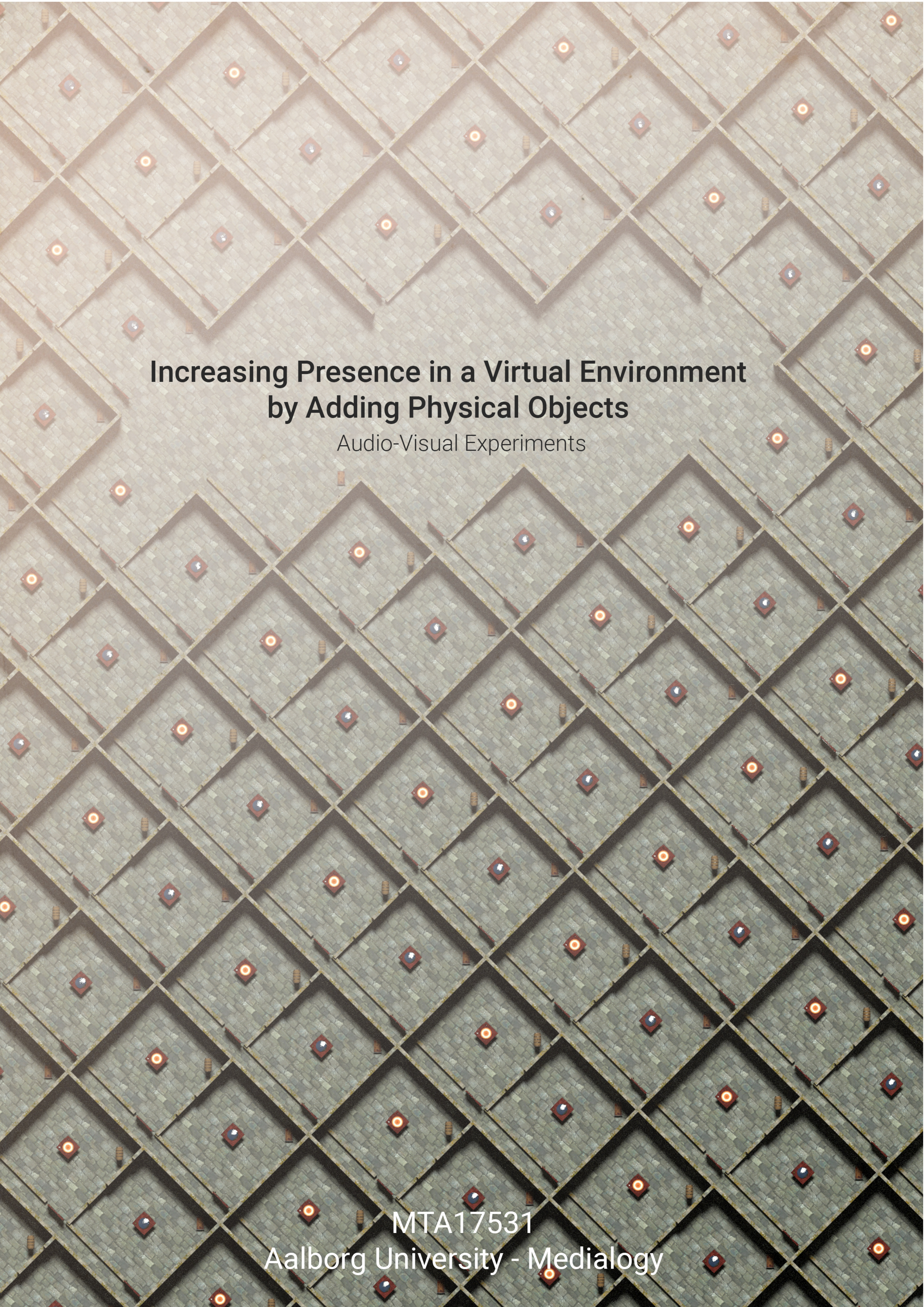

Increasing Presence in a Virtual Environment by Adding Physical Objects

Audio-Visual Experiments

MTA17531

Aalborg University - Medialogy

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STUDENT REPORT

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Title:
Increasing Presence in a Virtual Environment by Adding Physical Objects

Theme:
Audio-Visual Experiments

Project Period:
Fall 2017

Project Group: MTA17531

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Copies: 1
Page Numbers: 29
Date of Completion:
December 19th 2017

Abstract:

The goal of this project was to determine if presence of the user could be increased by adding physical objects to a virtual reality environment.
A puzzle-based escape room was created with self-overlapping architecture which puts emphasize on interacting with objects. These objects are built both virtually and physically so the same scenario can be played both with fully virtual controls and fully physical controls.
The problem formulation was answered using two tests; the Simulator Sickness Questionnaire and the Slater-Usoh-Steed Presence Questionnaire. The tests showed that there was no significant difference between the amount of simulator sickness between the two scenarios ($W = 86.5$, $p > 0.05$), and that there likewise was no significant difference between the amount of presence between the two scenarios ($W = 130.5$, $p = 0.45$).
With this it can be concluded that physical objects did not significantly increase presence in virtual reality.

Contents

Preface

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1. Introduction

Virtual reality is not a new technology: the first tracked head-mounted display was built by Philco Corporation engineers in 1961 [1]. Since then interest in virtual reality has come and gone, but in recent years a lot of new developments have happened to the technology - arguably because virtual reality has become a consumer product [2]. These developments include a wider field of view, and better framerate and resolution within the headset. Navigation has also changed, whereas before, the user moved using some sort of controller, now head-mounted displays, such as the HTC Vive, use room-scale virtual reality [3]. In this setup the room is equipped with two infra-red light towers which track the position of the headset and two controllers.

In the proposal that inspired the course of this project, the goal was to trick the user into thinking they were walking between multiple virtual rooms, while they were moving in the same physical area, using object trackers.

Using room-scale virtual reality gives the user the ability to walk around in the virtual environment, but it limits how big that space can be; SteamVR, used to utilize the HTC Vive in this project, limits the play area to 4 by 4 meters. Without any additional navigational features, you cannot do a lot in this small amount of space. To do any narratives that would consist of multiple rooms would require the rooms to be very small. Despite of this, walking in virtual reality does provide advantages over navigating using controllers [4].

