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Development and Evaluation of a Virtual Reality Shopping Experience in a Virtual Apartment

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Abstract

With virtual reality, we try to create a new shopping experience which combines the advantages of E-commerce sites and conventional stores. Our VR Shop uses a virtual apartment where products are placed according to the customer's expectations of their location. The user can traverse the virtual environment with physical movement and a teleport locomotion technique to search for the products.
But how can the user interact with, manipulate or purchase the products? To solve this question we created a scenario in which the user has to utilize two different interaction methods and shopping carts for purchasing. The first technique is based on the *Virtual Hand* concept and the other on the *Interacting by Pointing* concept. Those interactions allow the user to move the product around freely, examine it and view its information. In order to purchase the product, the customer places the desired product in the currently active shopping cart. One cart is based on a basket from a conventional store and the other one is visualized by a sphere where the purchased products float around it in a circular fashion.
A study was conducted to determine which combination of the two interaction methods and shopping carts best suits our application. The study also indicated that our prototype achieved a high score for *Immersion* and *User Experience*. Overall, our VR Shop provides an excellent customer satisfaction and showcases the possibilities of using VR as a medium for shopping.

Contents

1 Introduction

1.1 Motivation

Online shopping negates many disadvantages of conventional stores like limited operation time and is more focused on functionality. However, this focus comes at a cost leading to limited search functionality and product visualization (Lee and Chung [25]). In online stores, the products are only represented by text and images whereas in a physical store, the customer can interact with the products and view the product from every side. Also searching for a product is only possible through text input or filtering by categories while physical stores encourage exploration by the customer.

With virtual reality (VR), we can create an online shop that has the advantages of a physical store. Therefore in our VR Shop, customers can examine the products freely and the they are more engaged in the search for products.

Most of the existing VR applications try to simulate a conventional store accurately, but they did not try to address the limitations of those shops. For example, there is no need for a VR shopping application to display the same product multiple times like in a physical store. Therefore, we can reinvent the regular VR stores and test the feasibility of a new concept.

We propose to use an apartment as a shopping environment, where the products are located in the position an average buyer would expect them to be. Instead of categorizing the products, we hope that the customer finds the desired article based on its location. Consequently, we assume that the customer finds the products inside the apartment based on previous knowledge and thus we suppose that our location-based product search is more familiar to the user than online store categorizations. By representing those products with 3D models, the customers can manipulate and observe them. The purchase of the goods is accomplished by placing them inside a virtual representation of a shopping basket. We came up with two different shopping cart representations for our prototype. The first one is based on a shopping basket known from physical stores and the other one is a new non-realistic concept which is

more optimized on usability. There are also two different approaches for the object interaction. The first one is based on the concept of the *Virtual Hand* technique and the second method is based on *Interacting by Pointing*. Those methods will be later described in this thesis.
The main tasks of this thesis are to test the feasibility of this categorization and if our concept provides a high customer satisfaction.

1.2 Research Questions

Since we propose two different concepts for the shopping cart and product interaction, the following two questions emerged:

- Which combination of the shopping cart and product interaction provides the highest customer satisfaction?
- How is the performance affected by the product interaction techniques and the product placement?

We test the usability and answer these questions in a study (chapter 5). In this study, the task was to search for a product in the virtual environment using different shopping cart types and interaction modes. For each search trial, the completion time and the error rate was measured. Each participant had to complete multiple questionnaires for each combination of shopping cart modes and product interaction methods to measure the rating for *Immersion*, *Motion Sickness*, *Workload* and *User Experience*. Based on those scores we conclude which combination is the most suitable for our application.

1.3 Significance of the study

Like before mentioned most of the existing VR stores try to simulate a conventional store accurately. Therefore, we compare two different concepts. The first one is a realistic representation of a shopping basket and the interaction method based on the *Virtual Hand* technique. This combination represents the purchase method of a conventional store. The second concept of the virtual cart and the non-realistic interaction method is designed to use the capability of VR. With the help of the study, we determined whether there are drawbacks to the non-realistic approach like less *Immersion* or *Presence*.

Our assumptions lead to additional questions our study needs to address: Does the realistic concept provide a better user experience due to its familiarity or can the user adapt to the non-realistic methods? Which of the combinations has the best performance or requires the least amount of effort? How good is the product placement in the virtual apartment? Nonetheless, the results of the study indicated that our application had an overall high *User Experience* which was best for the combination of both non-realistic concepts. Henceforth, we can assume that the user successfully adapted to the methods. For performance, the different combinations achieved the same level of efficiency whereas the non-realistic interaction method had the least amount of effort. Furthermore, we discovered problems with the realistic basket due to the physical interaction.
According to the observations, we can assume that our approach of utilizing an apartment for product categorization was received well but was not viable for all kind of products. Generally speaking, the study showed that our concepts offered a great *User Experience* and that our virtual environment is very immersing for the user.

1.4 Outline

Starting with the *Related Work* part, we give a brief overview in this chapter on the fundamentals of designing a VR Shop and we discuss the concepts our application is based on. Subsequently, in the chapter *Concept* we explain the functionality of the different interaction methods and the two kinds of the shopping cart. Additionally, in this chapter we describe the characteristics of the products, the movement techniques and how the virtual environment is designed. In the chapter *Implementation*, we will further look into the functionality of our application in detail.
In the next chapter, we discuss the *User Study* conducted in this work. The content of this chapter features the requirements for the research and the design and procedure of the undertaken user study. Furthermore, in the section *Results*, we present the resulting values from the questionnaires and the recorded data of our application. Correspondingly, we analyze those results in the *Discussion* section. In the chapter *Conclusion*, we interpret the study results and answer our previously mentioned research questions. Furthermore, in the chapter *Future Work*, we give an outlook on how to improve the existing features of our VR Shop and which functionalities could be added in the future.

2 Related Work

In this chapter, we evaluate existing shopping interfaces in a simulated environment, their advantages and disadvantages and the requirements for implementing our prototype.

2.1 Shopping with Virtual Reality

Steuer [31] defines virtual reality(VR) as a real or simulated environment in which a perceiver experiences telepresence. Telepresence is described as the illusion of being inside a real environment making VR an advanced form of *visualization*.
In addition, it offers the advantage of increasing the naturalness of the user interface. Therefore, Walsh et al. [32] concluded that VR could address limitations of web-based shopping applications, expanding the range of e-commerce possibilities. This conclusion advocates the feasibility of creating a VR shopping application.
Essential characteristics of VR are *immersion*, *interactivity* and *presence*.
Witwer [34] states *immersion* is the extent to which the subject's senses are isolated from the real world and are stimulated by the virtual world.
Steuer [31] defines *interactivity* as the extent of the user's participation in modifying the form and content of a virtual environment in real time.
At last, *presence* is defined by Witwer [34] as the subjective experience of being in one place or an environment, even when one is physically situated in another.
Bhatt [17] examines the feasibility of bringing VR to e-commerce sites. He concludes that the balance between the three characteristics is necessary and dependent on the circumstances. For example in the fashion industry *immersion* is more crucial whereas in the financial sector *presence* is far more important.
As a conclusion, those characteristics are the fundamentals of each VR application and with a correct implementation, it may circumvent the limitations of today's shopping practices.

2.2 Designing a VR E-commerce Solution

2.2.1 Customer Satisfaction in a VR Shop

To legitimate the need of a VR shopping mall, the customer satisfaction must be positively affected in comparison to a physical shopping center. Therefore Lee et al. [25] compared the user interface of a VR shopping mall to an e-commerce site. For this purpose, they created a web-based prototype (Figure 2.1) with 3D functionality and conducted a study.

Figure 2.1: Snapshot of Lee et al.'s VR shopping mall [25]

The goal of this study is to investigate, whether the user interface of the VR shopping mall, positively affects customer satisfaction in comparison to online shopping sites.
The authors tested whether the *customer satisfaction* is significantly influenced by the three explanatory variables. These variables are defined as *convenience*, *enjoyment* and *quality assurance*, which are the main characteristics of the ordinary shopping center.
Lee et al. state that *convenience* is affected by the store layout, organization features and ease of use. *Convenience* is assured by store navigation features like search functions, sitemaps or product indices which are essential for large stores.
Enjoyment plays a crucial role in the online shop according to the authors, because people in a playful state find the interaction self-interesting, thus making them purchase something for pleasure and enjoyment.
At last *quality assurance* is correlated to several properties of the online shop like convenient access, reliability and flexibility.
The results of their study show that the *customer satisfaction* drastically improves in

comparison to an ordinary e-commerce site. Lee et al. explain those results with the fact that clients of an e-commerce site have to use rather plain user interfaces, which leads to a lower customer satisfaction. The customers remain as passive observers whereas in a VR shopping mall customers are engaged in the inspection and control of the 3D visualized target products. According to the study both *enjoyment* and *convenience* improve significantly and therefore the authors assumed that repeated visits to the VR shopping mall will increase.
Another conclusion of the authors is that customers in a VR shopping application can experience the value of the product information more richly and engage in a more active shopping activity. Therefore we strive for a realistic product representation to achieve this effect.
This study showcased the advantages of a VR E-commerce application and the reasons for the improvement of *customer satisfaction*, *enjoyment* and *convenience*.
Buffa et al. [20] describe further advantages of 3D virtual stores in comparison to physical stores. According to Buffa et al., customers benefit from less time-consuming shopping, which features a daily opened store and a better view of the product with more information.
To conclude core aspects of VR shopping are the user's control of the environment and the free inspection of 3D visualized target products.

2.2.2 Shopping Application with a VR Headset

To get a better understanding how a shopping application with a VR headset is feasible, we consider the *mixed-reality* shopping system of Ohta et al. [27], which assists disadvantaged shoppers. The authors describe those disadvantaged shoppers as not only senior citizens but also people who do not have enough free time to go shopping. Their prototype uses a *head-mounted display* to view a panoramic photo of a real store, as well as a smartwatch to interact with the products and to navigate through the warehouse. Additionally, there is the possibility to view the product in an *augmented reality mode*, which lets the user compare the desired product with those in their possession.
E-commerce sites are currently one of the most preferred methods to reduce the *inconvenience* of shopping according to the authors. The customers can search for their desired product through inputting the name or features of the article. But if the goods are named or described with an ambiguous term the user fails to find them, so they are forced to browse through a large number of products. Photo

images of a product are also insufficient for checking details and comprehending its size.
Whereas in brick-and-mortar stores, products of the same category are located in one area. Those products can be confirmed by touch. Despite the fact that those stores lack search-functions, they are more carefully screened than E-commerce sites and customers can estimate where their desired item is located.
The goal of their project is to simulate the shopping experience of those offline stores. By buying an item in this project, the customer reserves this product in the real warehouse, which was represented by the panoramic photo.
Their evaluation carried out by 11 students revealed that all probands want to use this system and so there is a high demand for it. 91% of the probands found this system useful and all favored the system to understand the size of an item. They concluded that users preferred this system over conventional e-commerce sites, whereby the authors identified usability problems, caused by hardware performance and implementation methods.
Our project uses different modes for traversing through the store and viewing an item. So techniques, like navigating through the simulated space and viewing or interacting with the products, need to be designed carefully. Because of the availability of more recent hardware, the *Oculus Rift DK1* is replaced by an *HTC Vive*, which resolves most of the hardware problems. Reasons are the better resolution and the better latency of the displays inside the headset. The mentioned usability issues can be addressed by a better implementation. According to Ohta et al. [27], shoppers with disadvantages are a big part of the audience in this kind of projects. So our project needs to consider them as target audience and design it for them. Therefore as stated by this research, one of the main advantages of simulating conventional stores is the ability to find the desired product better. This benefit of better finding the desired product should be further amplified, when the environment is more familiar to the user in a conventional store.

