Verifying Qualitative Improvement of User Experience by Physical Use of Real Product in Digital Environment Using Augmented Reality

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This study focuses on developing an augmented reality(AR) application on a smartphone to help the user place the digital environment in the physical world and put the real product into it while shopping in an offline store. The application, named Pocket Home, allows users to place the real product in their digital room while experiencing the product physically. Users can edit the position of products and interact with product animation to see if products fit their room (home or workplace) and meet their expectations.

In this study, two experiments were conducted to evaluate the user experience of prototypes from the Handheld AR Usability Scale (HARUS), physical experience, ease of imagination, presence, perceived value, and perceived risk. For the experiments, another application called Pocket Furniture, which can place virtual products in the physical world was also developed as a control group for the experiment. In experiment 1, a collection of 6 products was tested by 10 participants using Pocket Home 1.0 and Pocket Furniture 1.0. The results show that version 1.0 of Pocket Home suffers from unrealistic content, lack of interactivity, and non-intuitive gesture interaction.

After that, Pocket Home was iterated and updated with enhanced 3D model quality, added product animations, optimized interaction gestures. And then, Experiment 2 was conducted to further evaluate the usability of the prototype as well as explored how users perceive and evaluate the reference of product placement. A collection of 3 products was tested by 25 participants using Pocket Home 2.0 and Pocket Furniture 2.0. The result of HARUS proved that the iteration is effective. The results of the cognitive aspect evaluation indicated that products that can give users haptic feedback leads to better physical experience and ease of imagination when using Pocket Home, while products that focus on the audiovisual experience can give users a better sense of presence. In addition, the importance of the user's multi-perspective while using Pocket Home was found. Besides, users' ratings of perceived risk also indicate that both prototypes have privacy concerns. Overall, in the study, the prototype Pocket Home was created and iterated to achieve the improvement on the user experience of selecting products when compared with other AR placement applications (Pocket Furniture). The design approach of Pocket Home can be a guide for designing the type of mobile AR application which combines a digital environment with real products.

Main Academic Advisor: Seung Hee LEE
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Chapter 1

Introduction

1.1 Backgrounds

Augmented reality (AR) is an interactive technology that modifies the physical environment by superimposing a virtual 3D model of a product onto it [1]. Consumers can use real-time mobile augmented reality apps to visualize and evaluate products or services using their smart devices[2]. AR virtual product placement reduces consumer concerns about product placement while also increasing purchasing intention [3]. AR technologies influence customer decisions by increasing consumer enjoyment and reducing uncertainty of product selection [4].

However, The benefits of augmented reality for online shopping do not carry over well to offline shopping. In the offline, most researchers and developers focus on enhancing the information display of products themselves and in-store navigation. But, when customers find something they want to buy for their room, they only can use pictures of their room or size data to imagine how the product will look like when placed in their room. Despite AR can provide some detailed information for selecting products during offline shopping, people can't really know whether the products they are trying are fitting their living space and workplace. One of the solutions with AR is, simulating virtual products in their room and then going to the store to try the products by themselves. But, the purpose of going to an offline retail store can be to have fun, entertain, spend time. People often go offline shopping without a clear plan and purpose. If users didn't use AR to preview the products at home, they won't be able to get an intuitive reference when they come to offline stores. This separation of online and offline shopping methods poses difficulties for the application of AR in retail.

1.2 Purpose and Significance of the Study

With the aim of filling these gaps, the goal of this research is to provide a method of simulating personal space in an offline store and allow users to place the real product in this digital environment based on a smartphone. To prevent the digital environment covers the display of real products, the real products will be covered by digital copies (3D models) of themselves instead of real products being put into the digital environment. In this way, customers were able to interact with real products while watching how they look like in

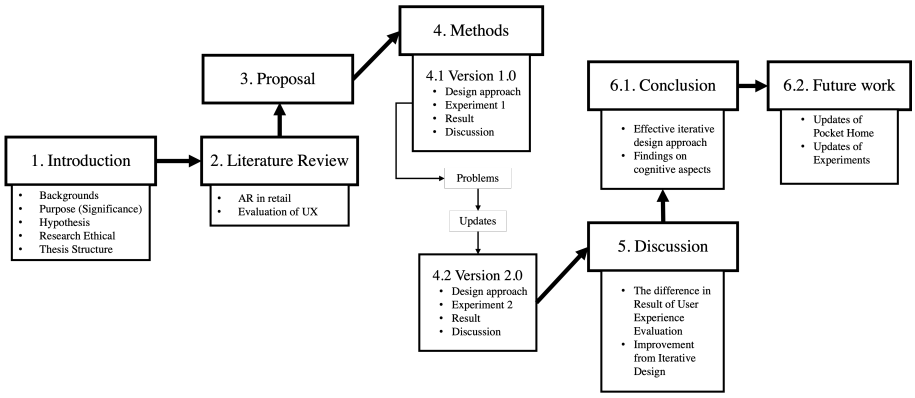
their room. Additionally, in the study, the prototype was tested by a series of experiments that compared it with the AR app which has a widely used function that is to place virtual products in a real room. In the experiment, the cognitive aspects of user experience were evaluated in terms of physical experience, ease of imagination, and presence. The usability of prototypes was evaluated by a Handheld AR usability scale. The perceived value and perceived risk of using the prototypes were also evaluated. The results of the evaluation were used to analyze the effectiveness of this method on user experience and to provide guidance for further development.

1.3 Hypothesis

The research hypothesis is that providing a reference of where to place the product in their room while allowing users to experience the product physically through AR, can effectively enhance the user experience when selecting products. Compared with the AR application that can place virtual products in the physical world when shopping online, this method of using AR to assist shopping offline can more effectively enhance the user's perception of the combination of products and environment, which helps to confirm the quality and performance of products.

1.4 Thesis Structure

The structure of this paper is summarized in a diagram, presented in Figure 1.1.



[a]AR = Augmented Reality.
[b]UX = User experience.

Figure 1.1: The structure of thesis

1.5 Research Ethical Considerations

The experiment had been approved by the Research Ethics review committee of School of Art and Design, University of Tsukuba. Informed consent was obtained by a dedicated survey item in which participants were asked if they had read and understood the experiment instructions and signed the Agreement Form.

Chapter 2

Literature Review

2.1 Augmented Reality in Retail

Augmented Reality(AR) enables the creation of new enriched environments to extend the physical world by blending real-world objects with virtual-world objects [5]. Although there are many definitions of augmented reality, they all have one thing in common: its features are interactive, simultaneous, vivid, and unique to the environment in which it is used. According to Azuma's research [6], AR is a real-time view of the physical world that is overlaid (augmented) with virtual computer-generated information such as text, images, video, or any other interactive computer-generated media. In support of this definition, Faust defines AR as the superposition of virtual objects (computer-generated images, texts, sounds, and so on) on the user's real environment [7]. In comparison to traditional media, AR provides the user with an enhanced and immersive experience benefited from high levels of interactivity and vividness [8].

2.1.1 Shopping Online with Augmented Reality

Regarding the AR literature, previous research focused on the media characteristics of AR. In online shopping, augmented reality (AR) provides consumers with highly interactive and vivid contextual information via virtual try-on tools [9]. For example, IKEA launched an augmented reality app that allows customers to select a catalog product and place it wherever they want in their homes. The augmented reality concept combines the efficiency benefits of e-commerce sites with the sensory benefits of traditional stores [2];

2.1.2 Shopping Offline with Augmented Reality

For offline shopping, Ashok's team created a shopping assistant app that uses augmented reality to deliver targeted advertising and in-store shopping assistance such as in-store navigation and customized product-specific information for customers [10]; In Cheng's research, they developed a revolutionary mixed-reality interactive in-store purchasing experience that enriches physical objects by combining continuous context awareness, natural user behaviors, and augmented web content that is relevant to the user and their context of usage at the time [11]. This combination has the potential to improve efficiency and purchasing certainty, as well as provide consumers with a more personalized and enjoyable experience.

Overall, AR's ability to overlay the physical environment with virtual elements such as text-based information, rich media images, and video, which can interact with the physical environment in real-time, opens up new opportunities for businesses to provide consumers with a unique experience.[12].Although AR technology is widely used in online shopping, we are not able to use AR well in offline stores, especially in terms of getting reference of product placement in our home.

2.2 Evaluation of AR User Experience

To investigate how AR impacts the user's shopping experience, previous researchers have often used evaluation methods from different domains to comprehensively assess the usability of AR applications.

2.2.1 Handheld AR Usability

Along with the widespread use of smartphones, handheld augmented reality (HAR) enables consumer applications in entertainment, marketing and sales [13]. Usability, or the ease of using an interface, is an important consideration that affects user adoption and user experience [14]. In Santos' study, they created a Handheld AR Usability Scale (HARUS) to assess the usability of AR apps on smartphones [15]. HARUS and its deconstruction into individual manipulability and comprehensibility scores are evaluation tools that researchers and professionals can use to assess their HAR applications. By giving such a service, they can obtain valuable input from users in order to enhance their HAR applications and propel them to commercial success.

2.2.2 Physical Experience

While AR can provide realistic visuals, in most cases it does not provide a great physical experience (PE), which is a very important factor for users when experiencing products and making purchase decisions. Physical experience allows consumers to fit, try and touch the goods before purchase. Consumers' value judgments of the offerings are directly influenced by their physical experience [16]. Furthermore, when consumers' mental representations of the product are concrete, the impact of product contact on purchase intentions and readiness to pay for the object being evaluated is clear [17][18]. What's more, Pino's research shows that even simply imagining a product's touch (vicarious touch) might increase customers' expectations of how easy it will be to use tactile-functional products and their intentions toward them [19]. In this study, the questionnaire about the physical experience is used to assess how much of the user's senses are used in experiencing the product to confirm the quality and performance of the product.