One of these advantages is a better sense of presence. Virtual reality relies on the user psychologically being somewhere that they physically are not, and this feeling can be controlled using several factors. For example, immersion improves when the physical head movements are represented accurately in virtual reality, when the user can interact with the environment, and when the range of senses available to the user is increased [1]. Virtual reality headsets are prone to induce cyber-sickness, which can require the user to be pulled out of the simulation and therefore break the immersion, or in other ways make the virtual environment feel less real.

Object trackers are small devices that are tracked the same way as the HTC Vive controllers, but without the user input buttons [5]. They can be attached to physical objects, which can then be recreated and tracked in virtual reality. This can be used with gaming peripherals, so that custom controllers can be made to look and feel like the objects in-game, such as a gun or a golf club. It can also be attached to a pair of gloves, so that the hands of the user can be used to select or grab items.

For this project the goal will be to increase the virtual play area beyond the borders of the physical play area, while retaining an acceptable amount of immersion and sense of presence. To support the research needed to achieve this goal the following initial problem formulation has been created.

> *How can a VR experience be made immersive with a comparatively smaller physical play area?*

To answer this problem formulation it is necessary to research ways of increasing the virtual play area beyond the border of the physical play area. Immersion and presence should also be researched to know how to preserve it when expanding the play area. It would also be worth looking into cyber-sickness and how to prevent it.

2. Related works

This chapter will explore current ways to increase the virtual environment beyond the borders of the physical play area. In order to properly implement this in the prototype without decreasing presence, it is necessary to understand what affects immersion in this context.

2.1 Immersion

Immersion, in the scope of this project, is the concept of how well the virtual reality is projected onto any sensory receptors of the user. As mentioned in chapter 1 immersion can be manipulated using multiple factors [1].

2.1.1 Characteristics of virtual reality immersion

Some of these factors are technical. Surroundness specifies how panoramic the experience is, such as how wide the field of view is, or if it is capable of 360°tracking. Vividness specifies the quality of the resolution, frame rate, lighting, etc. These are tied to the equipment used. Matching is how well the user's bodily movements are represented in virtual reality. If this does not match to a certain extend, it could cause cyber-sickness. Interactability is the extent of which the user can interact with objects, or the virtual world in itself. Plot is also a factor, as it ties the world together, and makes the user invested in the world. Extensiveness is the range of senses that are presented to the user. At the moment, most consumer virtual reality headsets only present sight and hearing to the user. These products normally use a set of controllers for picking up objects, so the sense of touch is not utilized [1].

How the user perceives these is a whole other thing. This is called presence, a form of spatial awareness, and it is different from person to person and is difficult to quantify. It is the feeling of being there. Immersion and presence can be distinguished by feeling like you are perceiving a place or like you are actually visiting the place. Though immersion and presence are different concepts, a greater immersion has a greater potential at making the user feel present [1]. Immersion is highly dependent on the capabilities of the media through which it is presented, while presence is rooted in the users themselves.

2.1.2 Cyber-sickness

One of the most discussed problems since the inception of virtual reality is the experience of the symptoms of motion sickness. There are three types of sickness that are usually discussed in the context of virtual reality: motion sickness, simulator sickness and cyber-sickness. Although all of these share symptoms, the exposure leading to them is slightly different [6].

Motion sickness is commonly caused by physical movement in different means of transportation, therefore it is also generally called travel sickness. It may cause nausea, dizziness, and vomiting in some subjects [6].

Simulator sickness is caused by shortcomings of the simulation, but not from the situation being simulated. For example, it has been observed in imperfect flight simulators, where the apparent motion did not match the physical one. This means that if the same situation occurred in a real plane, the pilots would not feel sick [1].

Cyber-sickness occurs during the use of virtual reality, where the user is moving in a virtual environment while physically remaining stationary. This concept of being stationary, and the sensation of self-motion in virtual reality is also referred to as vection. This is different from motion sickness, because the discrepancies in motion is much greater here. Typical symptoms are nausea, dizziness, and eye strain. Cyber-sickness has been found to be up to three times as severe as simulator sickness [6].

2.2 Change blindness and impossible spaces

Even though the room-scale setup at Aalborg University has an area of operation of 4 by 7 meters, SteamVR is only capable of operating in a 4 by 4 meter area. This area has to be cleared of any objects to be suitable, which might not be optimal to do in settings like a living room; but the play area can be expanded by manipulating the virtual space.

Because the preferred means of navigation was walking [4], the initial research is focused on scaling the locomotion of the user. For example, that the users move further in virtual reality than they do in real life. Many different ways of doing this exist [7]. Research shows that motion in the direction of the user's movements can be upscaled by 26% before they notice it [8].

Many papers have also experimented with self-overlapping architecture that takes advantage of *impossible spaces* [9, 10, 11].

A particularly interesting take on impossible spaces was found in [8]. The approach in this paper, was to take advantage of change blindness to manipulate the environment and thereby control the movement of the user instead of directly manipulating their movement, which can potentially induce vection. Within a 14′ by 14′ area they created an office environment with a 60′ hallway and 12 rooms with a walkable space of 2352 square feet. They did this by rotating a door and the adjoining wall 90 degrees, while the user looked at a computer screen inside the room. This created the illusion of the user walking out into the same straight hallway, but in reality they had been rotated 90 degrees. This does however mean that user has to visit the rooms in a specific order.

The results showed that only one out of 77 participants noticed that the scene changed while exploring. The participants were also able to draw a detailed map of the virtual environment, and a pointing task indicated that they maintained their spatial orientation when the scene changed. These results indicate that change blindness is a powerful tool in creating this illusion.

3. Measuring presence

The focus of the project is not to test the artifact itself, but to use it as a tool to measure the level of presence. Therefore it is important to find a reliable way to measure presence between two different settings.

3.1 Slater-Usoh-Steed Presence Questionnaire

The Slater-Usoh-Steed Presence Questionnaire (SUS) is a questionnaire consisting of six questions, which fall into one of three categories: the sense of being in a virtual environment, the extent of which the virtual environment becomes the dominant reality, and to which extent the user remembers the virtual reality environment as a place. The user answers each question on a scale from 1 to 7. The score is then calculated by looking at how many of the six questions scored six or seven [12].