2.2.3 Apartment as virtual e-commerce environment

The most familiar environment to the customer should be their home. So our concept proposes an apartment as an environment for the shopping application. Magic Home [33] introduces a concept prototype featuring a VR furniture store, which uses a mixed reality system. They showcase with this concept how the shopping experience could be like in the future.
Inside their approach customers walk inside a local physical store and try out the

furniture they want to buy. With this method, the search process for a product uses the *immediateness* of the physical world. When decided the customers can get a preview of the product inside a virtual representation of their home, which is connected to the store. Although the buyer's context is mostly physical, the increasing availability of electronic representations of physical products makes the *buyer's context* more accessible in the virtual world. So the customers can decide how well the furniture fits inside their home using the advantages of the virtual world, which are *portability* and *manipulability*. The author explains that they can bridge the context gaps in shopping with this concept and create a new shopping experience.

Our concept lacks the *immediateness* of the physical world, but customers can still interact with the virtual representations of the products and experience them. This prototype shows that simulating the home of the customer improves the buyer's context and thus increases the *customer satisfaction*. This circumstance strengthens our proposal of using an apartment as shopping environment. It is out of the scope of this work to create a unique apartment for each customer. Therefore, we need to build a standardized apartment, which looks familiar to the users. Caused by those circumstances our prototype lacking the functionality for users to see how furniture fits into their apartment. But due to a different focus for our prototype, we instead support a variety of products.

Although the apartment is not matching with the customer's apartment, they can immerse in the unique virtual apartment. In this virtual apartment, the customers can imagine the locations of the products and get a size reference of the product to the furniture. So we use the customer's expectations on the placement of products in an apartment as our *buyers' context*.

2.2.4 Product Placement

The customer's expected placement of items varies between different people because not everyone has the same location in mind for each unique item. To get a better understanding how customers expect items to be in a virtual apartment, we use the study conducted by Rutsch [28]. In her study probands tell in which room and on which exact location they expect a product to be inside an apartment. Placing the same item multiple times in every eligible location would result in redundancy, so we take the location where most probands of the study suggest the item should be (table 2.1).

Product Name	Kitchen	Bedroom	Bathroom	Living Room	Hallway	Office
towel	10%	32%	50%	0%	0%	0%
board game	0%	12%	0%	60%	16%	0%
deodorant	2%	12%	80%	0%	0%	0%
college block	0%	37%	0%	24%	3%	36%
magazine	19%	15%	8%	46%	4%	8%

Table 2.1: Part of the product placement expectation results (Rutsch [28])

2.2.5 Stock on Shelf Shop Interface

List-based store interfaces, which are used in e-commerce sites, might not be the optimal interface for VR applications because users can freely look around in the environment with head movement.
Ogier et al. [26] propose that *diegetic* (stock on shelf) user interfaces offer advantages, like increased player immersion in comparison to *non-diegetic* (list based) store interfaces. To evaluate their hypothesis, they need a single game with both shopping interfaces. For this purpose, they created a modification of the game "Fallout New Vegas" to convert a *non-diegetic* store to *diegetic* one. The in-game spatial volume of the purchasable stock needs to fit in the in-game spatial representation of the store's display shelves and counters. They can not increase the size of the warehouse because the narrative of the game would be affected. This constraint leads to additional requirements complicating the process. In our project, the virtual store size is also limited, because a bigger store also increases the distance to traverse to reach a product and the complexity of the environment.
While designing their model the authors compared two methods. The first one is to give each item or pack its in-game representation as a 3D model. The second method is to display each unique object only once and not display packs of goods as separate entities. The first method which is similar to the approach of conventional stores requires 26% more virtual space. In conclusion, our project should use the second method to reduce the needed area of the shopping environment and the density of products.
An important statement of the authors concludes that non-diegetic shop interfaces are not appropriate for VR applications. Even simple *non-diegetic* UI-Elements are disruptive and cause motion sickness. This circumstance supports our planned approach of using a *stock on shelf* shop interface for a VR shopping system.

2.3 User Interaction in a VR E-commerce Solution

2.3.1 Movement Techniques

To utilize our *stock on shelf* shop interface, we need to establish functionality for navigating through the virtual environment. Positional head tracking of the *HTC Vive* allows movement through the virtual environment by physically walking.
But the reachable area is limited by the physical tracking space. The traversing of a larger environment, like a virtual apartment requires a *locomotion* technique. Bozgeyikli et al. [19] analyze different *locomotion* techniques in comparison to the “Point and Teleport” mechanic.
With the “Point and Teleport Technique”, the user just points where they want to be in the virtual environment and they get teleported to that position (Figure 2.2). One of the compared locomotion techniques is the famous “walk-in-place” technique, where the user marches without actually moving forward. This gesture triggers the locomotion in the virtual world. But this method is described as inaccurate by the researcher Gillies [22], because it might fail to recognize actions that are intended to be walking, but registers similar head movements as walking.
Another locomotion technique investigated by Bozgeyikli et al. [19] is movement with a joystick. With this method, the *VR Viewport* moves merely in the direction the joystick is moved. In the user preference ranking “Point and Teleport” scored the highest against the other techniques.
After the first round of the study, they conducted a second experiment, where they tested the variation of the “point and teleport” to the original one. This modification adds the control to change the post teleport orientation, but it caused a degraded user experience.
So the results of this study indicate that the “Point and Teleport” *locomotion* technique in its purest form is the most convenient solution for our prototype. Combined with walking through positional head tracking the user can navigate through the whole apartment. The authors suggest to implement this technique with the use of a *fade in* and *fade out* effect for teleport if the virtual environment is crowded. Because we use a virtual apartment with many goods, this effect is required. In their implementation to trigger teleports, the user needs to point at the same location for two seconds and the activation of the teleport system is linked to raising the hand. They resulted in this implementation because they did not use any handheld controller. With the availability of trigger buttons on the *HTC Vive motion controllers*, we can activate the teleport system and trigger the teleportation through

button presses.

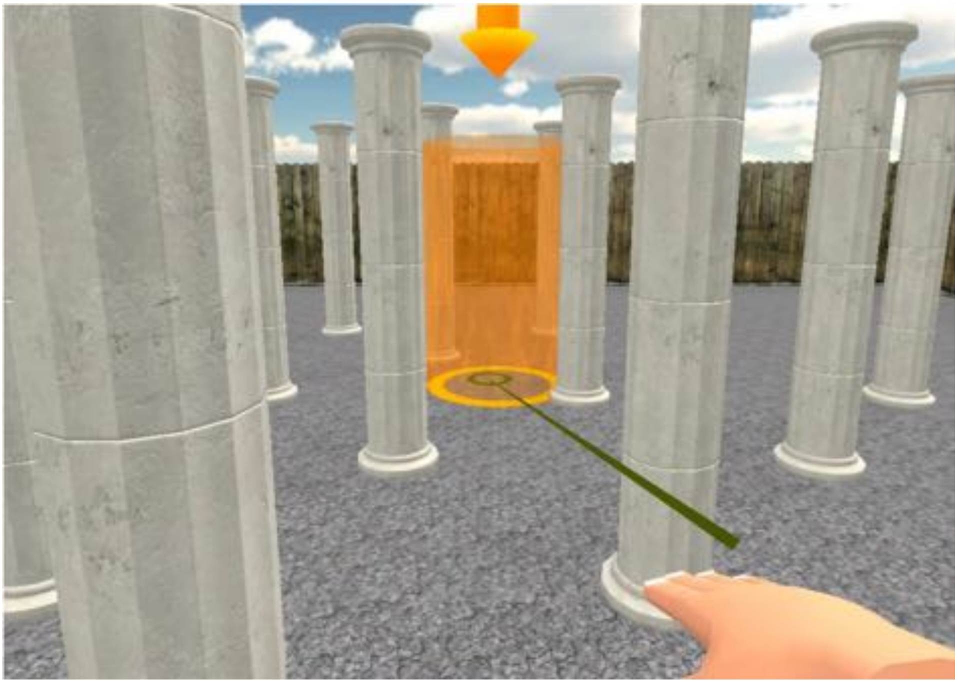


Figure 2.2: Bozgeyikli et al.'s implementation of the Point and Teleport method [19].

2.3.2 Object Manipulation

Although movement through the environment is established, *object manipulation* is still required to view the products up close and to insert them in the virtual shopping basket. Creating a VR shopping experience involves user interaction with the virtual products. The user should be able to manipulate the position and rotation of the selected object to examine and relocate it. This way we can allow our users to buy items by placing them inside a virtual representation of a shopping basket.
This virtual basket should always be available to the user, so we intend to parent it to one of the motion controllers. Because one motion controller is used for the *object manipulation* only, the other one is suitable for the basket because otherwise, it is not possible to place objects inside it.
So we need to consider techniques for manipulating 3D objects with one controller. Bowman et al. [18] describe two fundamental classes of methods for interacting and manipulating objects in a VR environment:

Direct Manipulation: Virtual Hand

With the direct manipulation technique, the user can directly manipulate virtual objects with his hand. The current location and position of the user input are visualized with a 3D cursor, which can be represented for example by a 3D model of a human hand. To select a product, the user intersects the 3D cursor with the targeted product and then uses a trigger command to pick it up. After picking it up the product attaches to the virtual hand and allows the user to translate and rotate it in the virtual environment easily. The object can be released with another trigger input.
Bowman et al. declare virtual hand techniques as an *isomorphic* interaction technique. Those methods are intuitive because they directly simulate interaction with everyday objects. The drawback of this approach is that only objects within the user's reach can be selected and manipulated. To pick objects out of reach, the user needs to use a locomotion technique to move to the object, which is inconvenient in many cases and increases the complexity of the process.