2.2.3 Ease of Imagination

Ease of imagination (EoI) is a metacognitive experience that consists of how easily people perceive a product and how it will operate, and it is used to assess the experience and make purchasing decisions[20]. According to the imagination accessibility method [21], the ease with which a customer can envision a product and its potential consumption is

an information factor, which can impact assessments and behavioral intentions. When using AR apps, part of the information is often virtual. Users always need to use some imagination to turn the virtual into real information. In my research, ease of imagination was used in the questionnaire survey as a factor to evaluate how easily users perceive a product's performance.

2.2.4 Perception of Presence

Presence is a psychological state of "being there" that is mediated by an environment that engages our senses, catches our attention, and encourages our active participation [22]. The environment in which presence is mediated can be real, virtual, symbolic, or a combination of the three. The level of presence felt in that environment is determined by the fidelity of its sensory components, the nature of the required interactions and tasks, the focus of the user's attention/concentration, and the ease with which the user adjusts to the environment's demands [23]. It is also affected by the user's prior experiences and current state. In my research, presence was used to evaluate if the participants have the feeling of standing in the room where target products were placed.

2.2.5 Perceived Value

Perceived value is a consumer's assessment of a product or service based on their view of the trade-off of sacrifices and advantages [24]. Previous research has shown that perceived value has a substantial impact on mobile service acceptance [25]. In this study, Perceived value is used to evaluate whether the prototype is valuable to the user in experiments for product selection and whether the benefits to the user are worth the effort and time.

2.2.6 Perceived Risk

Perceived is commonly defined as the "consumer's views of uncertainty and undesirable repercussions of buying a product or service" or "the subjective expectation of a loss" [26] are common definitions of perceived risk [27]. In this study, the Perceived risk is the expectation of a loss as well as the consequences of that loss if it occurs. It relate to user privacy and the trustworthiness of information when using AR apps

Chapter 3

Proposal

This study focuses on developing an application on a smartphone to help people simulate the digital environment around the real product in an offline store, which allows users to experience the product physically while getting a reference of where to place the product in their room. First, the study aims to explore the design approach of an augmented reality(AR) application on smartphones, which lets users be able to place the real products in their digital room while physically using the product. Making the user-product interaction more intuitive and effective for selecting products through the AR prototype is one of the objectives of this study. Second, the research aimed to verify the positive effect on the user experience of the prototype and compared it with a control-group application, which can superimpose a virtual 3D model of a product into a physical room. The comparison was conducted through two experiments that evaluate the user experience of using the pair prototypes in terms of physical experience, ease of imagination, Handheld AR usability scale, perceived value, and perceived risk. The results of the evaluation will be analyzed to figure out how users perceive the augmented reality information presented by prototypes and how they differ from each other and affect the user experience. The prototype was iterated once after experiment 1. The results of effective iterative experience and analysis of user perceptions can be summarized to produce design guidelines for further updates of the prototype.

Chapter 4

Methods

In the study, a prototype of an AR application named Pocket Home that achieved the research's objective was created. The name, Pocket Home (PH), which means "the home in your pocket", indicates it can help customers to simulate the digital environment (their home or workplace) around the real product (furniture or appliance) in the offline store.

To verify that Pocket Home can help users get a view of where the product is placed in the room and improve the user experience, it needs to be compared with the AR application which is popular in the market. Pocket Furniture (PF) was created as a competitor of Pocket Home. By referring to AR furniture placement applications on the market such as IKEA place and Amazon AR View, Pocket Furniture can be used to place virtual products (furniture or appliance) in the physical world. Its name means "the furniture in your pocket". Both of Pocket Furniture and Pocket Home have the same digital contents (3D model of products and rooms).

In the study, two experiments were conducted to test the prototypes. Experiment 1 was conducted to test version 1.0 (initial version) of the prototypes. By analyzing the results of Experiment 1, a series of problems of design were identified. After that, the prototypes' design and experimental design were improved and were iterated to version 2.0. Finally, Experiment 2 was conducted and the result of Experiment 2 was analyzed with factors in aspects of cognitive and usability. The design approach of prototypes as well as the experimental design, results, and discussion will be introduced in the next sections

4.1 Version 1.0

Version 1.0 of prototypes (Pocket Home 1.0 and Pocket Furniture 1.0) was developed for Experiment 1. In the development of version 1.0, the main goal was to build the basic functions of Pocket Home which can synchronize the real products' spatial and physical information. The 3D models of products, which was also called digital copy, can be superimposed on the real product by the Pocket Home, thus enabling the function of projecting information of the real product into the digital environment. Besides, Pocket Furniture 1.0, as a prototype for the control group, was developed as an AR application that allows virtual products to be placed in the physical world. Both of Pocket Home and Pocket Furniture provide a visual reference of the products placed in the room. The difference is that the user can physically use the real product during the use of the Pocket Home. On the other hand,

Pocket furniture only provides visual information. The development of this version focused on achieving the matching of real products with their digital copies (3D model) in the virtual environment and how to edit the position of the product in the virtual room by touch gestures. The development tool is Unity 3D which is a cross-platform game engine that fits AR software development. And the platform for the test is the Android smartphone. Exploring the difference in user experience between Pocket Home and Pocket Furniture is the main goal of Experiment 1.

4.1.1 Design Approach of Prototypes 1.0

Digital contents

The collection of products included in prototypes has 6 products. The products are shown in Figure 4.1 and the reason to be selected is explained as followed:

- Group 1: including a middle size table and a small size table with a potted plant. The group 1 is a pair of products that can be placed, and users should choose the best place in the room to fit the tables.
- Group 2: including a rattan chair and a swivel chair. The group 2 is a pair of products that can be physically sat on.
- Group 3: including TV and a portable fan. The products in group 3 are electronic and both of them can be active (TV: display the video, Fan: make the wind).

Figure 4.1: The collection of products in version 1.0

The 3D model of these 6 products' 3D models were all scanned by the 3D Scanner App which is an iOS application that supports scanning an object in reality and outputting it as a 3D model. The models were imported in both prototypes with the same quality. Figure 4.2 shows a screenshot of a product's 3D model captured by 3D Scanner App. The models made by the 3D scanner reflects the real color and texture of these, but their components are not detachable.

The digital environment was made by 3D Scanner as well. The original room was a 25 square meters room. The environment was scanned with the light on so that light information could be recorded in the textures. Figure 4.3 shows the interior design of the room and its 3D model scanned by 3D Scanner App. These digital contents of the rooms and products in Version 1 were prepared for Experiment 1. How they are applied in Pocket Home and Pocket Furniture will be described in the following sections.

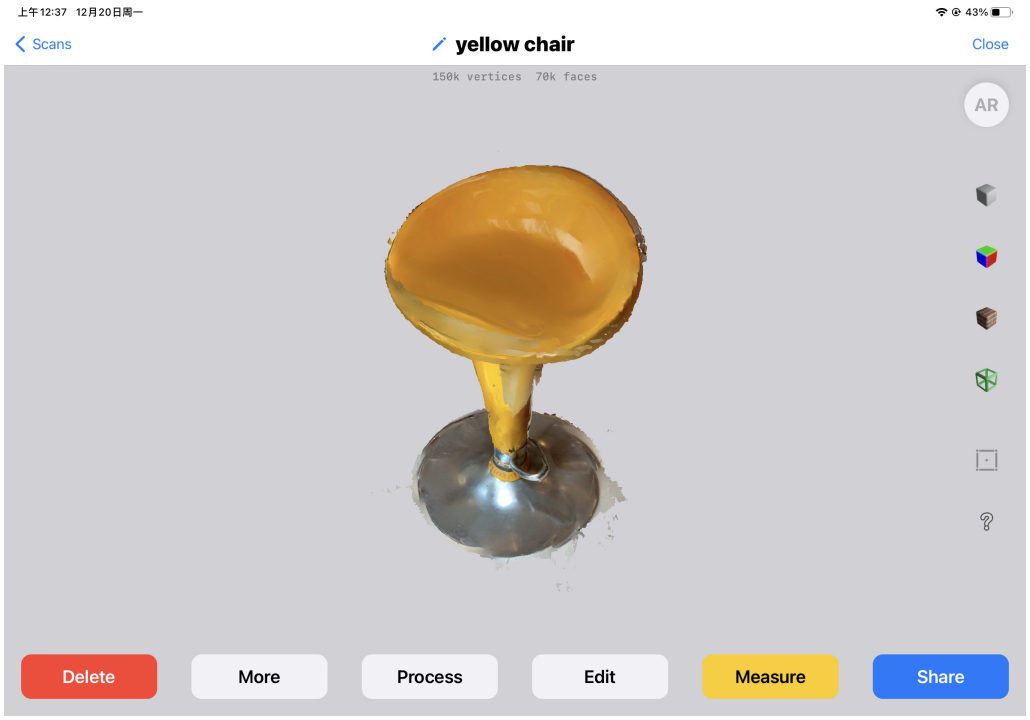


Figure 4.2: The screenshot of product's 3D model captured by 3D Scanner App

(a)The room for experiment 1

(b)The 3D model of the room

Figure 4.3: Experimental environment and scanned digital environment of experiment 1

Pocket Home 1.0

Pocket Home 1.0 was made to simulate the real product into the digital room. The digital contents in pocket Home 1.0 included 6 products' and a rooms' 3D model which were called digital copies. For matching the digital copy with the real product, the product was marked by a recognizable picture. When users use Pocket Home to scan the mark, the mark can be tracked and the digital copy(3D model) of the product would be activated. The digital copy tightly covers the real product. If you move or rotate the real product, the digital copy will synchronize all changes in position. After that, the user should use Pocket Home to detect the ground plane and a indicator would be shown on the ground. To place a digital room on the ground, users need to tap on the indicator. And then, the digital room should be simulated in the reality, and users could see the digital copy of the real product was

placed in the digital room through smartphone's display. Because the location of the copied product is superimposed on the real product location and stuck with it, users couldn't change the position of digital copy without moving the real one. They have to move the digital environment to change the position of digital copy in the digital environment. To adjust the position, users can use one finger point at the screen to change the position of the digital room's center point and use two fingers to rotate the 3D model based on the central axis of the room. The user can also change the position of the product by moving the real product. Figure 4.4 shows the interface and interaction of Pocket Home 1.0 and Figure 4.5 shows how to use the finger gestures to move or rotate the product by moving the room. With these features, users can first put real products into their digital environment, i.e. their own room, and then try the real products while watching the simulation of placement. Therefore, users can feel like they are in the digital environment to use the real product.