As stated in subsection 2.1.1 immersion is, among others, affected by: the display, which should optimally have a resolution that makes it non-visible *(Vivedness)*; how many senses the user is presented with in the virtual environment *(Extensiveness)*; how well the movements of the user is represented in virtual reality *(Matching)*; the extent of which the user can interact with the virtual environment *(Interactability)*. The unaltered questions of the SUS are as follows:

1. Please rate your *sense of being in the* virtual environment, on a scale of 1 to 7, where 7 represents your *normal experience of being in a place*.
2. To what extent were there times during the experience when the virtual environment was the reality for you?
3. When you think back to the experience, do you think of the virtual environment more as *images that you saw or more as somewhere that you visited*?
4. During the time of the experience, which was the strongest on the whole, your sense of being in the virtual environment or of being elsewhere?
5. Consider your memory of being in the virtual environment. How similar in terms of the *structure of the memory* is this to the structure of the memory of other *places* you have been today? By 'structure of the memory' consider things like the extent to which you have a visual memory of the virtual environment, whether that memory is in colour, the extent to which the memory seems vivid or realistic, its size, location in your imagination, the extent to which it is panoramic in your imagination, and other such *structural* elements.

6. During the time of your experience, did you often think to yourself that you were actually in the virtual environment?

These factors are at their optimum when the user is performing actions in reality. A test was conducted where a real environment was created in virtual reality, and a red box was hidden in both settings. Different participants tried to find the box and afterwards answered the SUS. The results should show that the participants from the real-life environment gave a higher SUS-score than the other group. It was shown that the score was slightly higher for the real-life setting than the virtual environment, but mostly because of two questions. It was concluded that when the test is performed on two different types of immersion (real-life / virtual reality or desktop / head-mounted display), the participants relativize their answers, and therefore the test is most valid when they experience the same type [12]. This makes the test valid for this project, as all participants will experience the same type of immersion, with only a single variation within this type.

3.2 Simulator Sickness Questionnaire

As mentioned in subsection 2.1.2, simulator sickness is a common phenomenon for people experiencing virtual reality. It is important to address this condition, as people experience it in situations that they normally would not in real life, and therefore it can pull them out of the experience and ruin the immersion.

A standard way of measuring simulator sickness is the Kennedy Simulation Sickness Questionnaire (SSQ). After examining 1000 participants they identified 27 symptoms that are common when in virtual reality. This questionnaire is a symptom checklist consisting of 16 symptoms. These symptoms cluster into three categories. Oculomotor includes eye strain, blurriness, headache, and difficulty focusing. Disorientation includes dizziness and vertigo. Nausea includes stomach awareness, increased salivation, and burping. The user ranks to which extent they experience each symptom on a four-point scale: none (0), slight (1), moderate (2), and severe (3) [13].

The different symptoms are weighted differently, so to calculate the final score it is necessary to follow the system on Table 3.1. The individual scores for each category are then calculated using the calculations in equation 3.1. When these have been calculated the total score is calculated with the equation $TotalScore = ([1] + [2] + [3]) * 3.74$, as stated in [13].

$$\begin{aligned} Nausea &= [1] * 9.54 \\ Oculomotor &= [2] * 7.58 \\ Disorientation &= [3] * 13.92 \end{aligned} \tag{3.1}$$

Weights of Symptoms			
Symptoms	Nausea	Oculomotor	Disorientation
General discomfort	1	1	
Fatigue		1	
Headache		1	
Eye strain		1	
Difficulty focusing		1	1
Increased salivation	1		
Sweating	1		
Nausea	1		1
Difficulty concentrating	1	1	
Fullness of head			1
Blurred vision		1	1
Dizzy (eyes open)			1
Dizzy (eyes closed)			1
Vertigo			1
Stomach awareness	1		
Burping	1		
Total	[1]	[2]	[3]

Table 3.1: The table used to calculate the weights of the symptoms

This questionnaire is to be used pre- and post-test. By having the participants answer it pre- and post-test, it can be seen how the test affected the participant, which it could not, had they just done the post-test questionnaire. The participants may have arrived with slight nausea and moderate burping, but by only doing the post-test, the conclusion would be that the test affected them negatively even though it might not have.

The SSQ can be used in tandem with the SUS questionnaire. If a user scores low on the SUS questionnaire, indicating that the artifact does not presence, but scores high on the SSQ, it can be assumed that simulator sickness had an impact on the extent of presence of the user. If the scores were reversed, it would indicate that simulator sickness does not affect the presence, and the SUS score would only be affected by the condition changed in the artifact.

4. Final problem formulation

Throughout the research it became clear that the effectiveness of over-lapping architecture has been researched and tested thoroughly by other teams. Therefore, this concept will not be the main focus of this project. However, the technique will still be used as a way to increase the space in which the project can be achieved and tested. Through research and several iterations, the design on Figure 4.1 was chosen as the play area for this project. Each room is 2.875 meters by 2.875 meters with a 0.625 meter wide corridor.

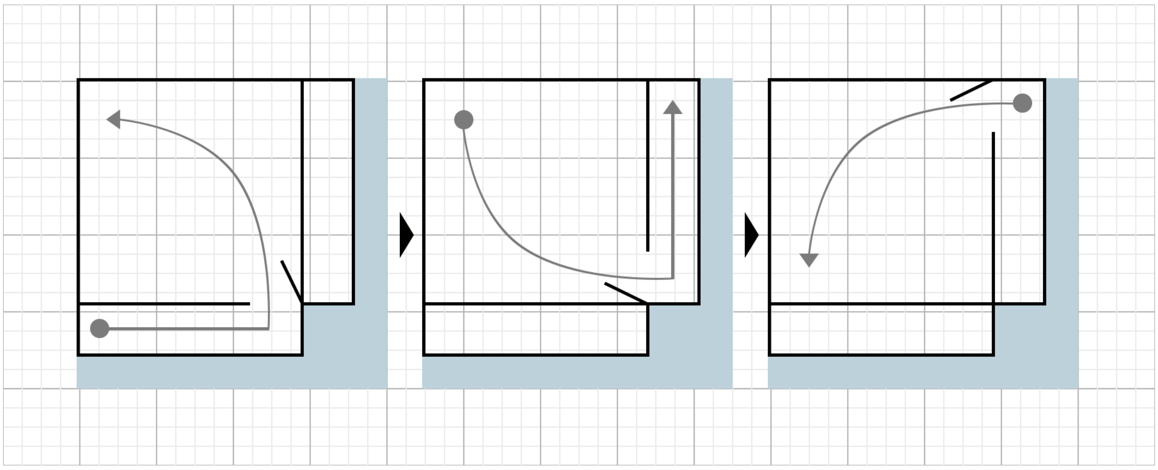

Figure 4.1: The overlapping architecture that was used in this project. One dark grey square equals 1 meter by 1 meter.