Interacting by Pointing

In contrast to direct manipulation, the pointing technique has the ability to select and manipulate objects, which are located far beyond the reachable area.
Multiple experimental evaluations led Bowman et al. to the conclusion, that pointing achieves a better selection performance than virtual hand-based techniques, due to requiring significantly less hand movement from the user. Consequently making pointing a powerful selection method. Nonetheless, Bowman et al. further claim that pointing is a bad positioning technique. Stated reasons are the low efficiency of manipulating objects through radial movement around the user or rotating objects around the axis of the pointing vector.
Another drawback is that it is not suitable for a controlled manipulation of the distance between the object and the user. Our attempt to solve this problem is to automatically pull the target product to the user and changing the interaction type to virtual hand. This approach makes pointing a suitable position technique for our scenario.
We can conclude that direct manipulation is more intuitive and more immersive but requires additional input. Compared to the interaction by pointing, the user needs to teleport or walk additionally, as described above.
Those facts would make pointing a better selection technique, but virtual hands

require the user to get closer to the location of the objects, which may be beneficially for our scenario because additional buyable items are looked upon by the user. Grabbing items may also be more intuitive and immersive for users.

2.4 Related Projects

Now that we have an understanding how to design and implement a VR store, we consider already commercial available VR stores with a head-mounted headset.

2.4.1 E-Bay VR Shop

Ebay created a VR department store [2] in collaboration with the shopping chain Myer. Ebay claims it to be the first VR department store and it only got featured in Australia as a test market. Customers can experience this store with an Android/iOS app and a custom VR cardboard. The products are grouped in categories in a connected graph (figure 2.3) instead of having a virtual environment like a shopping center. The user can select a product with a ray-casting pointing technique, which uses the head orientation.

Figure 2.3: Product search graph [1]

[1] https://www.youtube.com/watch?time_continue=81&v=yAuiXhJPnr8

When a product is selected, it goes to a detailed product page. On this detail page shown in figure 2.4, there is a rotating 3D object of the product and general information, which contains a delivery date and the price.

Figure 2.4: Product information display [1]

In conclusion, the basic functionalities of an online shop are implemented and the required hardware is easy to obtain. But because of the limited interaction possibilities, the *interactivity* of the application is limited, which reduces the customer satisfaction. Another disadvantage is that the product organization is dependant on the categorization complexity and data quality. Due to the lack of a virtual environment, *immersion* and *presence* are negatively affected.

2.4.2 Shelfzone VR

Another available VR shopping application is “ShelfZone VR” [10], which is a retail space simulator, which reproduces shops, supermarkets or malls. This application uses the HTC Vive and the Vive motion controllers. Customers can freely move through the store and manipulate the products with the controllers. While interacting with a product, various information is displayed concerning the selection (figure 2.5).

Figure 2.5: Product information [2]

The virtual environment is an exact representation of a physical store, where many products of the same kind are displayed. The payment process is accomplished with a standard 2D interface(figure 2.6), where the controllers are used as a pointer. The display of information during the interaction with the products needs to be considered in our prototype. The usage of a *non-diagetic* 2D interface for purchasing is disruptive and causes motion sickness.

Figure 2.6: Checkout UI [2]

[2] `https://www.youtube.com/watch?v=-2UT2KcnJiE`

The availability of multiple items of the same kind makes the store more complicated and increase the needed virtual space. The core aspects are close to our concept, but they do not use a home as the virtual environment. The usage of a home as environment should increase the customer's context compared to a unique store.

2.5 Conclusion

To create a VR shopping application with an excellent customer satisfaction, we need to consider the characteristics of VR carefully.

The *immersion* and *presence* are provided with the realistic virtual environment of an apartment. The products need to fit in the apartment and match the customer's expectation to create a buyer's context and further empathize *immersion* and *presence*.

Customers should be tempted to interact and to examine the products. So object manipulation should be intuitive and fun to use, which establishes *interactivity*. Interactable and purchasable products should be highlighted to stand out from the scenery. This further hint the customer to interact with the products and avoids confusion.

So in the scope of this work, we try out a different concept for VR shopping and validate its feasibility.

3 Concept

In this chapter, we describe the concepts of the elements of our project. One of the main parts of this thesis are the approaches for the two different shopping cart visualizations and the two distinct product interaction techniques. The multiple combinations of those visualizations and methods need to cohere with each other, which has taken high priority while designing the concepts. Nevertheless there are multiple other components of the project including the products and the virtual environment, which we discuss in this chapter.

3.1 Product Interaction

3.1.1 Grab Interaction Method

The *Grab Interaction Method* (Figure 3.1) uses the concept of the virtual hand technique (Direct Manipulation: Virtual Hand). This concept utilizes a motion controller with a button which triggers the interaction. The motion controller is visualized and the trigger button is marked by a tooltip. When the motion controller intersects with a product it gets selected. This selection is visualized by tainting the product with the color cyan. Additionally, the product information (section 3.3) is displayed at the right side of the selected product. The user can grab the selected product with the trigger button which hides the 3D representation of the motion controllers. While grasping the product, its rotation and position follow the hand motion. The product can be dispatched by releasing the trigger button and the controller becomes visible again.
This interaction method should be familiar to the user because it represents the everyday interaction with objects. A disadvantages of this concept is that objects out of reach need additional movement by the user.

Figure 3.1: Grab Interaction Method when the controller intersects a product.

3.1.2 Beam Interaction Method

The *Beam Interaction Method* (Figure 3.2) uses the concept of interaction by pointing (section 2.3.2). Like the Grab interaction, this concept uses a motion controller where a button press initiates the interaction. The motion controller is also visualized and the trigger button is highlighted by the corresponding tooltip. When the interaction gets activated a blue ray is displayed above the controller matching its orientation. A product gets selected by intersecting it with the ray. When the product gets selected it gets pulled towards the motion controller after a short dwell time. This dwell time is visualized with a 3D circle progress bar around the ray. After the product gets pulled towards the controller it follows the orientation and position of the motion controller with a small offset. This offset is needed because the motion controller does not get invisible while holding a product in contrast to the grab method. While holding, the product information is displayed at the right side of the product. Releasing the trigger button drops the product.
The advantage of this method is that the user can interact with products out of reach without the requirement of extra movement. However, we assume that this method is less familiar to the user compared to the Grab interaction method. Furthermore, the pointing to the desired product becomes more difficult when multiple products are close to each other.

Figure 3.2: Beam Interaction Method when selecting a product.

3.2 Shopping Carts

3.2.1 Realistic Shopping Basket

The concept of the *Realistic Shopping Basket* (Figure 3.3) is based on the real-world shopping basket. This basket is attached to the secondary motion controller. With the press of a button marked by a corresponding tooltip, the shopping basket can be toggled on and off. With the simulation of physics, the basket jiggles like its real-world counterpart. Products can be purchased by placing them inside the basket. The total price of those products is displayed on the handle of the basket. Larger products shrink in size which allows the basket to store more different products. But the amount of products which can be stored inside the basket is still limited to its physical bounds like a real shopping basket. All products can be removed from the basket by tipping it over. Furthermore, interaction with the products is still possible which allows the user to view product information or to remove a single product from the basket. To prevent the basket from getting stuck, it does not collide with the environment.

The advantage of this concept is that it should be familiar to the user because of its resemblance to an everyday shopping basket. Therefore, we assume that the functionalities of the Realistic Shopping Basket are intuitive for the user. However, the physical properties of this basket may cause issues for the user such as accidentally losing a product due to the swinging of the basket.

Figure 3.3: Realistic Shopping Basket

3.2.2 Virtual Shopping Cart

The *Virtual Shopping Cart* (Figure 3.4) is visualized by a sphere containing a shopping cart icon. This sphere is located above the motion controller. Like within the *Realistic Shopping Basket* the cart can be toggled on and off by pressing a button on the controller. When a product intersects with the visible sphere, letting it go adds it to the sphere. The product gets tainted blue when intersecting for additional feedback to the user. When products are placed inside the cart, they loose their physical properties such as gravity and follow the cart. These products are organized in a circular fashion around the sphere. The radius of the circle increases when more products are inside the cart. Larger products are shrunk down in size when placed inside the cart.
Below the shopping cart icon inside the sphere, a 3D text displays the current price of contained products. Those products are still interactable while hovering above

the cart, allowing the customer to remove a single product or to view its information. An additional button of the motion controller empties the whole cart after a short dwell time to prevent accidental activation. This dwell time is displayed by a red circle progress bar around the sphere.
The advantage of this concept is the unlimited amount of products which can be stored inside. Furthermore, the products are better organized than within the Realistic Shopping Basket. Therefore, the user gets a clear overview of all his purchased products and can better remove a targeted item. However this unnatural Shopping Cart may be less intuitive for the user because it lacks the familiarity of the Realistic Shopping Basket.

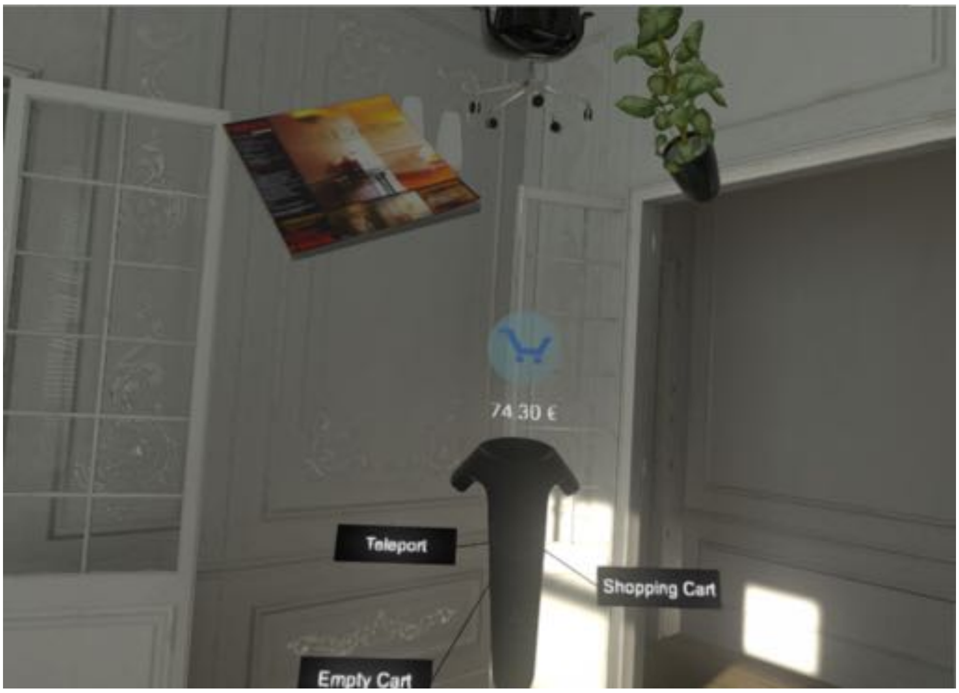


Figure 3.4: Virtual Shopping Cart

3.3 Products

Each retail product of our application is visualized by a 3D model representing its real-world counterpart. For separating the products visually from the environment, they are highlighted with a blue outline(Figure 3.5). Those products are located inside the apartment based on the previously mentioned product placement results (subsection 2.2.4). Every product has information which contains its name, a short description and its price. Every item uses physics with enabled gravity to improve the immersion. Displaced products return to their original location after a short delay. Exceptions to this behavior are when a product is inside a shopping cart or when the user currently interacts with the item. When a product falls to the ground, the delay gets shortened.

