment

Outside-in tracking
Positional tracking technology that requires external devices.

Presence
In the context of the user experience model : the feeling of actually being in the virtual world.

Proprioception
The sense of the position of one's body parts relative to each other.

Psychic distance
The discrepancy between knowledge and experience, or between the experiences of one person and the ability of another person to imagine the experience of being in this situation.

Room-scale
The movement area of an average room. A minimum of approximately 2 x 2 meters in the context of this project.

Simulation
In the context of the user experience model: any experience that aims to emulate a user's senses or otherwise provoke mental stimulation.

Single-button interaction
Interaction method where only a single button is used to interact with the virtual world.

Stereoscopy
The technique to provide different images for each eye to create the perception of depth.

SWOT analysis
Analysis of the strengths (S), weaknesses(W), opportunities (O) and threats (T) of a project or choice.

Tactile feedback
A type of haptic feedback relating to the sensation a surface generates. Tactile feedback includes the sensation of vibration, texture, etc.

Teleporting
Instantaneously transporting one's point of view to a different position in the virtual environment. This allows for movement within areas larger than the physically available space.

Tomato presence
The concept that hand presence can be maintained using a stand-in object in VR and that the brain will intuitively accept it.

UX
User experience. In the context of the user experience model: the user's subjective full psychological response to a simulation.

VR
Virtual reality. Computer generated experience taking place in a simulated environment.

References

Photo: Mark Wagtendonk

References

The following section will list the references used in this report. References with a number are referenced in the text and influenced choices made. References with a roman numeral are image sources and serve to illustrate points made.

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Icons used in created images

Brain: Meaghan Hendricks, the Noun Project
Computer: Icon Solid, the Noun Project
Eye: Artem Kovyazin, the Noun Project
Ear: Artem Kovyazin, the Noun Project
Vive Controller: Igor, the Noun Project

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Appendix


Photo: Mark Wagtendonk

Appendix

Appendix A:
Unity build: TestObjects.exe

Appendix B:
Unity build: PrototypeTrainee.exe

Appendix C:
Unity build: PrototypeTrainer.exe