A gap in the research was found to be the inclusion of physical objects in VR. The problem has previously been, that there was no way to make sure that the physical objects would match the objects in VR, and therefore making the error rate too large. However, with the new tracker technology, made for the HTC Vive, it is now possible to track objects as accurately as the user can be tracked. This means that physical objects can be placed in a VR scene with greater precision. Therefore, the problem statement that is being explored in this paper is:

> *How can physical objects be used to increase presence in a virtual environment made with self-overlapping architecture?*

4.1 Success criteria

To test the problem formulaion, it will be tested based on the following two success criteria:

1. Using physical objects in the VR experience increases presence compared to a fully virtual setup.
2. The physical scenario must not cause more simulator sickness than the virtual scenery.

The first success criterion will be measured using the Slater-Usoh-Steed Presence Questionnaire. The score from the test will be compared to the score from the same scenario in a fully virtual environment. To succeed with this criterion, the mean score from the test with physical objects has to be significantly higher than in the fully virtual environment.

The second success criterion will be measured using the Simulator Sickness Questionnaire. A pre-test/post-test design will be used, so the impact of our solution will be measured. Just as with the other questionnaire, the scores from the physical test will be compared to the scores from the fully virtual environment. The preferred output is that both of the tests have little or no impact on simulator sickness.

Including the Simulator Sickness Questionnaire has two purposes: First of all, it is important to know if the solution causes the users to get sick during their VR experience. If it does, the solution is not useful. Secondly, people experiencing simulator sickness while using the solution will also be dragged out of their presence. By testing for simulator sickness symptoms, it can be determined whether a low score in the presence test was caused by simulator sickness, or by pitfalls in the solution.

5. Experiment: Presence

This experiment is designed to measure how physical objects in a virtual environment affect the presence of the user. The experiment is designed to answer the problem formulation:

> *How can physical objects be used to increase presence in a virtual environment made with self-overlapping architecture?*

5.1 Hypotheses

For this experiment two hypotheses are tested. The first one is:

> *Users interacting with physical objects have a greater sense of presence in a virtual environment.*

Therefore the null-hypothesis that is being tested is:

> *Users interacting with physical objects do not have a greater sense of presence in a virtual environment.*

The second hypothesis is:

> *Users interacting with physical objects are more affected by simulator sickness in a virtual environment.*

Therefore the null-hypothesis that is being tested is:

> *Users interacting with physical objects are not more affected by simulator sickness in a virtual environment.*

5.2 Procedure

Each test participant will perform one of two tests. The tests are set in the same virtual environment, but with key differences in regards to interaction. The two settings are:

1. Virtual interaction: All interactions in this environment are performed with virtual objects using the Vive controllers. No trackers are used in this setup.

2. Physical interaction: All interaction in this environment are performed with physical objects using the hands of the participants. Trackers will be attached to the hands of the user and to the interactable objects.

In order to avoid any bias, the participants will be randomly allocated to a setting. The test itself is designed to take 10 to 15 minutes excluding the surveys, but the facilitators will not terminate the test if the participant needs more time.

The following procedure is used in this test:

1. Answer a pre-test Simulator Sickness Questionnaire.
2. Perform the test.
   (a) The participant picks up the flashlight and proceeds to the starting area.
   (b) The participant starts in the hallway and proceeds to the first room.
   (c) The participant uses the flashlight to reveal the riddle. He solves the riddle, and uses the answer of the riddle to solve the cipher wheel puzzle.
   (d) The door unlocks and the participant proceeds to the second room.
   (e) The participant uses the flashlight to solve the light sphere puzzle.
   (f) The chest unlocks and the participant opens it up to reveal the prize.
3. Answer a post-test Simulator Sickness Questionnaire.
4. Answer a Slater-Usoh-Steed Presence Questionnaire.

The questionnaires can be found in appendix A. To make the participants perform the required interactions they will be presented with a small amount of instructions to some of the puzzles. Ideally, the participant will not have any contact with the facilitators while performing the test. If the participant needs further guidance than the instructions, they may ask, but the facilitators will not speak to the participant unless the participants initiate the conversation. The facilitators have also been told not to touch the participants while doing the test, as that may affect their sense of presence and cannot be replicated equally for all participants. One facilitator will also control the cord during the physical scenario testing, as the cord may get tangled and topple over the objects; this may also cause them to feel slight tugs by the head-mounted display.

5.2.1 Physical and virtual setup

The test was run on a computer with the following specifications:

- Intel Core i7 6700K 4GHz
- nVidia GTX 1080Ti

- 32GB DDR4 RAM
- Windows 10 Pro

The HTC Vive sports two 1080x1200px displays, 110° field of view, 90Hz refresh rate and 32 motion tracking sensors, accompanied by a gyroscope and accelerometer [2].

For the two experiments the virtual environment was identical. It consisted of two rooms with different puzzles and a corridor connecting them, as can be seen on Figure 5.1. This is not the actual architecture, as the two rooms will appear on top of each other in the same space, but it is a representation of how the participants will experience it when in virtual reality. Both rooms had puzzles in them for the participants to interact with. The first room had a riddle split into three parts. Each part of the riddle and one possible answer could be revealed by a specfic colour shined from a multi-colour flashlight. By changing between the colours, the participant would understand the whole riddle and be able to answer it.