Figure 3.5: Highlight of the products

3.4 Additional Product Interactions

3.4.1 Item Information Viewer

With this concept, the user can view product information from afar. Through the press of a button on the motion controller, a yellow ray (Figure 3.6) is emitted pointing to its direction. To view the product information the beam has to intersect with the desired product. Once the ray touches the item, its information is displayed at the right side of the beam.

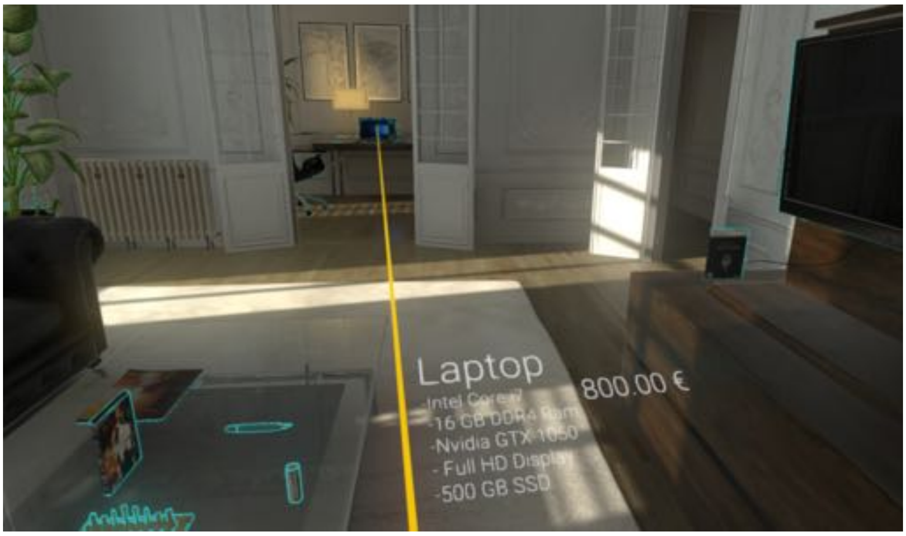


Figure 3.6: Showcase of how the product information can be viewed from the distance

3.4.2 Product Selection Mode

There is a limit on how many products we can add to the scene (subsection 2.2.5) without breaking the immersion of being inside an apartment. Therefore we should prevent that a product is placed uncommonly often inside the apartment. But there might be different variations of a product. For this reason, we created the concept for providing a variety of products without visualizing each variation inside the scene. When the user interacts with a product, the selection of variations become available by pressing the marked button on the controller. Once the mode is enabled, two different varieties of the product are displayed with a different color (Figure 3.7). The three different versions of the item are hovering in the air so the user can purchase or observe them.

Figure 3.7: Product Selection Mode activated for a cup.

3.5 Movement Techniques

As described in the related work chapter about movement techniques in virtual reality (subsection 2.3.1), we used the concept of headset movement and the *Point and Teleport* method as base.
By tracking the location and orientation of the virtual reality headset, walking inside the virtual environment becomes possible. The tracked position is relative to the center of the tracked area which boundaries are displayed with a virtual wall inside the application.
To reach locations outside of the boundaries, using the *Point and Teleport* technique relocates the virtual center of the tracking space. To start the teleport process the trigger button needs to be held. A parabolic curve is then displayed showing the target position (Figure 3.8) which can be confirmed by releasing the trigger button. The teleport position is therefore determined by the orientation and the position of the motion controller. A short fade-out effect prevents disorientation during the teleport process. The view direction of the virtual camera stays the same as before the teleport.

Figure 3.8: This is how teleport interaction looks like

3.6 Virtual Environment

The main requirement for the concept of this virtual environment is to maximize immersion and the feeling of presence. As mentioned in the related work section (2.2.3), our concept of the virtual apartment is based on its real-world counterpart. So the user should feel the presence of being inside an apartment. The apartment should create familiarity for the users to help them navigating through it. There are five well-known room types as main shopping areas for the products(Figure 3.9). Those rooms were the five most chosen rooms in the related work section about product placement (2.2.4). The room layout of our apartment is visible in figure 3.10.

(a) Living Room

(b) Bedroom

(c) Kitchen

(d) Bathroom

(e) Office

Figure 3.9: Rooms of the Apartment

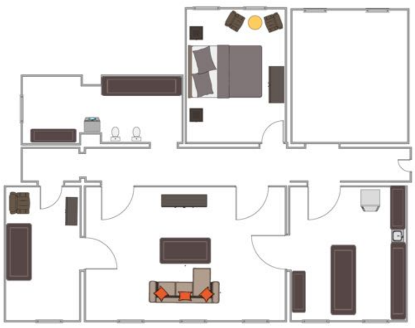


Figure 3.10: Blueprint for the room layout of the apartment.

4 Implementation

This chapter includes the mandatory technical requirements and goes in further detail to unclear aspects of the implementation of our VR Shop.

4.1 Technical Requirements

Hardware

The VR Shop was implemented and tested on a Windows 10 system equipped with an i7-5820k and a *Nvidia GTX 1080.* Despite our application not being very processor demanding, it requires the high end-graphic cards for using the HTC Vive [14] (Figure 4.1(a)). As input devices, we used the motion controllers of the HTC Vive (Figure 4.1(b)).

(a) HTC Vive Headset (b) HTC Vive Controllers

Figure 4.1: Picture of the HTC Vive headset and the controllers.

Software

Our VR Shop was build using the Unity Game Engine at the version 5.5.4f [13]. To use the HTC Vive, we integrated the Steam VR Plugin [12] in our application. For using and extending or VR Shop, the Steam VR Software must be installed on the system. Furthermore, the Steam VR Room Scale Setup must be completed for defining the walkable area.

4.2 Controller Mapping and Tooltips

The HTC Vive Controllers are visualized inside the application matching the user's inputs with the Steam VR Plugin. The user can see the action assigned to each button with the tooltips (4.2). We implemented them with the help of the VRTK-Unity-Plugin [16]. The right controller triggers the interaction methods and the Item Information Viewer(3.4.1). The Grab Interaction Method (3.1.1) is assigned to the Grip Button of the controller and the Beam Interaction Method (3.1.2) to the Trigger Button. The Item Information Viewer can be accessed by pressing the Touchpad-Button of the controller. We only used the term right controller based on the figure. This controller should be held in the user's dominant hand since it performs most of the interactions.
Moreover, the left controller handles the activation of the shopping cart and the initiating of the teleport (2.3.1). The Realistic Shopping Basket (3.2.1) and the Virtual Shopping Cart (3.2.2) are both mapped to the Touchpad Button. However, only one is enabled at the same time based on our circumstances. The teleport action is mapped to the Trigger Button. The Grab Interaction Method (3.1.1) is also assigned to this controller because it is natural to be able to grab an object with both hands.

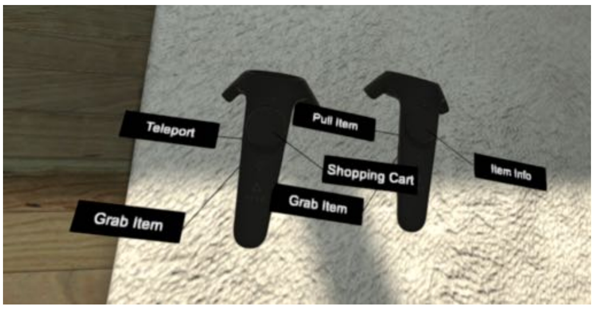


Figure 4.2: Tooltips of the two motion controllers which showcase the different button actions.

4.3 Headset Movement and Teleport Locomotion Technique

With the integration of the Steam VR Plugin, physical movement with the headset is already accomplished inside the previously defined room-scale area. We implemented the teleport locomotion technique (3.5) with the Vive-Teleporter plugin [15]. For preventing teleportation inside the scenery, we defined the allowed space by building a Navmesh [7] for our virtual environment. With the VRTK-Unity-Plugin [16], we implemented the fade-out effect when the headset is colliding with an obstacle.

4.4 Products and Interaction Methods

The highlighting of the products is implemented with the VRTK-Unity-Plugin [16]. Which generates an outline mesh at runtime for each product (Figure 4.3). The product information (3.3) is stored inside our JSON-Database using the LitJSON library [6]. The 3D Text for the product information is smartly orienting itself dependent on the look-vector of the headset. Each product is assigned with a Rigidbody [9] for providing the physics of the objects. Furthermore, a collider [1] is attached to them for hit detection. The Grab Interaction Method (3.1.1) detects a product with the sphere collider connected to the controller. Whereas, the Beam Interaction Method (3.1.2) recognizes an item with Raycasting [8]. For rendering the ray for this method and the Item Information Viewer (3.4.1), we used a Line Render [5].

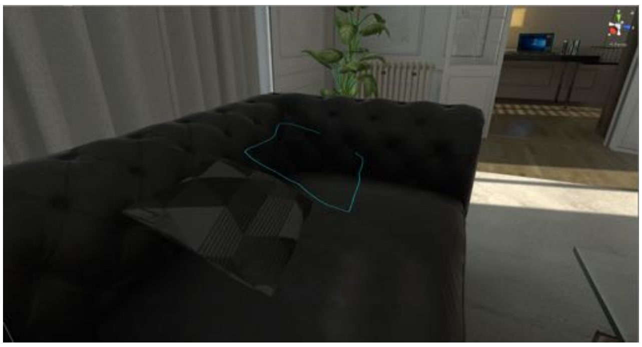


Figure 4.3: Regular product separated from its generated mesh for the outline.