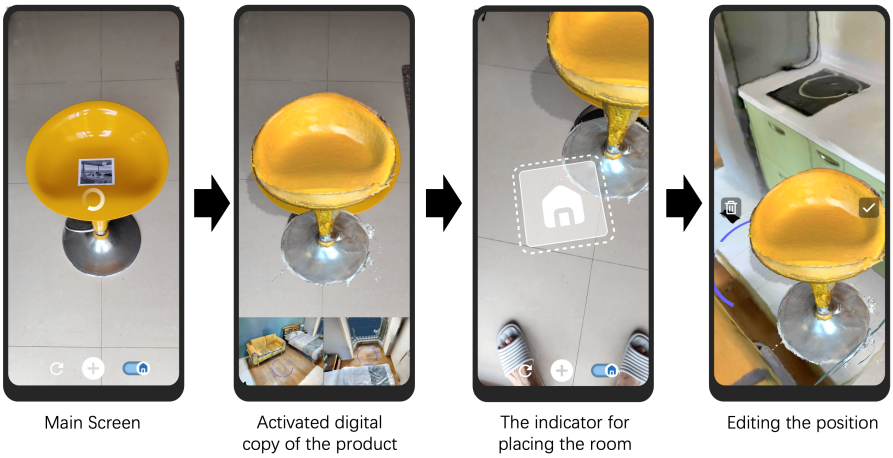
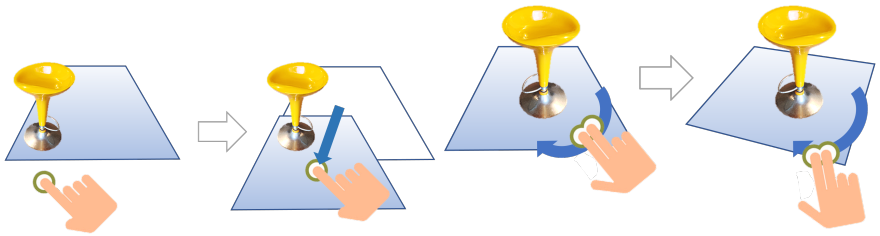


Figure 4.4: The interface design of Pocket Home 1.0



(a)Moving the room in Pocket Home (b)Rotating the room

Figure 4.5: Gesture interaction in Pocket Home 1.0

Pocket Furniture 1.0

Pocket furniture 1.0 was created to simulate the digital product (3D model) in the real room. The digital contents in pocket furniture 1.0 are the same as the Pocket Home's. There was no room model in the Pocket Furniture because it was used to test in a real room. As shown in Figure 4.6 Users can select products with a menu and use an indicator to place

the product on the ground. The virtual product can be moved by using a one-finger-tap gesture and rotated by using a two-finger-rotate gesture as shown in Figure 4.7.

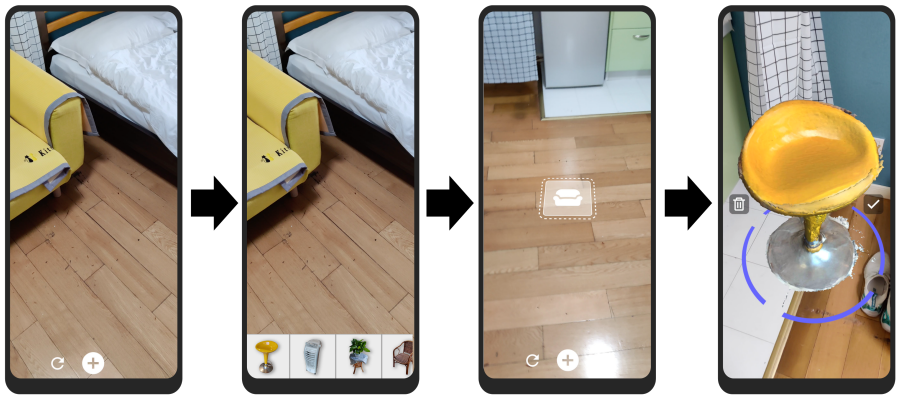


Figure 4.6: The interface design of Pocket Furniture 1.0

(a)Moving the product (b)Rotating the product

Figure 4.7: Gesture interaction in Pocket Furniture 1.0

4.1.2 Experiment 1

Experiment 1 was conducted to test the user experience of initial version of prototypes. The objective of this experiment was to compare Pocket Home 1.0 with Pocket Furniture 1.0 to figure out if Pocket home really improved the user experience of selecting products by provide the chance of physically using products. A non-probability sampling example of 10 participants (5 male and 5 female) aged between 22 years and 27 years old were recruited in the experiment. Each participant tested two applications both. Pocket Home was prepared for the experimental group and Pocket furniture was for the control group. The flow of the experiment 1 was shown in Figure 4.8.

Tasks of Pocket Home 1.0

For testing the Pocket Home, an experimental environment that simulated offline shopping scenario was prepared. it was half of the 25 square meter room with 6 products placed inside. The collection of the room and 6 products was introduced in previous section (section 4.1.1, Figure 4.3). The layout of 6 products was shown in Figure 4.9. Participants did the

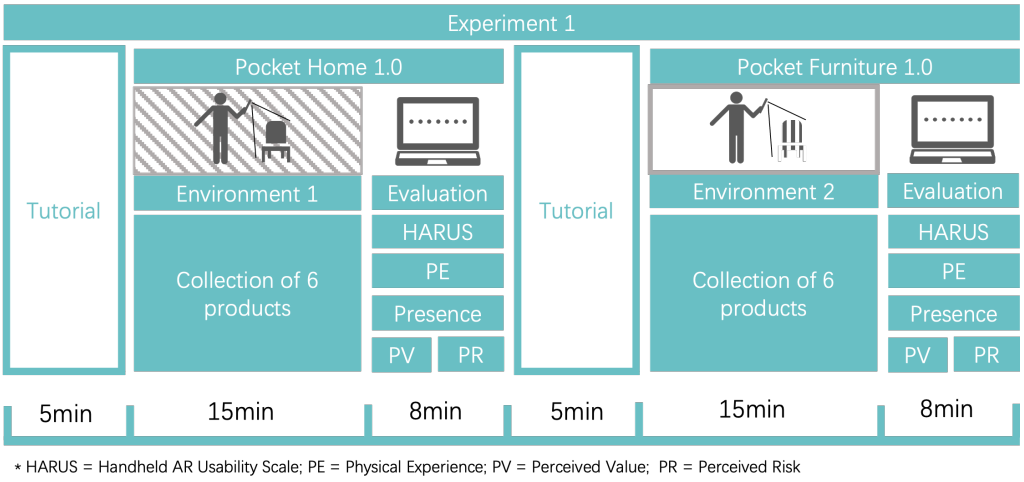


Figure 4.8: The flow of experiment 1

experiment in the left area of the room with products around them. The participants were instructed to imagine that they were going shopping at a furniture store where six products were laid out on the floor. Before the experiment start, the researcher explained the context of the study and taught them how to use the Pocket Home on an experimental device (an android smartphone). After that, participants were told that the goal of the task was to selecting and trying suitable products for their own room. The digital room (3D model) which was prepared as their own room and they wanted to buy products for it, was shown in Figure 4.3. After watching the room information, participants were asked to use Pocket home to place six products from the experimental environment in their digital room in 15 min. After the placement, participants could interact with the real products while observing the simulation on the screen, such as sitting on a chair and looking around, turning on a fan to feel the wind, turning on the TV, etc. After they finished trying all the products, they were asked to finish a questionnaire to evaluate their user experience of using Pocket Home. The contents of evaluation would be explained in next sections.

Tasks of Pocket Furniture 1.0

For testing the Pocket Furniture, the experimental environment 2 was the same 25 square meter room which simulate users' own room. The participants were instructed to imagine that they were at home and want to use AR to shop products online. There were no target products placed in, so participants should place the digital products in reality by themselves through Pocket Furniture 1.0. The available area for placing the virtual products was marked in Figure 4.10. The green area is the area where digital furniture can be placed. At the beginning of the task, the researcher explained the use of Pocket Furniture to participants. Participants had minutes to familiarize themselves with the room. When participants got ready, they were asked to use the PF with the experimental device to place the six virtual products (same as the products used in Pocket home) in the real room and adjust them to the position they felt was appropriate with the same gesture control as Pocket Home has. After that, participants were asked to fill out the same questionnaire as

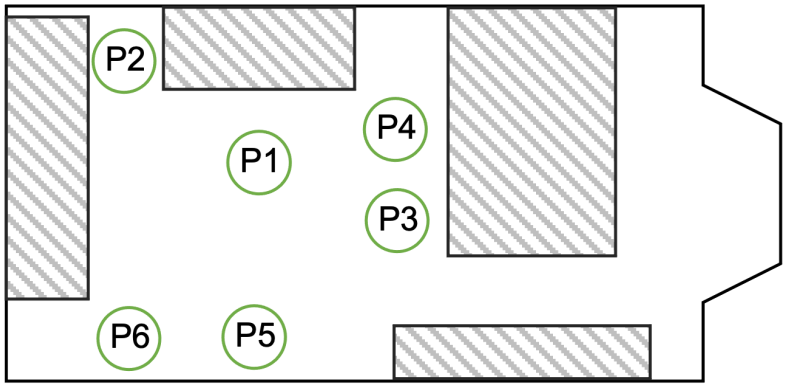


Figure 4.9: The layout of 6 products in the experimental room for testing Pocket Home 1.0

in the Pocket home experiment.The contents of evaluation would be explained in the next section.