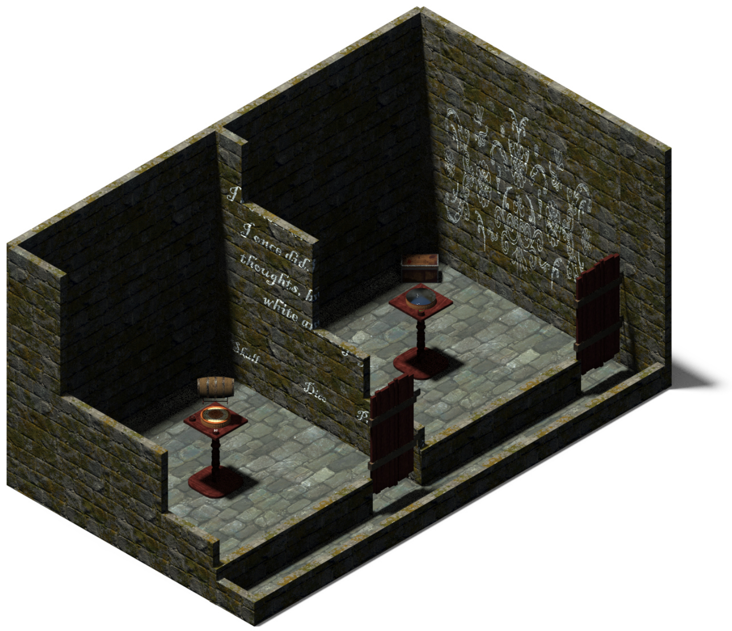

Figure 5.1: How the virtual setup would appear to the participants in-game, but not in reality. For the full specs, refer to the portfolio chapter 2.

In the same room was the cipher wheel. The cipher wheel consisted of two rotating rings; one with runes and one with a single arrow. It used the answer for the riddle, "SKULL", to decipher a set of runes on the wall, the runic symbols for "J", "H", "G", "X", and "C", into the word "BRAIN" as can be seen on Figure 5.2. The order of the symbols matter, which is why both the riddle answer and the rune set is five symbols long.

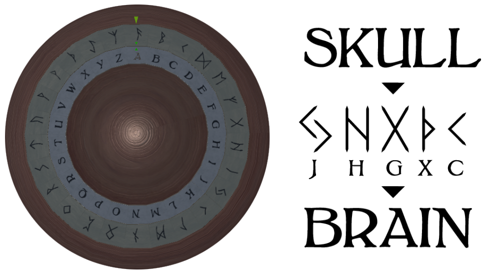

Figure 5.2: The answer to the riddle ("skull"), the set of runes, and the deciphered word ("brain")

For example, to decipher the runic “J”, from the rune set in Figure 5.2, the participant would turn the runic “A”, with the arrow, so it lined up with the Latin “S”, from the word "skull", as seen on Figure 5.3a. This changed what Latin letters all the runes corresponded to. The runic “J” now lined up with the Latin “B”, and the first letter had now been deciphered. To choose the letter, the user pressed the button, which changed the ring the user could interact with, seen on Figure 5.3b. They could then turn the arrow to point at the deciphered rune and press the button to input it seen on seen on Figure 5.3c. This process has to be done to all the runes in the rune set.

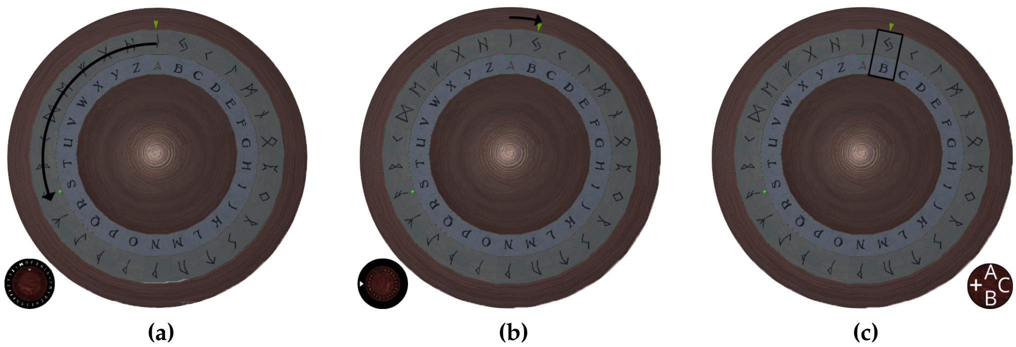

Figure 5.3: Steps of solving the cipher wheel. Steps a, b, and c is repeated until the answer is input.

In the second room was the light sphere puzzle, which used the same base model as the cipher wheel. This puzzle projected different parts of an image onto the wall, depending on the colour being shined on it by the same flashlight used for the riddle. The sphere could be turned, so by using the different colours of the flashlight, the user could assemble the full image, which solved the puzzle.

This virtual space was built within a 4 meters by 4 meters physical area. For the virtual experiment this area was empty, so the participants could walk freely,

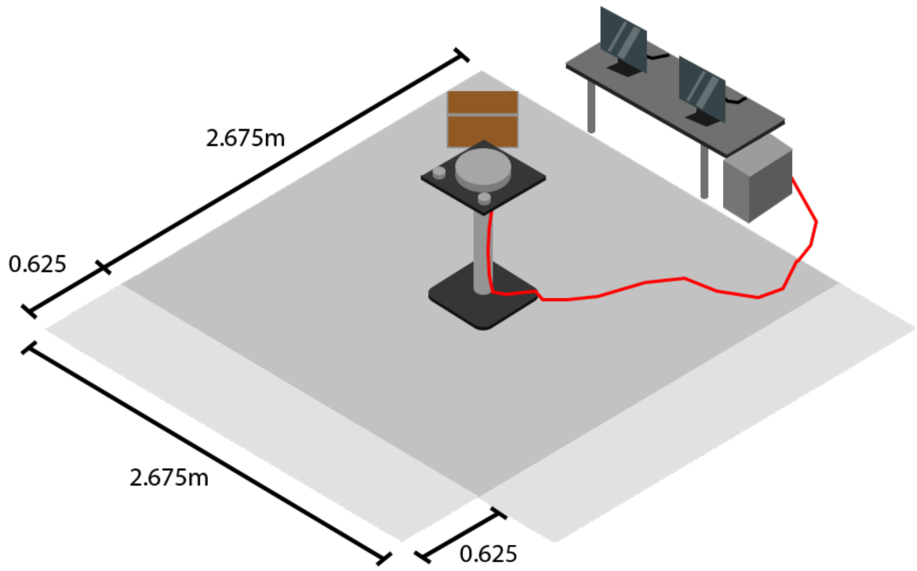

Figure 5.4: The physical setup for the experiment.

but in the physical experiment it was occupied by objects for the participants to interact with, which can be seen on Figure 5.4. In this experiment the pedestal and the chest had trackers attached to them, so the user could interact with two objects. These trackers connected wirelessly to the bluetooth dongles in the PC, so they did not need any wires. The red wire on the floor on the picture attaches the Arduino to the computer, so it can transfer the data, and it was taped to floor so the participants would not trip on it. Next to the play area were two computers which had the pre- and post-exposure questionnaires.