4.5 Realistic Shopping Basket

For creating a realistic feeling shopping basket(3.2.1), we used a Hinge Joint [3]. The handle is an individual object which is connected to the basket with the Hinge Joint. This handle is attached to the controller. For storing products the main body of the basket uses several colliders(Figure 4.4). The largest collider servers as a trigger volume for detecting products. Whereas the other colliders are matching the boundaries of the basket for containing the products. The scenery gets assigned to a specified layer [4]. The collision of the basket with this layer gets disabled.

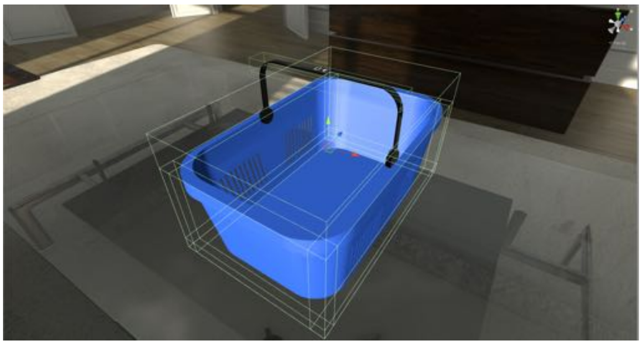


Figure 4.4: Colliders and Components of the Realistic Shopping Basket

4.6 Virtual Shopping Cart

The main part of the Virtual Shopping Cart(3.2.2) is a translucent sphere with a matching collider(Figure 4.5) attached to it. This collider serves as detection volume for the products. Every product inside this shopping cart gets its Rigidbody disabled. The circular arrangement of the products is determined by a formula which prevents overlapping between the objects while keeping the circle minimal.

Figure 4.5: Components of the Virtual Shopping Basket.

5 User Study

We conducted a study to evaluate the end-to-end experience of users as they interact with our system using the different interaction methods and shopping cart modes. Additionally, we gather insights on how viable the product search is in a virtual apartment as the environment.

5.1 Hypothesis

H_1 The Grab interaction method and the Physical Shopping Cart achieves a higher immersion than the Virtual Shopping Cart and the Tractor Beam interaction method.
H_2 The Tractor Beam interaction method and Virtual Shopping Cart have the highest user experience.
H_3 The Grab interaction method requires more temporal demand and physical demand than the Tractor Beam interaction method.

5.2 Participants

We recruited 10 participants (9 males and one female) ranging in age from 21 to 29 from the university campus. The average level of experience with VR applications was low overall (Mean = 1.9, Standard Deviation = 0.875) which was related on a *Likert-scale*. Only three out of ten subjects had already used the HTC Vive.

5.3 Apparatus

The experiment setup consists of one HTC Vive headset, two HTC Vive controllers and two HTC Vive lighthouses for tracking the position of the involved HTC Vive hardware components. The Lighthouses are mounted at the ceiling of the room and the system got a calibrated fitting to the walkable area of this room. A cross on the floor tells the participant where to stand at the beginning. The used computer

is equipped with the graphics card GTX 1080, the processor i7-5820k & 16GB of DDR4 Ram, thus guaranteeing a smooth user experience without noticeable frame drops.
The whole application was executed inside the Unity Engine while the Steam VR Service was running. All tracked devices need to be recognized by the Steam VR for guaranteeing the functionality of our project.

5.4 Design

We use a within-subject design for the experiment. The two independent variables with two levels each are:

- Interaction Method (Grab, Beam)
- Shopping Cart (Realistic, Virtual)

The dependent variables are:

- Task Performance (task completion time, error rate)
- User's Preference (user experience, workload, usability, immersion, motion sickness)

Each participant performs four tasks in a row as a unique combination of interaction method and shopping cart visualization. Each task consists of 10 trials, whereas in each trial the participant had to find a target product within the time limit.
Before each task, there is a "warm-up phase" to allow the users to get used to the controls and functionality of the current setup. In this step, a different scene is used where all objects are replaced with simple cubes (Figure 5.1). This replacement prevents the probands from already memorizing the location of items and thus preventing incorrect results.
The order of the interaction method and the type of the shopping basket of each task gets determined via latin square design to prevent a learn effect. The 40 target items have a pre-calculated random distribution with the same order for each participant. In this distribution, each of the five rooms in the virtual apartment has at least five target items. With this approach, the room distribution is more balanced. For avoiding confusion a preview of the item model and its name is displayed before each item search.
After each task, the participant completes the post-task questionnaires which are as follows:

- Motion Sickness Questionnaire (MSAQ) [21]
- Presence/Immersion Questionnaire (SUS) [30]
- Workload Questionnaire (NASA-TLX) [23]
- User Experience Questionnaire (UEQ) [24]

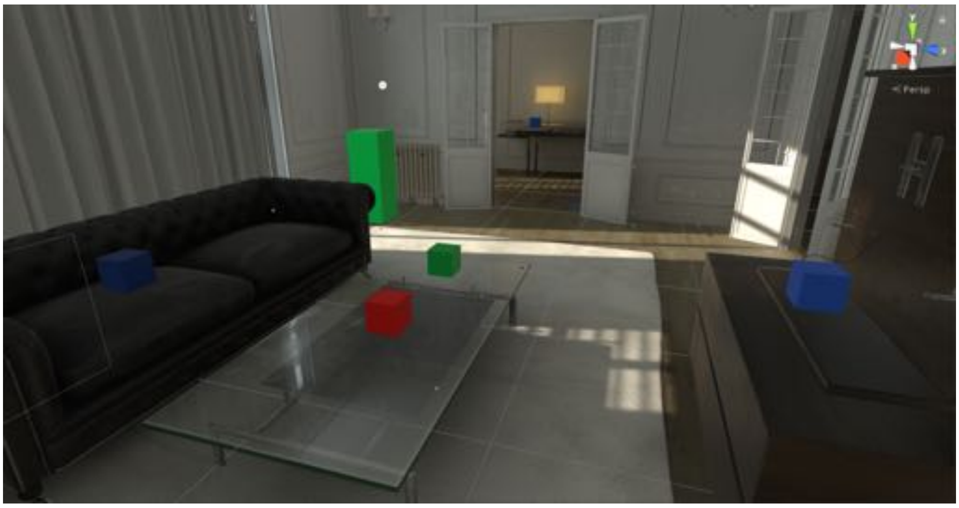


Figure 5.1: Warm-up scene were all products are replaced by cubes.

5.5 Task

Each task consists of a warm-up phase followed by 10 trials in a row. As mentioned in the design paragraph the tasks get associated with an interaction method and shopping cart visualization. Before the item search begins, the participant takes a warm-up to get used to the new conditions of each task. During that warm-up phase, the experimenter can give the participant an idea what to look for and how to interact with the product and basket. This explanation prevents that the participant misses features, he may not use in the primary task, but which are questioned in the final questionnaire.
After the warm-up phase, he has to walk to the marked position and orientation of the virtual reality space. To achieve the same starting conditions, the proband needs to recenter before each item search and the scene gets restarted to avoid incorrect results. To assist the participants before the search begins, a countdown (Figure 5.2) is displayed with the name of the target product and a 3D preview of it. After the

countdown is completed the participant begins the product search. The proband decides when the task is completed, after searching and placing items inside the shopping cart. If no or wrong items are in the basket, this search is treated as a failure. The item search is a success only when the correct item is inside. During this process, the observer is not allowed to give hints. A search task can timeout, or the proband can abandon the search, which results in a failure.

Figure 5.2: Target Product Display before the start of each search trial.

5.6 Procedure

At the beginning of the study, every participant is greeted and gets to fill out a consent form to participate in the study and a form which explains the tasks of the study (Step 1, Figure 5.3).
After a short introduction to the hardware, the proband absolves the Steam VR tutorial (Step 2, Figure 5.3) if the usage of the HTC Vive hardware is unknown to the subject.
After the participant feels ready to use the HTC Vive the observer starts the warm-up phase (Step 3, Figure 5.3) with the settings for the first task.
The participant is now inside the virtual apartment and is able to access one kind of basket and one interaction method corresponding to the task number.
During this step, the observer gives an introduction about the basic movement controls like teleporting and walking around. After the participant feels comfortable

to use the movement controls, the examiner explains how the product interaction works and motivates the subject to try it out.
When the proband gets used to interacting with items, the subject is asked to activate the basket and appraise it and place some items inside. After this introduction in the warm-up phase, the task phase begins. At the beginning, the subject needs to recenter and to reorient according to the marked point, which has an arrow for direction, on the ground of the virtual scene.
The first search trial (Step 4, Figure 5.3) begins and a countdown appears with the information of the target item. As soon as the countdown finishes the subject searches the apartment for the item and purchase it by placing the product inside the basket. When the subject feels successful, the proband tells the observer that the trial is finished. The search trial gets repeated 10 times. After the item search phase is completed, the subject removes the headset and takes the following questionnaires in this order: MSAQ, SUS, NASA-TLX and UEQ (Step 5, Figure 5.3). Step 3,4 and 5 are repeated 4 times in total until the proband has searched for 40 items with all four combinations of shopping carts and interaction methods. After the four tasks are completed the participant takes the Demographic Questionnaire(Step 7, Figure 5.3).

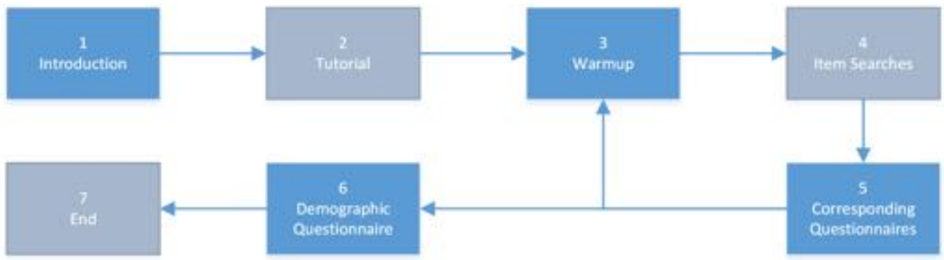


Figure 5.3: Study Procedure

5.7 Results

In this section and the following discussion section, we use abbreviations for the interaction methods and cart modes we tested: G for the Grab Interaction Method (3.1.1), B for the Beam Interaction Method (3.1.2), 1 for the Realistic Shopping Basket (3.2.1) and 2 for the Virtual Shopping Cart (3.2.2). The four combinations for the tasks are: G1 (*grab and basket*), B1 (*beam and basket*), G2 (*grab and cart*), B2 (*beam and cart*). Furthermore, we abbreviate standard deviation with SD and the mean value with M. We analyzed the results of the experiment with the software IBM SPSS Statistics 24 [11].