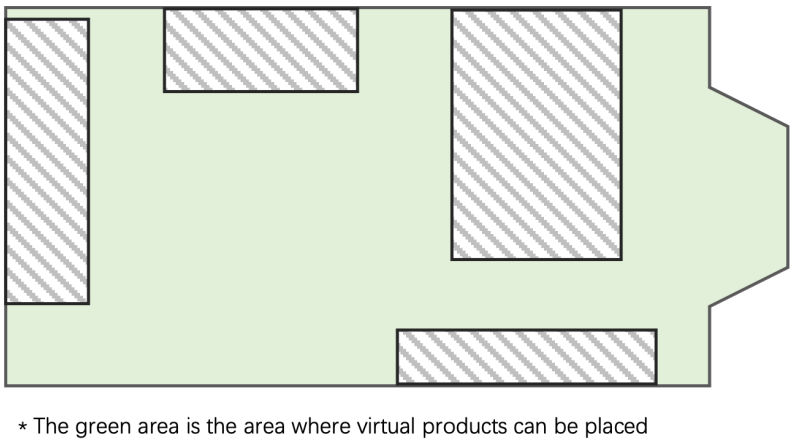


Figure 4.10: The area for product placement with Pocket Furniture 1.0

Evaluations

The user experience of testing products through Pocket Home and Pocket Furniture was evaluated by the questionnaire made with Microsoft Forms. Participants were asked to rate their user experience 7-point Likert questions (from 1 = Strongly disagree, to 7 = Strongly agree) in terms of the HARUS, physical experience, presence, perceived risk, and perceived value. The reason of using these factors was explained in section 2.2. The questions of each factors was shown in Appendix A. Participants finished the questionnaire on the Microsoft forms with a laptop in the experimental room.

Counterbalanced Design

In order to avoid order effects, a counterbalanced design was used in this experiment. Participants were numbered from 1 to 10. In the experiment, participants with odd numbers did the Pocket Home's experiment first, and those with even numbers did the Pocket Furniture's experiment first.

4.1.3 Result of Experiment 1

The result of each factors' mean rating was shown in Table 4.1. Figure 4.11 shows the medians and interquartile ranges of rating of each factors in experiment 1. The score of Pocket Home (PH) was shown in orange and Pocket Furniture (PF) was shown in blue. A series of Wilcoxon Signed-Rank Tests were performed by Statistical Product and Service Solutions (SPSS) to find where the differences actually occur between Pocket Home and Pocket Furniture. All of the evaluation was done after participants finished using Pocket Home or Pocket Furniture to experience all of 6 products in the experimental environment. The result shows that the mean value of PH's Physical Experience (M = 5.26, SD = 0.72) was higher and significantly differ from PF's Physical Experience (M = 4.52, SD = 0.77), p = 0.013. Besides, the mean value of PH's Presence (M = 3.99, SD = 0.75) was lower

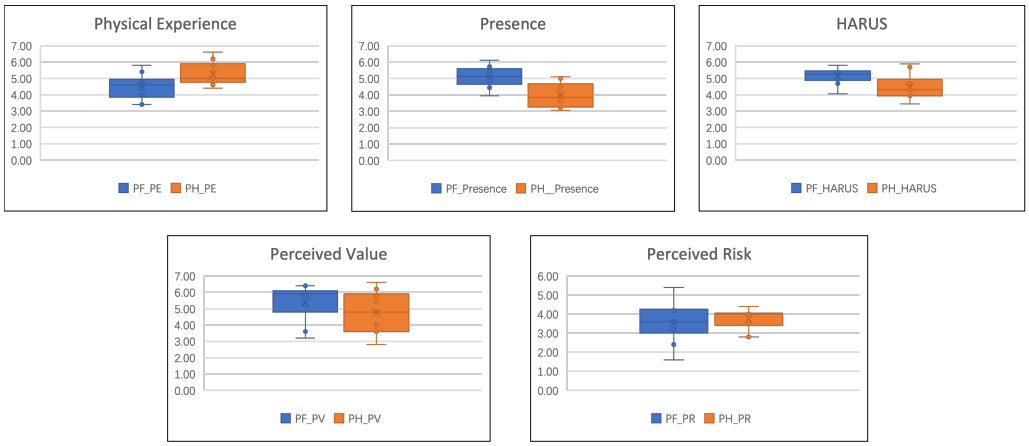


Figure 4.11: Medians and interquartile ranges of rating of each factors in experiment 1

and significantly differed from PF's Presence (M =4.52, SD =0.77), p = 0.005. The mean value of PH's HARUS (M = 4.47 , SD = 0.77) is lower and significantly differ from PF's HARUS(M = 5.15, SD = 0.50), p = 0.017 . In addition, The average value of the Perceived Value of PH 1.0 (M = 4.76, SD = 1.25) did not significantly differ from the PF 1.0 (M = 5.40, SD = 1.12), p = 0.201. Furthermore, comparison of the Perceived Risk between PH 1.0 (M = 3.74, SD = 0.55) and PF 1.0 (M = 3.52, SD = 1.05) would be also viewed as non-significant, p = 0.385.

In a summary, version 1.0 of Pocket Home only achieved a significantly higher score in terms of Physical Experience. However, Pocket Home's rating of presence and HARUS were both significantly lower than Pocket Furniture. When comparing parameters of Perceived value, and Perceived risk, both of the results were viewed as non-significant.

Table 4.1: Average ratings and Wilcoxon signed ranks test statistics for experiment 1

		Physical Experience	Presence	HARUS	Percived Value	Percived Risk
Pocket Furniture		4.52	5.11	5.15	5.40	3.52
Pocket Home		5.26	3.99	4.47	4.76	3.74
PH-PF	Z	-2.492^a	-2.807^b	-2.397^b	-1.278^b	$-.869^a$
	Asymp. Sig. (2-tailed)	0.013	0.005	0.017	0.201	0.385

a. Based on negative ranks. b. Based on positive ranks.

4.1.4 Discussion of Experiment 1

About Physical Experience

The results of the data analysis show that PH has a significant benefit in terms of physical experience. This result indicates that users are more willing to physically using the real product while simulating the product in the virtual environment by PH. When users use PF to simulate virtual products, they are less able to get information beyond the visual because there is no product they can experience in real.

About Perception of Presence

In the comparison of Presence, PH scored significantly lower than PF. One of the possible reasons is that the 3D models in PH are not realistic enough, which to some extent reduces the user's immersion. Especially when compared with the real room in PF's task, the virtual room simulated by PH does could not give the user a better sense of immersion and presence. Some of the participants also complained that the products' movement didn't perfectly match the digital copy shown in the virtual room. The mismatch of real products and their digital copy may lead to a decrease in the feeling of presence.

About Usability

About usability, the result shows that PH had a lower score of HARUS, which means users feel more uncomfortable situation when using the PH. During the experiment, most of the users said they feel a struggle when moving the virtual environment around the product. It is hard for them to adjust the products to a suitable position with the current version of interactive gestures. From these feedback, I knew that the gesture control of Pocket Home need to be further improved.

About Perceived Value and Perceived Risk

The Perceived Value (PV) and Perceived Risk (PR) both showed non-significant differences between the two treatments. It investigates the PH's update of physical experience didn't actually bring more value to product selection when compared with PF. Besides, when considering the risk such as information discrepancies and privacy issues, the participants can't really tell there is an obvious difference between the two apps. This result might caused by the weakness of PH's usability and Presence. During the experiment, some participants said that they were continuously feeling the inconvenience of operation which leads to misunderstand product's performance. And another possible reason is that the participants were not able to think about the value and risk of each of the two apps from

the customer's point of view. The lack of clarity of the participants' goals in the experiment resulted in them not thinking they were actually using the prototype to select a product.

Summary of Problems

In summary, the initial version of PH indeed gives more chance for users to physically use the product while putting them into the virtual room. But, the weakness of usability and Presence inhibits PH from showing its advantages. Low-quality 3D models and the mismatch between real products and models reduce the user's sense of presence. Besides, The non-intuitive interaction gestures also affect the user's fluency and focus on the task. Therefore in the next version of prototypes, Pocket Furniture needs to be updated in terms of the realism of the 3D model, matching with a digital copy (3D model), and gesture interaction. Besides, the experimental design also needs to be improved. To increase participants' involvement in the task, I need to make the roles and goals of participants in the experiment clear and set a reliable role for participants to play.

4.2 Version 2.0

The version2.0 was developed for improving the shortcomings of the previous version and adding new features to further optimize the user experience. It fixed the problem exposed in experiment 1 and especially make progress of match of real product and its digital copy. Version 2 is dedicated to upgrading the following points:

- The realism of 3D models (products' and environment's)
- Matching the functions of a real product and its digital copy with animation.
- Optimize the interaction gestures and interface design of the app to improve the usability of the prototype.

Figure 4.12 shows the updates from version 1.0 to version 2.0. The design approach was explained in the next section. The detail of each update will be explained in the next sections.

4.2.1 Design Approach of Prototypes 2.0

Digital contents of version 2.0

To give participants a clearer goal of tasks and a reliable role to play, experiment 2 was planned to be conducted in a meeting room and the user would be asked to select products for meeting rooms. Therefore, the products that would appear in version 2.0 were products commonly used in the meeting room. The product selection of version 2.0 include a chair, a TV, and an electric fan which shown in Figure 4.13. Each of these three products has different interaction properties.

- Chair: users can physically sit on the chair.
- TV: users can be turned on the TV to play video.