5.3 Pilot test

During pilot testing several design flaws became apparent. A major one was that the mechanics of the cipher wheel were too complicated for the participants to figure out in the 10 to 15 minutes the test was approximated to take. The cipher wheel uses a set of runes and a keyword, in order to decipher the answer. One participant was stuck on this puzzle for 25 minutes, where the facilitators frequently spoke to him which went against how the test was designed. To counter this, the cipher wheel is changed so that it is not used to decipher a set of runes, but simply to spell out the answer for the riddle. This way the experiment is made simpler and faster, while still maintaining the interaction, which is the main part of the test.

Because the light sphere image had to be constructed on a specific area, the users needed some guidance on where to assemble it in order to solve the puzzle. To do this, an outline of the image is added to the wall so the users can match the projections with the outline. This does not affect the interaction, but serves to make the puzzle simpler.

At the end of the experiment, the participants were supposed to open a chest. A sound was added to indicate that the chest unlocked, but the participants had a hard time figuring out what the sound meant. In order to direct them towards the chest a light is implemented to light it up when the last puzzle is solved.

5.4 Final test results

The experiment was conducted with 30 participants, with 15 people testing each scenario. The participants were from the Medialogy study on Aalborg University, and as virtual reality research is a part of this study, most have a basic knowledge about the medium.

The architecture of the rooms was well implemented, as no participants noticed that the door changed position. Some participants commented on how they did not know where in the physical world they were positioned after they went into the corridor a second time. The participants did not seem to find the corridors too narrow either. A few participants encountered a bug where a door would appear on a wall in the first room. This door is the door leading into the second room from the corridor, but it was triggered by the participants walking over a specific area in the first room. When this happened, the facilitators made sure to tell them that it was a bug.

Because of the difficulty of some of the puzzles, the facilitators frequently initiated contact in order for the participant to progress. The participants did well in understanding how to read the riddle, but often missed the three possible answers underneath it. Some people thought that they were a continuation of the riddle, or that all three of them were answers to different parts of the riddle. There was also a user experience problem with the button, as users, both in the virtual and physical scenario, did not realize what it did or even that it was interactable. Instead they just turned the wheel to each letter in sequence.

The light sphere was considerably easier. The participants quickly shined the flashlight on the pedestal, either by accident or on purpose, and connected that with the outline on the wall, though some participants did not immediately realize that the sphere could be rotated similarly to the cipher wheel. They did however realize that there was a button attached to it that could be interacted with.

5.4.1 Simulator Sickness Questionnaire results

To prepare the result for statistical analysis, the first step was calculating the difference of the pre- and post-test scores from the virtual experiment found in Table 5.1, and physical experiments found in Table 5.2 . To get an idea of how the results turned out, the differences in scores were visualised in a boxplot, see Figure 5.5. The boxplot shows that in both cases, the median value and the results are close to 0, except for a few outliers. This may indicate that both conditions had little impact on simulator sickness in the participants, but this has to be confirmed.

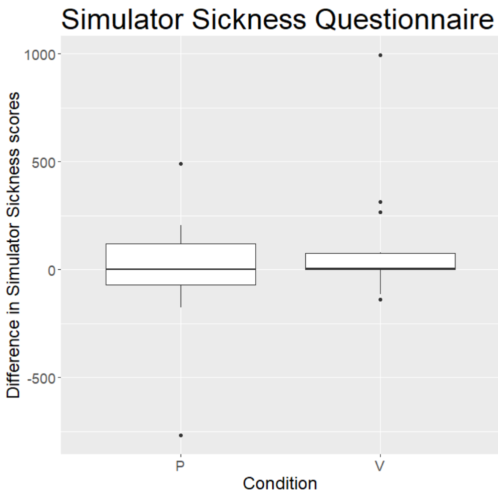

Figure 5.5: The boxplot reveals that the scores are centered around 0, but have some outliers.

Before deciding which statistical test to use, it was determined whether the data was parametric. Since two means were being compared, a t-test can be used if the data was parametric. Since Homogeneity of Variance has very little impact on a t-test, the data was only be tested for normality [14].

Figure 5.6: The histogram reveals that most results are centered around 0, with a small standard deviation.

According to the histogram in Figure 5.6, the data for both the physical and virtual conditions seem to be non-normally distributed. This was confirmed by a Shapiro-Wilks test, which gave a result of $W = 0.855$ and $p < 0.05$ for the physical condition, and $W = 0.644$ and $p < 0.05$ for the virtual condition. This confirms that the two samples are not normally distributed, and therefore they cannot be tested using the t-test. Instead, the non-parametric equivalent, the Wilcoxon Rank-Sum test, will be used.

The Wilcoxon Rank-Sum test reported a $W = 86.5$ and $p > 0.05$, meaning that there is not a significant difference between the two conditions, and it only represented a small effect size ($r = -0.19$).

This means that the participants did not get significantly more sick when using physical controls ($M = -8.58$), than when using virtual controls ($M = 0.01$). Therefore the hypothesis can be rejected and the null-hypothesis is supported.

5.4.2 Slater-Usoh-Steed Presence Questionnaire results

To get an impression of the results, they were plotted in a barchart showing the means with errorbars, see Figure 5.7. The barchart shows that the two means are relatively close together, and that the errorbars have a big overlap. This indicates that there is no significant difference in presence between physical and virtual controls, but this assumption must be tested.