5.7.1 Task Completion Time

The task completion time is the elapsed time to complete a single product search. For each search trial the task start time begins after the product countdown and the task ends when the proband tells the observer that the search task is completed.
Regarding all search trials the overall task completion time was on average 17.27s with a standard deviation of 12.99 seconds. In concern to all four tasks (5.4) , B1 was the fastest task with a mean time of 15.32s (SD=10.32) followed by task G2 with 16.84(SD=10.85). Task G1 was the second slowest with 18.36s(SD=9.72) and the most time-consuming task was B2 with an average time of 18.56s (SD=18.73).
Furthermore, we conducted a univariate ANOVA analysis with cart mode, interaction method as factors and the elapsed time as the dependent variable. But we could not find significant differences between the cart modes or interaction modes with regard to the elapsed time.

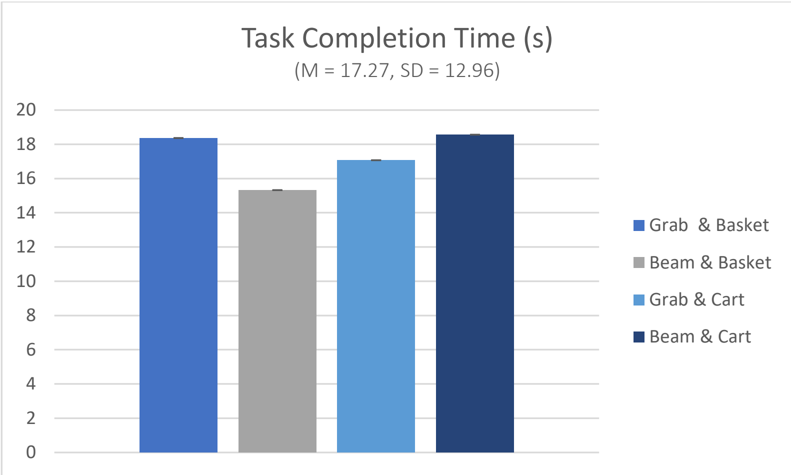


Figure 5.4: Elapsed time for each search trial regarding the interaction method and cart mode.

As we conducted an ANOVA with the room of the target item as factor, we found a significant difference for the elapsed time($F_{(1,394)} = 14.087, p < 0.01, \eta^2 = 0.125$). The elapsed time dependent to each target room can be seen in Table 5.1 whereas the bedroom required the highest time with 28.22 seconds(SD=26.13) and the bathroom the least amount of time for the search with 13.11 seconds (SD=4.03).

Room Name	Elapsed Time	Standard Deviation
Office	19.22s	12.57
Living Room	14.28s	7.02
Bath Room	13.11s	4.03
Kitchen	15.41s	7.39
Bed Room	28.22s	26.13

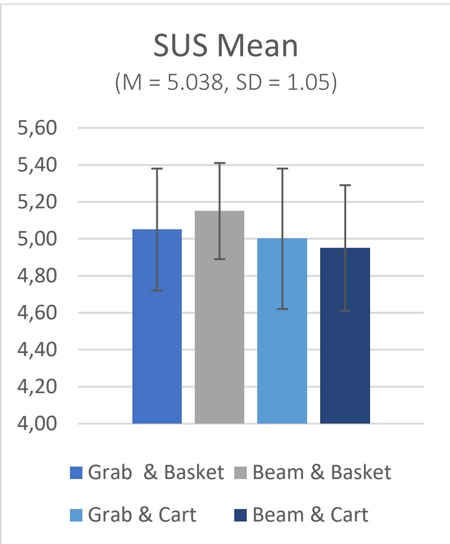
Table 5.1: Elapsed Time for the item searches dependent to the located room

5.7.2 Error Rate

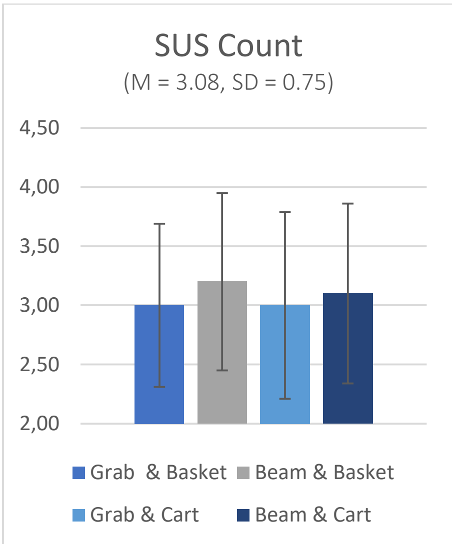
At the end of each search trial, all probands had the correct item inside the cart except for one case. We conducted a univariate ANOVA analysis with cart mode, interaction method as factors and the numbers of incorrect product placements inside the shopping cart as dependent variable. Regarding this dependent variable, we discovered a significant difference for the cart mode ($F_{(1,396)} = 20.641, p < 0.01, \eta^2 = 0.05$). The average number of corrections for the Physical Basket was 0.24 (SD=0.73) whereas no wrong products were placed inside the Virtual Cart.

5.7.3 Immersion

The immersion and presence of the virtual environment was measured with the immersion questionnaire for virtual reality applications from Slater et al. [30]. The probands answered the six questions of the SUS questionnaire [30] with values from 1 to 7. The *SUS Mean* is the mean score across all six questions. Regarding the *SUS Mean*, task B1 scored the highest immersion score with 5.15 (SD = 0.84) followed by task G1 with 5.05 (SD= 1.05). Whereas task G2 had the second lowest immersion mean with 5(SD=1.2) and task B1 the lowest immersion with 4.95 (SD = 1.08). Additionally, we looked upon the *SUS Count* which is the amount of answers which had a higher score than 5. The *SUS Count* was highest for task B1 with 3.2 (SD=2.37) followed by B2 with 3.1 (SD = 2.4), task G1 3 (SD = 2.2) and G2 3 (SD = 2.5) with the lowest score. We found no significant differences for *SUS Mean* and *SUS Count* with concerning the interaction method and cart mode. Our virtual reality shopping environment achieved an overall score of 5.038 (SD=1.05).



(a) SUS Mean



(b) SUS Count

Figure 5.5: Rating for *SUS Mean* and *SUS Count* for all four tasks.

5.7.4 Motion Sickness

We measured the motion sickness with the Motion Sickness Questionnaire from Gianaros et al. [21]. The average factor for the overall motion sickness was 14.93% (SD=3.6) for our application (Figure 5.6). Task B1 achieved the lowest overall motion sickness score with 14.3% (SD=2.81), followed by task G1 (M = 15%, SD = 4.2), task B2(M = 15.14%, SD = 3) and the highest motion sickness caused task G2 with 15.28% (SD = 4.13). We found no significant differences between the cart modes or the interaction methods for the overall motion sickness.

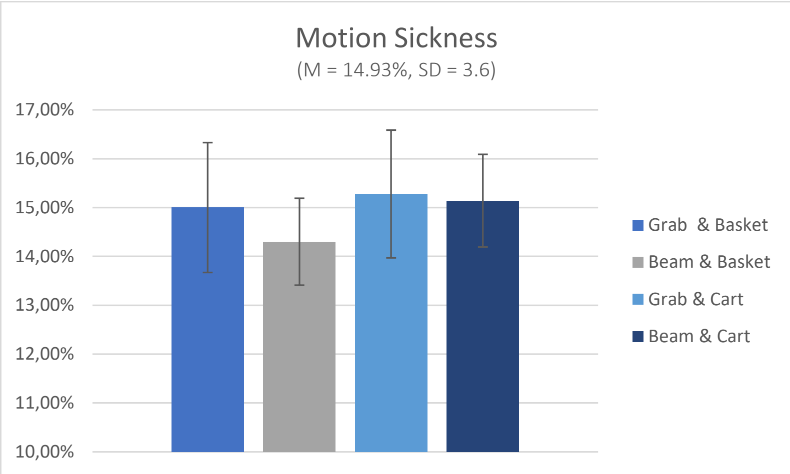


Figure 5.6: Overall motion sickness rating for all four tasks

The motion sickness questionnaire verifies four categories of motion sickness which are *Gastrointestinal*, *Central*, *Peripheral* and *Sopite-related*. The results for these categories are shown in Figure 5.7. We conducted a multivariate ANOVA analysis with the four categories of motion sickness as dependent variables and interaction method and cart mode as factors. We found significant differences between different cart modes with regard to the *Peripheral Factor* ($F_{(1,396)} = 10.18, p < 0.01, \eta^2 = 0.03$). Additionally, significant differences between the interaction modes could be found in regard to the *Sopite-related* factor ($F_{(1,396)} = 14.18, p < 0.01, \eta^2 = 0.04$). Significant effects could be found between the different interaction modes with regard to the *Gastro Factor* ($F_{(1,396)} = 6.02, p < 0.02, \eta^2 = 0.02$) and to the *Peripheral Factor* ($F_{(1,396)} = 4.53, p < 0.04, \eta^2 = 0.01$).
Finally, interactions could be found between the cart mode and interaction mode for the *Gastro Factor* ($F_{(1,396)} = 11.80, p < 0.01, \eta^2 = 0.03$) and the *Central Factor* ($F_{(1,396)} = 4.19, p < 0.05, \eta^2 = 0.01$).

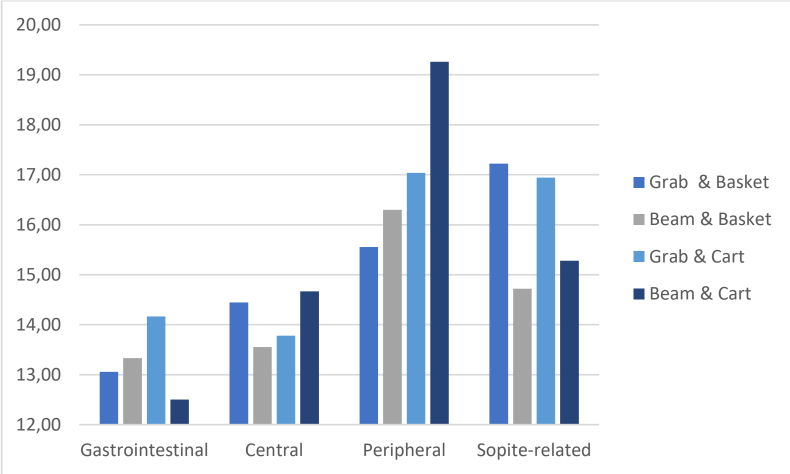


Figure 5.7: Motion Sickness Sub Scales

5.7.5 User Experience

We evaluated the user experience of our application with the User Experience Questionnaire from Laugwitz et al. [24] which has a scale of -3 to 3. Our application achieved an average user experience of 1.42(SD=0.52). Regarding the tasks, B2 had the highest user experience score with 1.62 (SD = 0.42), followed by task G2 (M = 1.37, SD = 0.63), task B1 (M = 1.36, SD = 0.42) and task G1 had the lowest score with 1.34 (SD = 0.54). Furthermore, we conducted a univariate ANOVA analysis with interaction method and cart mode as factors and the overall user experience as dependent variable. We found significant differences between the cart modes with regard to the overall user experience($F_{(1,396)} = 8.54, p < 0.01, \eta^2 = 0.021$). Additionally, we found a significant difference between the interaction modes in regard to the overall user experience ($F_{(1,396)} = 6.884, p < 0.01, \eta^2 = 0.017$).