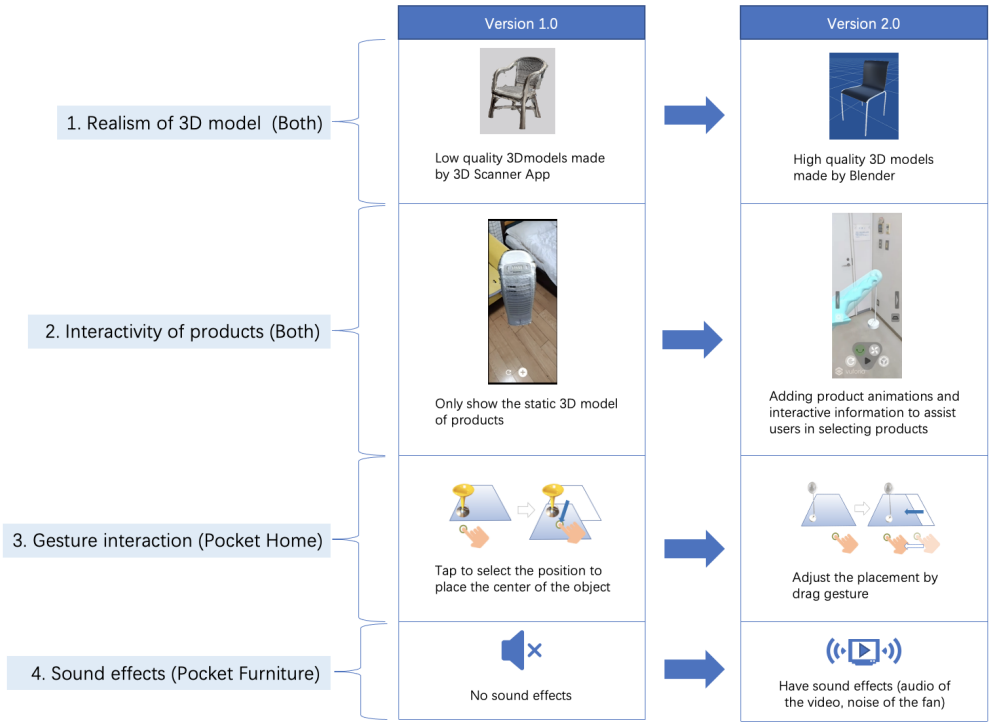


Figure 4.12: Comparison of Version 2.0 and Version 1.0

- Fan: users can turn on the blowing function, and adjust the wind and the direction of blowing through the remote control.

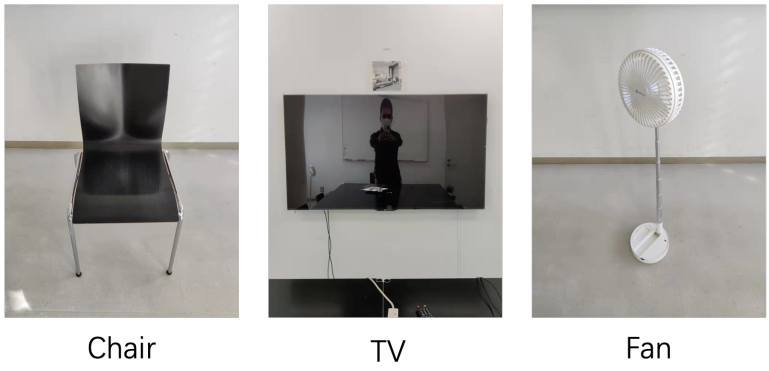


Figure 4.13: The collection of 3 products in version 2.0

To improve the realism of 3D models, the 3D scanner was abandoned and all of the 3D models used in version 2.0 were modeled in Blender (an open-source 3D creation suite) and Unity 3D. The model is made from the real scale of 3 products tested in the experiment. Thanks to Blender, these digital contents have more realistic shapes, more detail, and smoother materials. Besides, different from the 3D models made by 3D Scanner, their components can be separated to create animations that shows products' functions. Figure 4.14 shows a 3D model of meeting room was also created as a digital environment where the user would place their product when testing the Pocket Home 2.0.

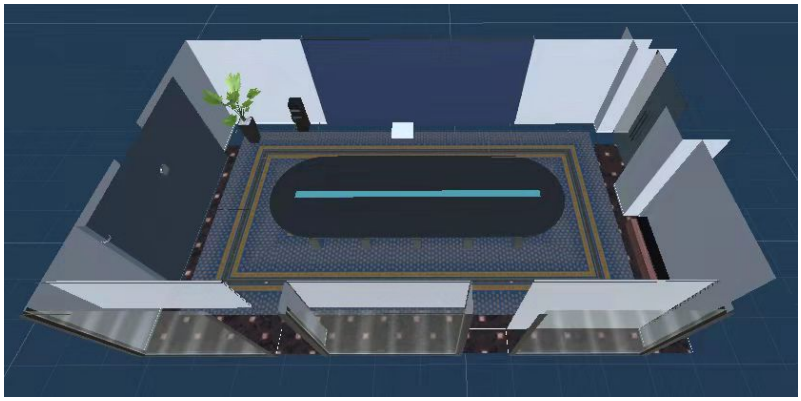


Figure 4.14: The 3D model of virtual meeting room

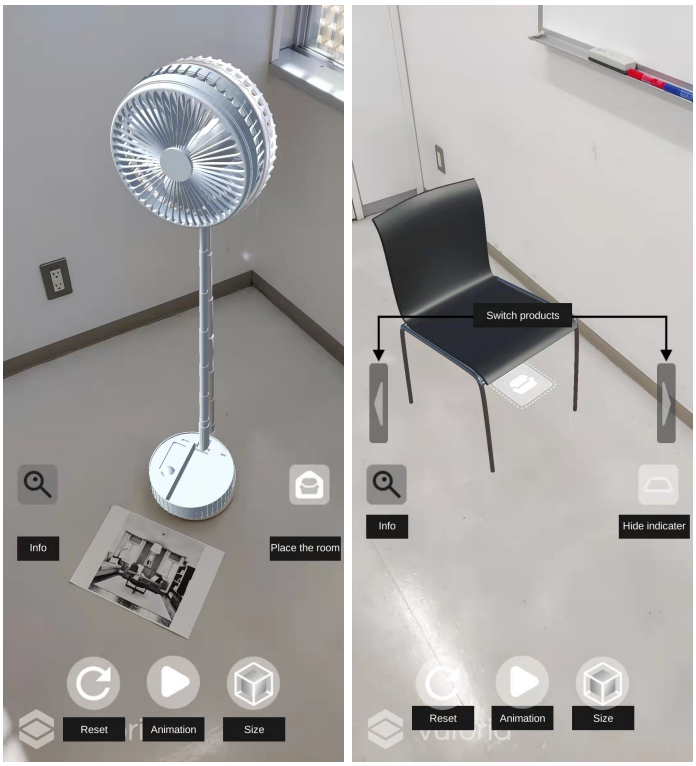
Pocket Home 2.0

In version 2.0, Pocket Home made a stronger connection between products and its digital copy. For electronic products that can be manipulated (the TV and the fan), animations that show their functions are built-in to improve the match of the digital copy and the real product. During the experiment, the display of animation can be synchronized manually with the operation of the actual product, so that the working product can be displayed in the virtual world synchronously. The main interface of Pocket Home 2.0 is introduced in Figure 4.15 (a). The introduction of function of each button is following:

- Info button controls the display and hiding of introductions.
- Place-the-room button controls the display and hiding of the virtual room
- Reset button can be used to reset the scene.
- Animation button is used to activate or stop the product's animation.
- Size button is used to activate or hide the dimensions and distance scales of TV.

For interacting with the TV, a clip of video could be displayed on the both screen of digital copy and real TV while using Pocket Home 2.0. Users can activate the display of the animation by tapping the Animation button. What's more, there was a Size button for users to activate scales of the dimensions and distance of the TV. The ruler is perpendicular to the plane of the TV, showing the distance between TV and user. The user can switch between the three states of "distance scale turned on", "size scale turned on", and "scales turned off" by clicking the Size button.

About the functions of Fan, blowing the adjustable wind and swing, as made as a series of interactive animations. Wind button and Swing button are used to active the animation which is shown in Figure 4.17. Firstly, users should click the Animation button to activate the Wind button and Swing button. Once the Wind button is activated, the fan blades of the digital fan will start to rotate. At the same time, the range of the wind will be simply indicated by a transparent colored cylinder and an arrow. Once the user taps on the wind button again, the level of the wind will be boosted by one level and there are 3 levels of wind that can be chosen. The transparent cylinder and the arrow will be adjusted synchronously



(a)Pocket Home 2.0 (b)Pocket Furniture 2.0

Figure 4.15: User interfaces of Pocket Home 2.0 and Pocket Furniture 2.0

Figure 4.16: Using Pcoket Home 2.0 to interact with the TV (with a screenshot of interface)

to show the correct range of winds. The swing animation can be activated by clicking the Swing button.

To optimize the interaction gestures, the tap gesture which was used to update the position of the digital room was replaced by a dragging gesture which is shown in Figure 4.18. In contrast to the original interaction method of moving the center of an object to the clicked position by tapping which is easy to cause error triggering, dragging gestures can help the user to move multiple times precisely by dragging the object (digital rooms).