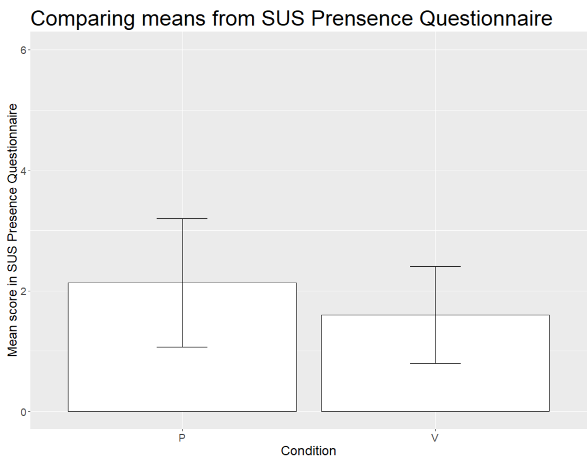

Figure 5.7: The bars reveal that the difference in means is small, and that the standard error is rather large.

Since it is the two mean values that will be compared, a t-test can be used if the data is parametric, while a Wilcoxon Rank-Sum test can be used if the data is non-parametric. A histogram of the scores can be seen in Figure 5.8. The histogram already indicates that none of the conditions have normally distributed data. This was confirmed by doing a Shapiro-Wilks test, in which the physical

Virtual scenario experiment		
Participant	**Total Score pre-exposure**	**Total Score post-exposure**
1	0	0
2	0	80.41
3	135.388	139.8012
4	260.5284	253.198
5	0	35.6796
6	172.788	35.6796
7	56.6984	56.6984
8	28.3492	28.3492
9	201.1372	1196.5756
10	35.6796	35.6796
11	28.3492	99.7084
12	0	28.3492
13	149.0764	35.6796
14	28.3492	293.2908
15	324.5572	637.1464

Table 5.1: The Simulator Sickness Questionnaire results from the pre-exposure survey from the virtual scenario.

Physical scenario experiment		
Participant	**Total Score pre-exposure**	**Total Score post-exposure**
16	537.438	388.586
17	99.7084	116.0896
18	0	489.7904
19	92.378	52.0608
20	251.4776	151.7692
21	445.06	437.7296
22	1241.5304	437.1848
23	236.8168	208.4676
24	0	0
25	0	0
26	132.4708	324.5572
27	92.378	156.4068
28	1406.7636	1610.3692
29	52.0608	227.5416
30	518.1396	340.9384

Table 5.2: The Simulator Sickness Questionnaire results from the post-exposure survey from the physical scenario.

condition scored $W = 0.83$, $p < 0.05$, and the virtual condition scored $W = 0.88$, $p < 0.05$. This means that the data is considered non-parametric, and therefore it was analysed with the Wilcoxon Rank-Sum test.

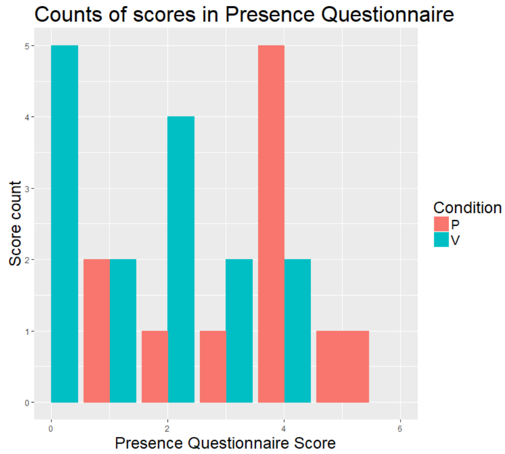

Figure 5.8: Histogram showing the scores in the two groups.

The Wilcoxon Rank-Sum test reported a test statistic of $W = 130.5$, $p = 0.45$. Since the p-value is much higher than 0.05, the assumption that was made based on Figure 5.7 is confirmed, and there is no significant difference between using physical ($M = 2.133$) and virtual ($M = 1.6$) controls, and it also only represented a small effect size ($r = -0.14$). Therefore the hypothesis can be rejected and the null-hypothesis supported.

Virtual scenario		Physical scenario	
Participant	**Score**	**Participant**	**Score**
1	4	16	4
2	1	17	0
3	3	18	5
4	1	19	4
5	0	20	2
6	2	21	0
7	3	22	4
8	0	23	4
9	0	24	0
10	0	25	1
11	4	26	0
12	2	27	0
13	2	28	3
14	2	29	4
15	0	30	1

Table 5.3: The scores from the Slater-Usoh-Steed Presence questionnaire.

6. Conclusion

By researching the characteristics of presence, it was possible to locate where the feeling of presence in virtual reality could be improved. This research also revealed a gap in experiments on the inclusion of physical objects in virtual reality. In theory, adding an extra sense, the sense of touch, to the virtual environment should increase presence, as it increases both interactability and extensiveness. By using object trackers and measuring simulator sickness with the Simulator Sickness Questionnaire and presence with the Slater-Usoh-Steed Presence Questionnaire, it was possible to test how physical objects affect presence in a virtual reality environment.

To test whether physical objects affect presence, the same environment had to be created with two different sets of controls: a fully virtual one and a fully physical one. To design this product, a preliminary experiment was conducted to see whether the users preferred having a visual representation of their hands in virtual reality. The experiment showed that there was no significant difference in precision between seeing and not seeing one's hands, but the majority of the participants preferred to see their hands. This meant that in the physical scenario, two object trackers had to be allocated to the participants' wrists. With this knowledge the interactive puzzles could be designed. The puzzles had to be made virtually, as well as physically, and as the project utilized self-overlapping architecture, and with only two trackers for puzzles, some of the puzzles had to use the same physical object and tracker. With these considerations, a virtual environment was created where the emphasis was on different variations of interaction.

In the final experiment, the participants in both scenarios had to answer a pre- and post-test Simulator Sickness Questionnaire, to see how much they were affected by the product, and a post-test Slater-Usoh-Steed Presence Questionnaire. The results showed that there was no significant difference between how the participants were affected by simulator sickness, which met the second success criterion, found in section 4.1. There was also no significant difference between the virtual and physical scenario in terms of presence, meaning that the first success criterion was not met.

It can be concluded that this experiment did not prove that physical objects significantly increase the feeling of presence in a virtual environment made with self-overlapping architecture. The next chapter talks about the pitfalls of the solution, and what can be done to achieve more significant results.

7. Discussion

The actions of the participants during the test indicated that there were a few design oversights in the artifact. Even though the cipher wheel had a hidden affordance of rotating, the participants quickly figured it out, by seeing the golden arrow pointing at the letters, and seeing that in the virtual scenario the controller lit up near the wheel, indicating that it was interactable. This was not the case for the button labeled "+ABC" however. This button did not activate the shine of the controller indicating interactability, and the users did not realize that it was a button or what its purpose was, indicating that the signifiers were too weak.