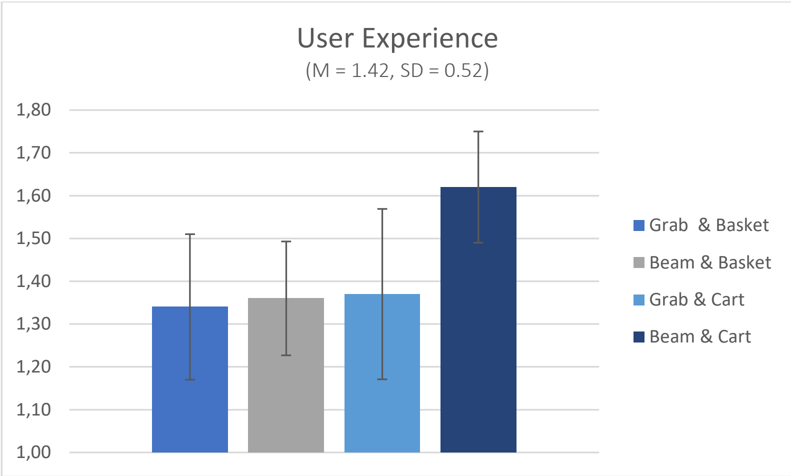


Figure 5.8: Overall user experience score regarding the different interaction methods and cart modes.

The User Experience Questionnaire contains six categories which are *Attractiveness*, *Perspicuity*, *Efficiency*, *Dependability*, *Stimulation* and *Novelty*. Our results for those categories are shown in figure 5.9. Additionally, we conducted a multivariate ANOVA analysis with the categories as dependent variables and interaction method and cart mode as factors. Concerning those categories, we found significant differences between the cart modes with regard to *Dependability*($F_{(1,396)} = 38.96, p < 0.01, \eta^2 = 0.09$) and *Efficiency* ($F_{(1,396)} = 25.95, p < 0.01, \eta^2 = 0.062$). Additionally, significant differences were found between the interaction modes with regard to *Perspicuity*($F_{(1,396)} = 18.69, p < 0.01, \eta^2 = 0.045$) and *Efficiency* ($F_{(1,396)} = 32.85, p < 0.01, \eta^2 = 0.015$). Furthermore we found significant effects between the interaction modes concerning the *Attractiveness* ($F_{(1,396)} = 10.608, p < 0.02, \eta^2 = 0.026$). Eventually we found interactions between the interaction mode and cart mode for Perspicuity ($F_{(1,396)} = 58.52, p < 0.01, \eta^2 = 0.129$), *Novelty* ($F_{(1,396)} = 17.138, p < 0.01, \eta^2 = 0.041$) and *Stimulation* ($F_{(1,396)} = 17.87, p < 0.01, \eta^2 = 0.043$).

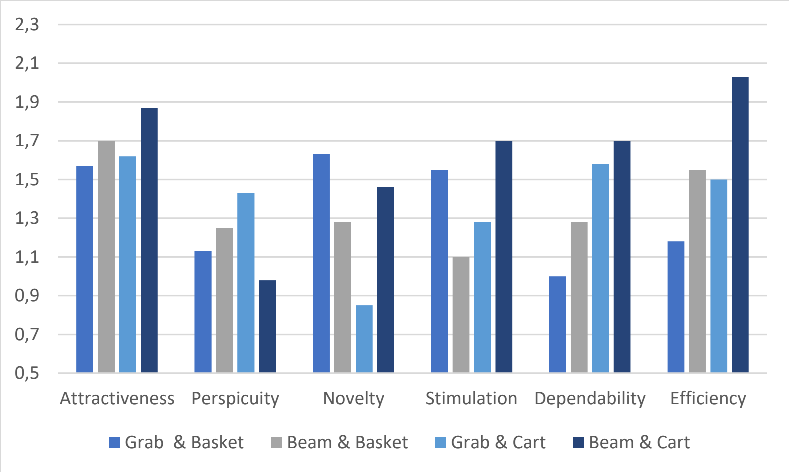


Figure 5.9: User Experience Sub scales

5.7.6 Workload

We measured the workload of our application with NASA TLX from Hart and Staveland [23]. Our application achieved an overall workload score of 28.28 (SD = 21.34). Task B1 required the least amount of workload with 26.97 (SD = 22.53), followed by B2(M = 27.13, SD = 20.77), G2 (M = 28.8, SD = 21.3) and the task G1 required the highest workload with 30.23 (SD = 20.85). We found no significant differences in the overall workload for the tasks.

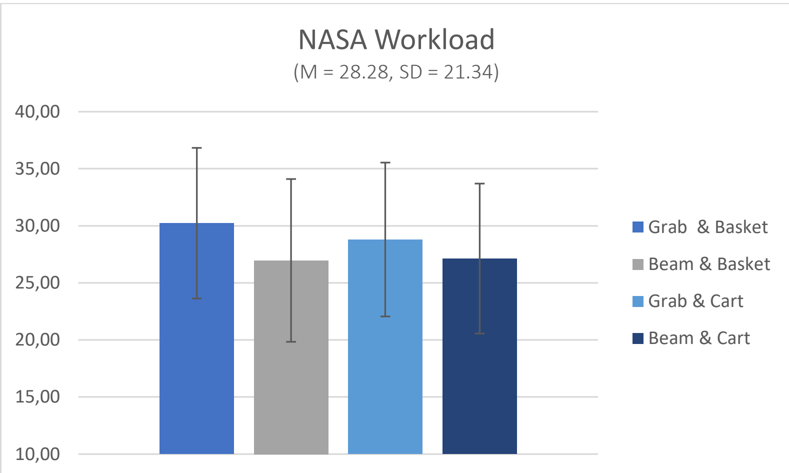


Figure 5.10: Overall workload of our application regarding the different interaction methods and cart modes.

NASA TLX contains six rating scales which are *Mental Demand*, *Physical Demand*, *Temporal Demand*, *Performance*, *Effort* and *Frustration Level*. Our results for those rating scales are shown in Figure 5.11. Furthermore, we conducted a multivariate ANOVA analysis with the six rating scales as dependent variable and the interaction method and cart mode as factors. Regarding those scales, we found a significant difference between the cart modes with regard to the *Frustration Level* ($F_{(1,396)} = 9.44, p < 0.01, \eta^2 = 0.023$). Moreover, significant differences were found between the interaction modes with regard to the rating of *Physical Demand* ($F_{(1,396)} = 13.14, p < 0.01, \eta^2 = 0.032$) and rating of the *Frustration Level* ($F_{(1,396)} = 13.59, p < 0.01, \eta^2 = 0.033$).

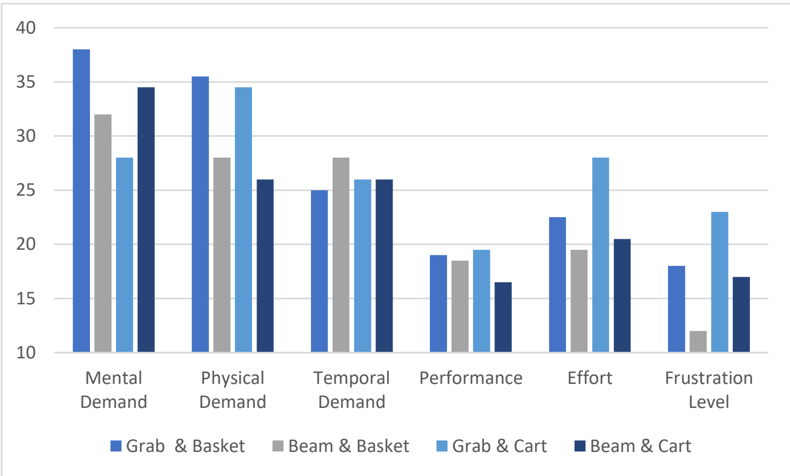


Figure 5.11: NASA TLX rating scales

5.8 Discussion

In this work, we investigate the different results for the two interaction methods and the two shopping cart modes. Hence we analyze the results of the tasks in consideration of the objective aspects which is the task completion time and error rate and the subjective feedback from the questionnaires.

5.8.1 Task Completion Time

The analysis of the task completion time showed only a marginal difference for the four task concerning speed. Therefore, we assume that the product search takes the most amount of time and has a higher impact on time. The Beam interaction method is expected to be faster than the Grab interaction method because the user can purchase products from afar. However, the *Point and Teleport Locomotion Technique* 2.3.1 allows the user to reduce the travel time which counteracts the close distance requirement of the Grab interaction method. Observations during the study showed that this interaction method is visibly slower when the product is on the ground or above head height because the user had to stretch or bend. We speculate that task B1 was the fastest because of the advantages of the Beam interaction method for speed and because of the more prominent trigger volume of the basket. Moreover, we suspect the trigger volume as the cause for task B2 being the slowest although it benefits from the advantages of the Beam interaction method. Additionally, we assume that the small trigger volume of the Virtual Cart cause a loss in speed because the user has to aim the product inside this volume precisely. Whereas the user in the case of the Realistic Basket just has to release the product above the basket. Consequently, we should increase the size of the trigger volume of the Virtual Cart to improve the speed of task B2.
As has been noted, the product search has the most impact on the elapsed time since we found a significant difference in elapsed time regarding the room of the target product. Thus, the environment and the product placement are essential factors to optimize the time. Although the bedroom and office were the two rooms which were furthest away from the starting location, the customers found the products of those rooms remarkably faster than the rest of the places. So the distance to the starting point is not impacting the search speed dramatically. The bedroom was significantly slower than the rest of the rooms given that the layout of the hallway obtrudes the view for the room entrance. Therefore, we have to optimize the corridor in a further iteration or maybe connect the rooms with a different approach than a hallway.