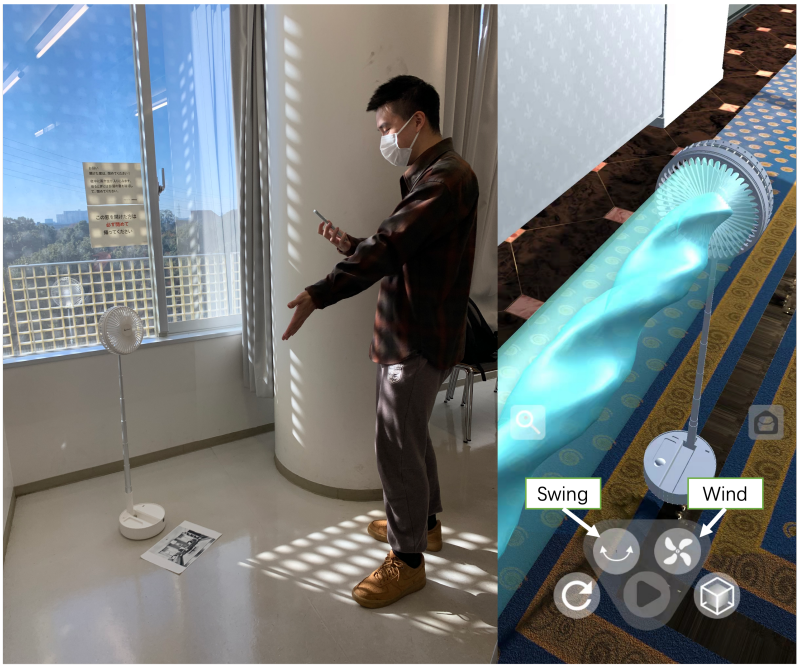
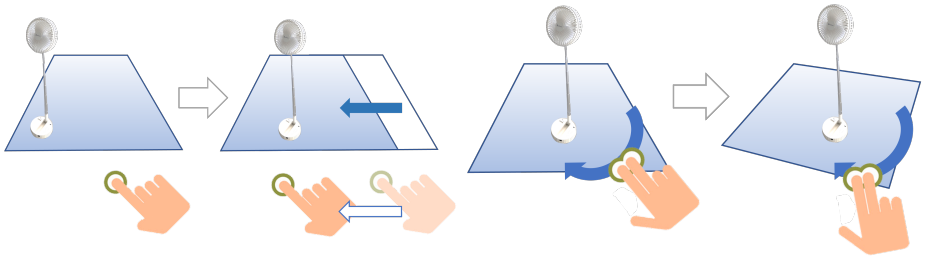


Figure 4.17: Using Pcoket Home 2.0 to interact with the Fan (with a screenshot of interface)

Users can drag multiple times to place the digital in a satisfactory position, thus reducing frustration when the room is misplaced.



(a)Moving the product (b)Rotating the product

Figure 4.18: Gesture interaction in Pocket Home 2.0

Imagine tracking was the way Pocket home detects real products as well. To improve the accuracy of detection, the recognizable image marks used in Pocket home 2.0 was all in 8*8 inches, which is much bigger than 1.0 version. And all of the marks were set to place beside the product. So the mark would not disturb users while experiencing the products.

Pocket Furniture 2.0

As a control group app, Pocket Furniture 2.0 has the same animation setting as Pocket home 2.0 has. As shown in Figure 4.19, the products can be placed on the real ground with an indicator and their animation can be active with the same buttons which were used in Pocket home 2.0. the only difference is the animations in Pocket furniture 2.0 have sounds. For example, when testing the TV, the sound of the video was included in the animation and would be played by the speaker of a smartphone. Besides, for the fan, a series of recorded

audio of fan noise was also prepared. Once the wind animation was activated, the audio would be played at the same time to match the wind animation.

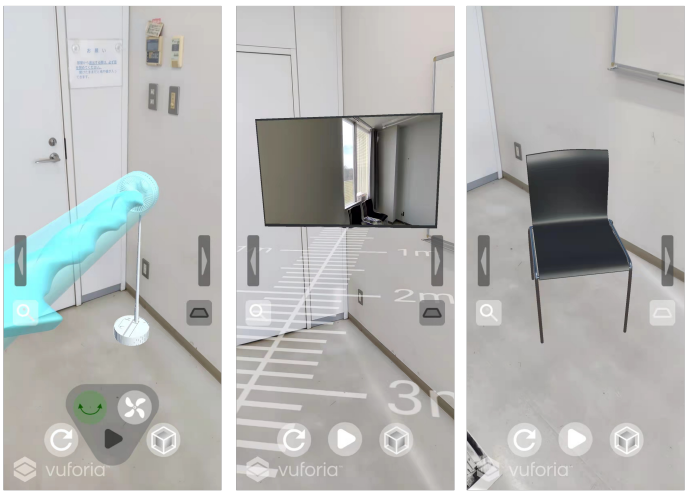


Figure 4.19: Placing and interacting with virtual products through Pocket Furniture 2.0

The interaction of version 2.0 of Pocket Furniture is shown in Figure 4.20, which follows the version 1.0. When placing and moving the product, users need to tap on the indicator shown on the ground. To simplify the operation process, the interface of version 2.0 has been simplified to ensure that the interface design of Pocket Home and Pocket Furniture is relatively consistent. In contrast to version 1.0, I eliminated the use of menus to select products in version 1 and using only two Switch button (Figure 4.15(b)) instead to control the selection of products.

(a)Moving the product (b)Rotating the product

Figure 4.20: Gesture interaction in Pocket Furniture 2.0

4.2.2 Experiment 2

Experiment 2 was conducted to check the effectiveness of prototypes (from version 1.0 to version 2.0) with more rational experimental treatment and a more detailed evaluation. A non-probability sampling example of 25 college students (10 male and 15 female students) aged between 22 years old and 29 years old were recruited in the test. Each participant tested two applications both. Pocket home is for the experimental group and Pocket furniture is for the control group. The experiments were conducted in a well-lit meeting room (Figure

4.21). One side of the meeting room is relatively empty and the other side is an area with a table and TV (as the base product of this room).

Figure 4.21: The real meeting room for experiment 2

Tasks of Pocket Home 2.0

For testing the Pocket Home, the experiment was conducted with 3 target products (a chair, a TV, and a fan) placed in the room. The layout of these products was shown in Firgure 4.22. Besides, the digital meeting room (Figure 4.14) was prepared for the participants as their own meeting room. The flow of testing Pocket Home 2.0 was shown in Figure 4.23. First, the researcher explained the context of the study and taught them how to use the Pocket Home 2.0 on an experimental device. Afterward, the researcher showed the participants the virtual meeting room and tell them the roles they should play. To give participants a more immersive role and a clearer goal, the participants were instructed to imagine that they were in an example room at a furniture store. And they were interested in these 3 products and want to see if the products fit their own meeting room. After that, There were three tasks for participants:

- The first task was using Pocket Home 2.0 to experience the chair. Participants were told to find a suitable position for placing the chairs in the virtual meeting room, participants could physically sit on the chair and watch the visual display of sitting on the chair in their own meeting room until they are satisfied.
- The second task was to simulate the TV in the room in their virtual conference room and check the display by activating the video and ruler of the TV. Researchers will

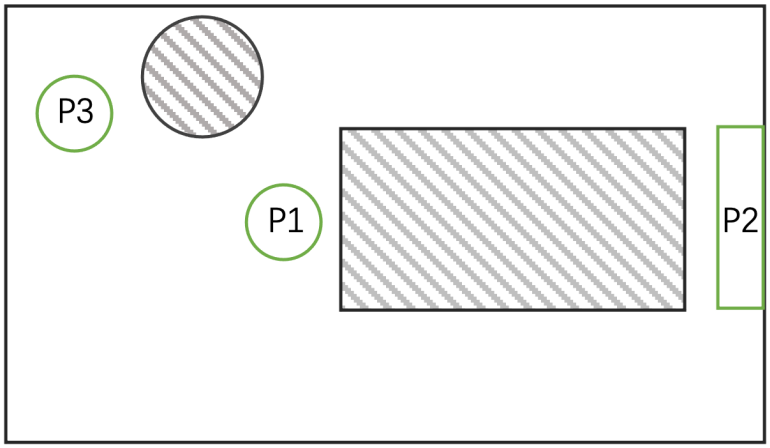


Figure 4.22: The layout of 3 products in the meeting room

manually synchronize the progress of video playback between real-world TV and a digital copy of TV. Participants could turn on the ruler function while the video is playing and walk around in the room (the real and virtual location information is synchronized) to check the performance of display from different positions.

- The third task was testing the function of the fan. The researcher would manually synchronize the real fan's functions and its digital copy's animation, aligning the fan's animation with the real fan's movement. Participants would clearly see in the monitor the extent of realistic wind coverage in the virtual room and will be asked to place the fan in a proper position.

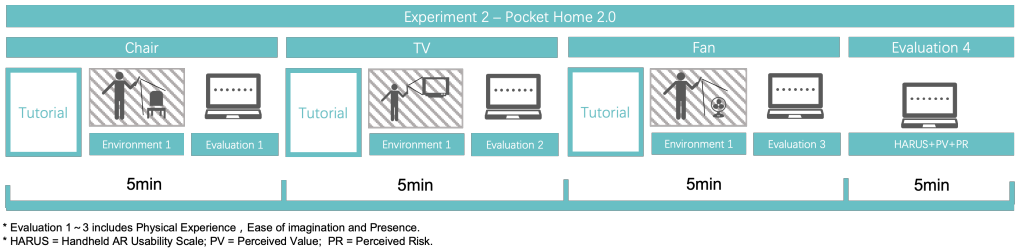


Figure 4.23: The flow of testing Pocket Home 2.0

Each time a product was placed and tried, they were asked to complete a questionnaire to rate their user experience with the following factors: physical experience, ease of imagination, presence. Ease of imagination is the new factor that help to evaluate the feeling of using the product. Once all 3 products had been tested and evaluated, participants were asked to assess the HARUS, perceived value, and perceived risk of Pocket home 2.0 and Pocket Furniture 2.0. All of the questionnaires used in this experiment used 7-point Likert questions (from 1 = Strongly disagree, to 7 = Strongly agree) and the detail of questionnaires was shown in Appendix A.

Tasks of Pocket Furniture 2.0

For testing the Pocket Furniture 2.0, the 3 experimental products were hidden and participants couldn't see or touch the real products. They were instructed to imagine that they wanted to buy and place some new products for this meeting room. First, the researcher explained the use of PF. After that, participants had 2 minutes to familiarize themselves with the meeting room that was treated as their own meeting room. When participants got ready, they were asked to use the Pocket Furniture with the experimental device to place the 3 virtual products (Same digital copies as tests in Pocket Home 2.0) in the real meeting room and adjust them to the position they felt was appropriate. Users can activate the product animation after placing the product to experience the product's functions. The order of tasks was same as the test of Pocket Home 2.0 as well.