This lack of use of design principles also showed in the five light bulbs and the light sphere. The light bulbs were meant as indicators for correct letters the participant input, but because they did not have any reason to look up at that wall after the runes were removed, the majority did not look at them while solving the puzzle. As a correct letter was also accompanied by a sound, this connection was clearer, but could have been increased further by having a sound for incorrect inputs.

The light sphere also had the hidden affordance of rotating and lacking any signifiers, as the cipher wheel and the light sphere were designed to be interchangeable in the architecture. Many participants did not realize that it could be rotated, but they quickly realized that the button was actually a button. The participants pressed the button on the pedestal every time a piece of the image had been put to the correct place. This indicates that they used what they learned about the mechanics from the cipher wheel, where this was the correct course of action, but in the light sphere the button was only meant to be pressed once, after all the pieces have been aligned correctly. This could also explain why this puzzle was easier.

As the result from the statistical analyses of the difference between the pre- and post-exposure Simulator Sickness Questionnaire was non-significantly different, it can be concluded that the physical scenario did not induce more simulator sickness than the virtual scenario. This means that simulator sickness would not decrease presence when adding physical objects to virtual reality, which concludes that the product met the second success criterion found in section 4.1. By looking at the mean it can be seen that on average people were not affected by the virtual scenario ($M = 0.01$), but actually showed fewer symptoms of simulator sickness after the physical test ($M = -8.58$).

The results from the Slater-Usoh-Steed questionnaire were likewise found to be non-significant. By doing a Wilcoxon Rank-Sum test on the data, the p-value was calculated to be 0.45, meaning that there is a 45% chance of getting the same results without controlling the variables. This indicated that adding physical objects for the participants to interact with did not affect presence. Though the test results did not indicate any strong evidence of improved presence in the physical scenario, several indications of improvement were found by observing the participants. When the calibration of the room was ideal, and the trackers, controllers, and head-mounted display had a good connection to the lighthouses, several participants started using the physical objects for other things than planned. A few participants needed somewhere to place the flashlight, when they wanted to turn the cipher wheel or light sphere, and some of them put it on the floor. When they wanted to pick it up, they felt safe enough to support themselves on the pedestal. However, these observations are not scientific and were not confirmed by the participants. It was concluded that the first success criterion was not met.

All in all, the product of this project was found satisfactory, as it answered the problem statement, though a puzzle-based scenario may not be the best approach to perform this kind of experiment; it adds the obstacle of being difficult for the user to do without assistance, without adding any benefits, that would not have been there, by just doing a series of simpler tasks.

7.1 Reliability and validity

Unfortunately, the group did not have a thorough plan or a predetermined system planned out to provide the hints to the testers. This means that different hints were given at different times to the players. Sometimes this was based on the facilitators discretion, other times the testers asked for hints, as they were told they were free to do so at any point they felt the need for one. The difference in hints includes some of them being more specific ("Try to look behind the barrel.") while others given at the same point of the test were more vague ("Try looking around the room, there may be further hints on the walls."). A better approach would have been to write the hints the facilitators would give to the testers, and set the points in time at which the hints would have been given. This would have ensured that the users received the same prompts at the same points in time unless they requested assistance before the set times. The difference between the hints mean that the experience was not the same across all participants and this part of the testing was inconsistent.

Because of the limited time and equipment, multiple people had to share rooms while conducting their experiments. As this project aimed to measure presence of the participants, the noise from the other group could have interfered with the results.

Both of these issues have decreased the reliability due to the fact that it would be difficult to recreate the project with the same testing results.

The Slater-Usoh-Steed presence questionnaire is valid for testing virtual reality experiences and comparing presence within the same system, but it cannot be used to compare different VR systems, as explained in 3.1. Therefore the internal validity is high, but since the test cannot to applied across systems, the test lacks external validity.

7.2 Future works

The project could benefit from some changes in case the development continues.

A minor, yet impactful change would be the inclusion of some kind of tutorial that would guide the testers through a small scenario that makes use of all the controls and mechanics that appear in the project in order to familiarize themselves with the mechanics of the system. Using short, easy examples of the puzzles in the tutorial would mean that the participants would have the knowledge on how to solve the puzzles.

All of the participants needed further hints from the facilitators. This potentially breaks presence, as the users are interacting with people not present in the virtual environment. Ideally, the testers should be able to solve the puzzles without any outside help, but because no lo-fi prototypes were thoroughly implemented, the puzzles were not streamlined and intuitive to the participants. The aforementioned tutorial could help with this, but in the case a tutorial is not included, some better in-game hints could be of assistance. This could be implemented as pop-up UI elements explaining the mechanics of the puzzles, or a button that would provide hints to the user at their request. This system would provide a vague hint to begin with, and the subsequent ones could get more specific to aid the participant more.

Another improvement could be including other, decorative objects in the rooms. They would serve no purpose other than making the environment look more pleasant and realistic. This would make little difference in the virtual test, but would be a problem in the physical test with the trackers, as there are a lot of objects that one can seemingly interact with, but have no physical counterpart. This could be circumvented by doing user experience research The goal of this would be to find out how non-interactable objects could be included in the project, while still successfully communicating to the participants, which objects can be physically interacted with.

The physical setup of the HTC Vive did introduce some problems to the test. The cable for the head-mounted display was too short to comfortably move around the entire play area. Ideally, getting rid of the cable (i.e. have a wireless head-mounted display) would completely remove this factor, but the experience could also be improved by some modifications to the setup. For example, the whole scene could be rotated so the corridors were closer to the computer. This means that the cable would reach the areas that the participants were forced to move in, and only be a problem if the participant decided to explore the far corners of the scene.

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A. Appendix A

The appendices are collected in the zip-file accompanying this report. In the zip-archive you will find the following documents:

- Experiment: Presence
  - Script used in presence experiment
  - Pre-test questionnaire
  - Post-test questionnaire
- Statistics
  - Plots
  - Calculations
  - Raw data
- Implementation
  - Full source code of the system
  - 3D models
  - Textures
- AV Production
- This report
- The Portfolio accompanying this report