5.8.2 Error Rate

The analysis of the results of the error rate showed that nearly all search trials were successful hence we guess that the realistic representation of the product in the environment helped with the search process. Additionally, we suspect that the item information assisted during the search of products which looked similar to different products in the scene. The fact that the Realistic Shopping Basket caused unintended product placements inside the shopping cart was remarkable. However, the Virtual Cart produced none of this unexpected behavior. For this reason, we can assume that the wrong product placements were not intended by the user. Seeing that products can be placed inside the Realistic Basket without interacting with the product first, we should improve this basket in a further iteration by adding the constraint that the user has to interact with the products before the basket registers them. This limitation should fix the unintended behavior of the Realistic Basket.

5.8.3 Immersion

Our application achieved a high average *Immersion* score. Therefore, we speculate that our users had a feeling of being present inside the apartment. Our Hypothesis H1 (5.1) was incorrect because task B1 achieved a higher *Immersion* score than the task G1. Moreover, due to the nonsignificant difference in *Immersion* for the different tasks, we can assume that the interaction method and cart mode are not marginally influencing the feeling of presence for the user.

5.8.4 Motion Sickness

Being that the different tasks did not have a significant impact on the overall *Motion Sickness*, we can assume that their effect is neglectable. Regardless, we found significant differences for the subscales of the Motion Sickness Questionnaire. The *Sopite-related* factor describes how annoyed, tired or uneasy the participant was. The Grab interaction method had a higher *Sopite-related* value and a significant difference to the Beam interaction method since of the additional physical demand of the Grab method. As a reason for the higher *Sopite-related* factor, we speculate that the requirement for the user to bend or stretch out for objects which are out of arm's reach is responsible for this result.

5.8.5 User Experience

We can assume that our application provides an excellent user satisfaction since it achieved a high user experience score. Nevertheless, there were significant differences for the four tasks regarding the overall user experience. Task B2 scored remarkably higher which confirms our hypothesis H2 (5.1). With the help of the User Experience Questionnaire(UEQ) benchmark[29], we get a scale for our results of the categories from the UEQ.

All tasks achieved a good score for *Attractiveness* according to the previously mentioned benchmark. Consequently, we can assume that the users had a good overall impression for our application with those tasks. However, task B2 even achieved an excellent score for *Attractiveness* hence we can suspect that users had the best overall feeling for this task.

Regardless, task B2 attained the lowest score in *Perspicuity* with an above average rating. In effect, we guess that the behavior of the Beam interaction method and the Virtual Shopping Cart is hard to understand. Henceforth, we should add additional indicators for task B2 which signalize when the product is placed inside the cart.

Whereas, task G2 had a good rating for *Perspicuity*. Under those circumstances, we can assume that the Virtual Shopping Cart is harder to understand with the Beam interaction method. We suspect that the offset of the product to the motion controller when using this method reduces the clarity on how the product can be placed inside the cart.

Equally the Realistic Shopping Basket also has problems with the *Perspicuity* hence task G1 and B1 achieved only an above average rating for *Perspicuity*. Although the Realistic Shopping Basket tries to resemble the real-world counterpart of a basket, it behaves differently in some cases like when it downscales large products. This behavior might confuse the user on which parts of the basket resemble the real-world and which do not.

When we regard the *Novelty* rating of our tasks, we found out that task G1 achieved an excellent score. With this in mind, we presume that this task is considered as something new for the user although this task resembles the procedure of the real world. However, we suspect that our accurate representation of the Realistic Shopping Basket was unexpected for the users and thus they received it as something uncommon in virtual reality.

Since task B1 only achieved a good score in *Novelty*, we assume that the Beam method ruins the impression of our accurate representation of a basket in VR.

Nonetheless, task G2 had the lowest score for *Novelty*. Seeing that, we suggest

that this combination does not feel very innovative to the user. Regardless task B2 achieved an excellent rating in *Novelty* thereupon the interplay of Beam Interaction method and the Virtual Shopping Cart mode feels more original to the user.
When we analyze the results for the *Stimulation* score of our application, task G1 had an excellent score. Given that, we assume that the realistic approach of this task and the fun factor achieved by throwing products or by tilting the Realistic Shopping Basket are responsible for this rating. In contrast, task B1 had only an above average score for *Stimulation*. Therefore, we assume that the Beam interaction method makes this task less fun to use in interplay with the Realistic Shopping Basket due to grabbing feeling more satisfactory than placing a floating inside the basket. Furthermore, task G2 had only an above average score for *Stimulation*. With this in mind, we speculate that the enjoyment of placing a product inside the Virtual Shopping Cart lacks with the Grab interaction method hence we combine a realistic interaction method and a non-realistic cart. Consequently, task B2 which utilizes a combination of two non-realistic approaches achieved the highest rating for *Stimulation* with an excellent score. In contrast to task G1, task B2 has a lower requirement for effort. Therefore, we can explain the high rating of this task by its reduced required amount of hand movement.
Nevertheless, we evaluate the results for *Dependability* of our tasks. Task G1 had only a below average rating in this category. Therefore, we speculate that the reasons for this lousy score are that the Grab interaction is a nuisance when products are falling to the ground and that the physics of the basket cause unexpected behavior which can result in the loss of products.
Given that task B1 achieved a better score for *Dependability* with an overall average rating, we assume that the cause is the higher reliability of the Beam interaction method when products are out of arm's reach. Additionally, task G1 had a good rating in *Dependability*. Therefore we guess that the Virtual Shopping Cart is more reliable than the Realistic Shopping Basket due to the lack of physics which prevents unexpected behavior like losing products. Likewise, task B2 achieved an excellent score for this category. Seeing that, we assume that the interplay of the reliable Beam interaction method and the Virtual Shopping Cart caused this task to be the most trustworthy out of the four tasks.
For *Efficiency* task G1 scored the lowest due to the before mentioned additional requirements of taking a product with the Grab method. Whereas, task B2 achieved an excellent rating. Hence we assume that the Beam interaction method and the Virtual Shopping Cart are the optimal combination for minimizing the amounts of

steps the user has to take.

5.9 Workload

The analysis of the results for NASA-TLX further confirms our assumptions for the user experience. The users felt that the Realistic Shopping Basket was significantly more frustrating to use than the Virtual Shopping Cart. As mentioned before, the physical behavior of the basket can cause unexpected behavior like the loss of products which we assume as an explanation for the higher frustration. Moreover, the users had a significantly higher *Physical Demand* and *Frustration Level* for the Grab method. As reasons for this result, we assume the additional movement requirement for objects out of reach and the frustration of objects falling to the ground which makes them harder to grab.

5.10 Observations

During the study, we made the following observations.
The probands liked the innovative idea of our VR shopping application. 90% of the participants were interested in a VR shop and would possibly use it in the future. In the annotations section of the immersion questionnaire, the probands remarked that the locomotion technique negatively impacted the *Immersion*. Even so, the *Point and Teleport* technique was the best option to address the limited walking space. In the future, there might be a different method to solve this problem, but that is not within the scope of this work. Furthermore, some probands stated that black screen effect when the headset collides with an object seems to have taken them out of the immersion. It is an efficient method to prevent the user to walk through walls, but this feature seems to have confused the user when a product is triggering the effect. Therefore, we should only use this effect when the user collides with a wall.
As for the product placement, some products were hard to find. An example would be the product “Tissue” which probands expected in nearly every room. So we assume that not all products are optimal for the room based product search. The participants noted that they could better grasp the size of the products based on the scenery. Furthermore, we asked the participants in the demographic questionnaire which types of products are relevant for the VR shop. The participants found groceries and clothing as not relevant. Whereas, the participants rated the suitability for VR of electronic products as above average. However, the probands found the

VR shop very relevant for furniture and property and only relevant for traveling. Therefore, we suspect that our VR Shop should specialize for the significant product categories.

6 Conclusion

Our thesis focused on developing a virtual reality (VR) shop with two different interaction methods and two shopping cart variations. As the medium for VR, we used a head-mounted display which was in our case the *HTC Vive*. In contrast to other VR stores, we use a standardized apartment as our virtual environment for easier finding the products.

Our interaction techniques were implemented by altering the *Ray-Casting* technique and the *Virtual-Hand* technique. As locomotion technique for our application, we used the well-known *Point and Teleport* method. Those interactions were done by using the motion controllers of the *HTC Vive*.

With a study, we compared the different interaction techniques and shopping carts. Based on the results, we concluded that the Virtual Shopping Cart and the Beam interaction technique are the best for the user satisfaction. Furthermore, the non-realistic interaction method and cart are not bound to limitations of every-day methods. Contrary to our initial suspicion that the non-realistic methods would interfere with the *Immersion* of our application, their negative impact was neglectable. This supports our assumption that VR Shopping might achieve better results when striving apart from real-world based concepts.

The performance of our application was dependent on our product categorization but not on the currently active interaction method. According to our observations, we assume that not all products are viable for this classification but the viable ones where easy to find for the user. Based on our outcome, we should restrict our product range to furniture and everyday objects. Especially these products could best utilize the interactivity and immersion provided by virtual reality.

The analysis for the study results indicated that our application achieved a remarkably high score for *Immersion* and *User Experience*. Furthermore, most of the probands enjoyed their experience with the VR Shop and would adequately like to use it in the future. Therefore, we can assume that VR shopping could become a new shopping medium which combines the advantages of E-commerce sites and physical stores.

7 Future Work

Our chosen combination of the implemented *Beam* interaction method and the *Virtual Cart* needs additional feedback to improve its clarity. An example would be to add a short vibration of the motion controllers which gives the user an indication when the product can be placed inside the shopping cart. Correspondingly, the *Virtual Cart* can be improved by adding a scrolling feature to rotate the products in circular formation. Another notable addition would be a categorization feature and an option to increase the amount of a product entity inside the cart. Our shopping cart is currently only a symbolic way for purchasing. Thus a checkout system needs to be implemented in the future. Furthermore, the VR Shop should have an interface with an existing online shopping service to order the products and for handling the payment process.

Our introduced concept for the Product Selection Mode increases the amount of product variations without overcrowding the apartment. In the future, this mode needs to be improved by adding more options for variety than the currently available color option. Furthermore, the function can be added for the user to customize a product. Not to mention, we assume that the room-based product categorization can be further improved by adding a room variation mode. This would introduce the customer to different themed presets for the room scenery and contained products. Another approach would be to add the option for a customizable apartment matching the user's home. The user can position the previously purchased products in the altered version of the virtual environment to test the interplay of the products. Based on this configuration, product suggestions would appear with the possible use of *Machine Learning*. This would assist the customer with choosing suitable products for the current setup. Those suggestions could be highlighted in a different color to indicate special offers or promoted products.

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