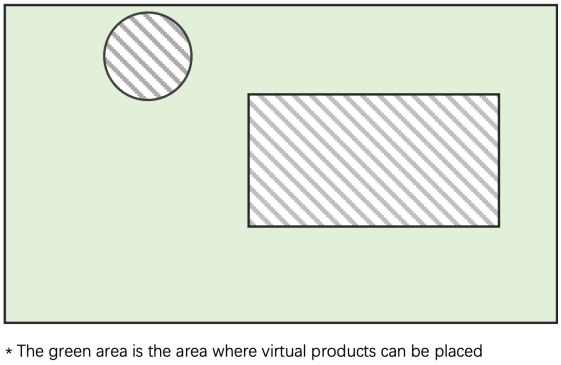


Figure 4.24: The area for placing virtual products in the meeting room

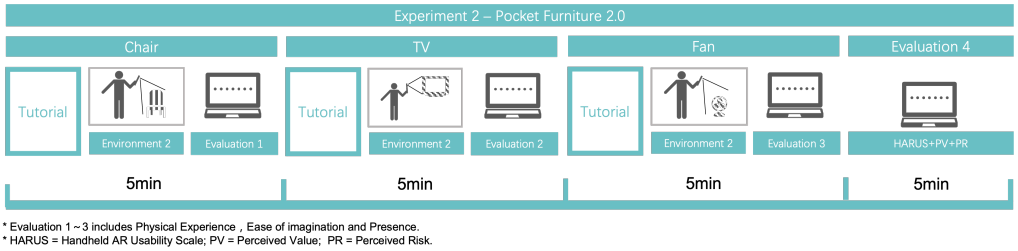


Figure 4.25: The flow of testing Pocket Furniture 2.0

Each time a product was placed and tried, they were asked to complete a questionnaire to assess their user experience (physical experience, ease of imagination, presence). Once all 3 products had been tested and evaluated, participants were asked to assess the HARUS, perceived value, and perceived risk of Pocket furniture 2.0.

Counterbalanced Design

In order to decrease order effects, a counterbalanced design was used in this experiment as well. Half of the participants did the Pocket Home's experiment first, and the others did the Pocket Furniture's experiment first.

Interview

After finishing both of the tests and questionnaire evaluation, an unstructured interview would be conducted. The interview was mainly about the advantages and disadvantages of each of PH and PF, where participants would be asked about their most exciting and upsetting moments during the experiment. Finally, we would collect some suggestions from users for future modifications and upgrades of these two AR applications. The contents of interviews were recorded by the researcher in papers. The structure of Experiment 2 is shown by Figure 4.26.

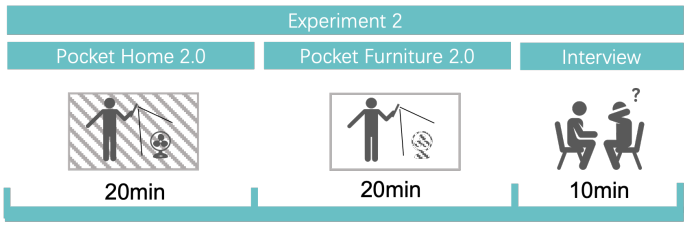


Figure 4.26: The flow of experiment 2

4.2.3 Result of Experiment 2

A Wilcoxon Signed-Rank Test was conducted to find the difference in the cognitive aspect of User experience while participants using different products and effectiveness of design iterations. The results of the questionnaire recorded how participants rated user experience with each product when using the Pocket home 2.0 (PH 2.0) and Pocket Furniture 2.0 (PF 2.0). Figure 4.27 shows the medians and interquartile ranges of the rating of physical experience, ease of imagination,and presence of each product.

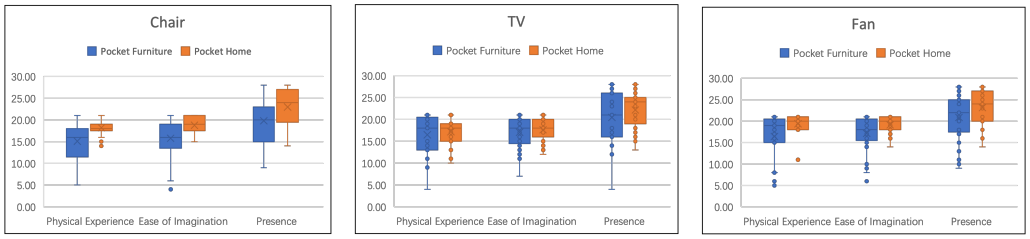


Figure 4.27: Medians and interquartile ranges of physical experience, ease of imagination,and presence's score of each product in experiment 2

About the evaluation of the using Pocket Home 2.0 to test the chair, Table 4.2 shows results of Wilcoxon Signed-Rank Test indicates that the average value of the Physical experience ($M = 5.03$, $SD = 1.50$, $p = 0.001$), Ease of imagination ($p < 0.001$), and Presence ($p = 0.006$) of PH 2.0 are all significantly higher than PF 2.0's score.

About the TV, according to the result shown in Table 4.3 although PH 2.0 got higher mean scores in terms of physical experience and ease of imagination, there is no significant difference was found. But for evaluation of the sense of presence, a significant difference ($p = 0.041$) was found and PH 2.0 has a higher mean score.

Table 4.2: Average ratings and Wilcoxon signed ranks test statistics for testing the Chair in experiment 2

		Physical Experience	Ease of Imagination	Presence
Pocket Furniture		5.03	5.25	4.95
Pocket Home		6.07	6.25	5.74
PH-PF	Z	-3.270^a	-3.737^a	-2.752^a
	Asymp. Sig. (2-tailed)	0.001	0.000	0.006

a. Based on negative ranks.

Table 4.3: Average ratings and Wilcoxon signed ranks test statistics for testing the TV in experiment 2

		Physical Experience	Ease of Imagination	Presence
Pocket Furniture		5.49	5.69	5.11
Pocket Home		5.73	5.88	5.54
PH-PF	Z	-1.092^a	$-.995^a$	-2.042^a
	Asymp. Sig. (2-tailed)	0.275	0.320	0.041

a. Based on negative ranks.

Furthermore, Table 4.4 shows the result of Fan and indicates that the mean value of PH 2.0's physical experience ($p = 0.015$) and ease of imagination ($p = 0.026$) are both significantly higher than PF. But there was no significant difference was found in the evaluation of Presence between the two treatments.

Table 4.4: Average ratings and Wilcoxon signed ranks test statistics for testing the Fan in experiment 2

		Physical Experience	Ease of Imagination	Presence
Pocket Furniture		5.48	5.72	5.22
Pocket Home		6.47	6.37	5.79
PH-PF	Z	-2.436^a	-2.230^a	-1.914^a
	Asymp. Sig. (2-tailed)	0.015	0.026	0.056

a. Based on negative ranks.

After concluding the evaluation of each of the three products, users also evaluated the HARUS, Perceived value, and Perceived risk of using Pocket Home and Pocket Furniture. According to Table 4.5 and Figure 4.28 there was no significant difference of these three evaluations was found between the two treatments.

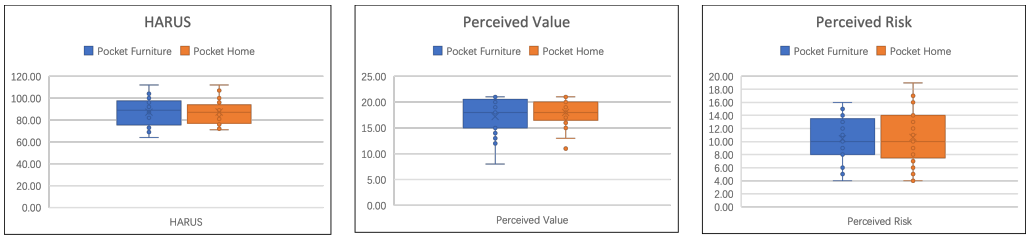


Figure 4.28: Medians and interquartile ranges of rating of HARUS, Perceived value, and Perceived risk in experiment 2

Table 4.5: Average ratings and Wilcoxon signed ranks test statistics for evaluating HARUS, Perceived Value, and Perceived Risk in experiment 2

		HARUS	Perceived Value	Perceived Risk
Pocket Furniture		5.45	5.73	3.48
Pocket Home		5.46	6.00	3.55
PH-PF	Z	$-.016^a$	$-.912^b$	$-.524^b$
	Asymp. Sig. (2-tailed)	0.987	0.362	0.600

a. Based on positive ranks. b. Based on negative ranks.

4.2.4 Discussion of Experiment 2

After being updated from version 1.0, Pocket home 2.0 and Pocket Furniture 2.0 both have been improved with better interaction methods and interactive content. And the validity of the update was shown in the result. By evaluating and analyzing the experience of testing the three products separately, some detailed reasons about how Pocket home benefits users were found.

About the Task of Experiencing the Chair

In the task of placing the chair, the PH showed significantly higher scores in terms of Physical experience, Ease of imagination, and Presence. This is mainly because participants could not only use PH to place the chair in front of them to the position where they want to place it at home, but also sit on the real chair to feel whether the chair is comfortable. What's more, according to the feedback of participants from interview, sitting on the chair with the first-person perspective to feel the environment at home through PH, made participants feel excited and surprised. 8 participants mentioned in interviews that the task of the chair was one of their favorite parts of the experiment. From the phenomenon in the chair task we can learn that users may get a better user experience when the product's founction is relatively simple with some haptic feedback and can be experienced from multiple perspectives.

About the Task of Experiencing the TV

In the evaluation of TV, only the result of Presence showed a significant difference between PH 2.0 and PF 2.0 and PH 2.0 got a higher score of presence. The possible reason is that PH can provide a more realistic sound as well as a display by synchronizing the video with the real TV, thus making the simulated scenes more realistic and reliable. While the TV in PF can also play the same sound through the phone as well as observe the display through the phone screen, these two pieces of information weakened by smartphone's speakers are exactly what users care about when selecting a TV. This weakness of PF 2.0 might cause PF's couldn't give a same sense of presence as PH 2.0 did. However, PH is not significantly different from PF in terms of Physical and Ease of Imagination. This result suggests that for a product such as TV, which focuses on the audiovisual experience, the haptic feedback of the TV is not enough to help participants imagine the use of TV product. Participants may focus more on the digital TV displayed on the screen and ignore the TV in real. That is why PH 2.0 couldn't significantly enhance the visual and auditory performance of the product itself.

About the Task of Experiencing the Fan

The Fan, which provides multiple Interactive function and tactile feedback, are likely to be favored by the participants. 13 (over 50%) of the participants think the fan was the best experience in the test of PH. In terms of evaluation of PE and EOI, PH got a higher score significantly. This result may indicate that visualization of wind can effectively help users to match the haptic sensation given by the real product with the virtual copy of the product, making them feel like they are in a virtual environment and using this product physically. Compared to other products (chairs and TVs) which don't have animation of movement, the swing of the fan leads to both tactile and attractive visual feedback, which may also enhance the user's trust in the PH simulation. In the test of PF, The visualization of airflow provided by the fan was also mentioned as useful by 9 participants. However, the result of the presence evaluation didn't show any difference between the two treatments. This result may be caused by the lack of interaction and feedback between the fan and the virtual environment. When participants testing PH, although they could physically feel the wind, this wind did not bring an impact to the virtual environment. It led users to doubt the realism of this simulated scenario. Similar error exists on PF as well. In PF, although the user can clearly see the range of wind in a real room, the information provided by PF lacks some credibility because there is no real wind blowing on real objects.

About the Usability

The result of HARUS showed there is no significant difference between PH and PF which indicates that the usability of PH 2.0 and PF 2.0 are in same level. From the result of interview, participants mentioned the bad experience of bugs in PH 2.0 and PF 2.0 equally. In PH 2.0, some of participants are meet Model glitch (clipping), which made them feel the scene is unreal. In PF 2.0, the function of ground detection may wrong which affect the size and position of 3D models, was complained by participants for a lot of times. In summary, to keep improving the usability, Pocket Home needs to further improve the realism of the scene and add the hitbox to models; For PF, it needs to further improve the accuracy of environment recognition for display and placement of digital products correctly.

About the Perceived Value and Perceived Risk

Contrary to my expectations, the two prototypes of version 2.0 shows no significant difference in the evaluation of perceived value and perceived risk. Although we upgraded the experimental setup with clearer goals for the participants as well as role setting, there was still no change in the results. So I tried to find the reason from the interview results. Regarding perceived value, users generally believe that both apps have their own usage scenarios that they are good at. PH is more suitable for offline shopping, while PF is suitable for online shopping at home. Since their functions are complementary, their values are not directly comparable. Regarding the risks, users also show two attitudes, with one group of users believing that uploading their room information through PH is a big privacy risk. And the other group of users thinks that taking videos of their rooms in real-time while using PF also poses lots of privacy issues. In summary, although PH and PF can provide similar reference effects to users, because of the different usage scenarios, users will make their own

judgments based on their own needs at the moment (online or offline). In addition, for privacy issues, both apps will involve shooting or obtaining users' personal space information, so we should attention to privacy protection in further development and operation.

Chapter 5

Discussion

In previous sections, the result of experiment 1 and 2 has been discussed.In this chapter, the discussion will focus on the comparison of version 1.0 and version 2.0 to verify the effectiveness of iteration.

5.1 Difference in Result of User Experience Evaluation

In this section, the difference between result of evaluation in experiment 1 and experiment 2 was discussed. According to the scores rating in the two experiments based on physical experience, presence, HARUS, perceived value and perceived value, the conclusions found in the experiments and the issues that need to be fixed were fully discussed.

5.1.1 Comparison in physical experience and presence

In Experiment 1, by analyzing the overall experience of testing six products, I found that the physical experience of PH 1.0 was significantly stronger than that of PF 1.0. However, in Experiment 2, by evaluating the experience of each product separately, we found that the improvement in physical experience did not appear on all products. Only on the test of chair and fan, PH 2.0 can provide better physical experience. Compared to the TV, which does not have haptic feedback, the chair and the fan can give users more haptic feedback to assist them in evaluating the performance and functionality of the product. In the experiment, when participants testing the chair, they usually changed their sitting position to feel the comfort of the chair. When testing the fan, most of them actively followed the direction of the wind to feel the wind. These phenomenon may indicate that participants value the haptic feedback from the product during the test. Overall, the rating of physical experience was determined by the types of products, and the result hints that product with haptic feedback may improve the physical experience of products in Pocket Home.

The rating of presence of PH 1.0 was significant lower than PF 1.0. However, in Experiment 2, the presence score of TV-test of PH 2.0 is higher than PF 2.0. This result may indicate that when interactive with product which can give user audio-visual feedback, it may improve the perception of presence. It might because the sound from a real TV is more realistic than the sound made by smartphone. Besides, observing the real TV in reality and the simulated digital TV synchronously by PH 2.0 also allows users to clearly

know about the display quality of the TV. As a conclusion, we can infer that when testing the products focus on audio-visual experience, Pocket Home can improve better sense of presence by providing realistic display and audio with spatial information.

5.1.2 The similarity in aspects of Handheld AR Usability Scale

In the experiment 2, the result of HARUS showed there is no significant difference between PH 2.0 and PF 2.0, which means the usability of them are at same level. This result was achieved thanks to the upgrades in version 2.0 that made the software interface and operation easier to use and understand. Therefore, The effectiveness of iteration was verified. However, from the interview, some participants still find it's difficult to change the position of the product by moving the scene instead of moving the product directly in PH. The gesture interaction of PH might increase the cognitive load of users. Based on this feedback, I think this is no longer a problem with the control gestures themselves, but with the operation of moving the object. To solve this problem, other operation methods of moving such as teleportation (tapping on the position in the digital room where you wish to place the product and the digital room will teleport directly to the right spot to make the product placed in proper position) may be a better choice and should be tested as an option in the future work. In addition, many participants also mentioned in interviews that they occasionally encountered spatial recognition errors when placing products, which occurred in both of experiment 1 and 2. The possible reason is both of the floor of experiments environment are in single color and lack of easily identifiable detail features. Therefore, for the further experiment, covering a colored carpet on the floor may make the environment more easily recognizable, thus reducing bugs in use. In a conclusion optimizing the parts of the interaction design that conflict with user perception and increasing the accuracy of spatial recognition are the next steps for both apps.

5.1.3 The similarity in aspects of perceived value and perceived risk

The result of evaluation of perceived value and perceived risk in experiment 1 and experiment 2 are similar. Neither of them showed a significant difference. And in the discussion of experiment 2, I mentioned it might because the users prefer to use PH during offline shopping and prefer to use PF during online shopping, so the value they bring to the user is determined by the shopping scenario. Besides, both of them have the step of recording or scanning their personal space, so users are facing same level risk in these two apps. About the possible reason, because no difference in value and risk evaluation was found in either experiment. I suspect that the shopping scenario is not well simulated by the experimental setting. In the experimental setting, even though the participants were asked to play the role of shoppers, the participants did not really want to buy these products. Therefore, when asked what value or risk the two prototypes brought to them, they could not give a clear answer, resulting in similar evaluation for both.

5.2 Improvement from Iterative Design

From the results of two experiments, Pocket Home 2.0's improvement in most of the rating of factors verified that the design iteration after Experiment 1 is effective. First, Pocket Home 2.0 maintains its strengths in physical experience, suggesting that version 2.0 enabled participants to focus not only on visual information but also on multiple modalities through the app's function of enhancing users physically interacting with products. Second, the rating of presence also improved thanks to easier-to-use interaction gestures and more realistic 3D models. In addition, Pocket Home 2.0's strength in Ease of imagination can be attributed to well-matched product animations, which helped users understand the product's functionality in an intuitive way. Finally, the improvement in handheld AR usability could be attributed to the use of dragging gestures. Overall, this design iteration effectively improves Pocket Home's user experience and can be used as a guide for designing similar AR software in the future.

Chapter 6

Conclusion and Future Work

6.1 Conclusion

Augmented reality, as a popular interactive technologyprovides consumers with highly interactive and vivid contextual information via virtual try-on tools for online shopping [9]. However, in offline shopping, customers don't have an intuitive way to visualize how they would use or place a product they like at home when they see the product in real. To benefit users with a more convenient, intuitive, and consistent shopping experience, this study focuses on developing an application on a smartphone to simulate the digital environment around the real product in an offline store, which allows users to place the real product into the digital environment (their room) while experience the product physically.

In the study, a prototype application (Pocket Home) that achieved the research's objective was created. It went through one round of iterations and two experimental tests. Another prototype, Pocket Furniture, as a control group's prototype application that can place virtual products in the physical world, was created and tested as a competitor to Pocket Home. After two rounds of experiments comparing the user experience of Pocket Home and Pocket Furniture, the following results and conclusions were obtained from this study.

6.1.1 The Effective Iterative Approach for Pocket Home

Through the comparison of Experiment 1, I promptly found out the problems of Pocket Home in terms of unrealistic contents, lack of affordance, and non-intuitive gesture interaction. After iteration, Pocket Home's evaluation of usability and sense of presence in Experiment 2 was improved, which proved the iteration is effective. Therefore, this iteration methods can be used as a guide for designing the same type of software interactions. The detail of iteration and its effect are listed as follows:

1) Improving the realism of 3D models (both products and environment) by manually modeling to obtain a more detailed and beautiful 3D model than the one obtained by the 3D scanner app. The increase in realism may have a positive impact on the user's sense of presence.

2) Matching the functions of a real product with its digital copy by adding animation to its digital copy(3D model). This improvement effectively helps to increase the interactivity

of products and the user to perceive the product's digital copy displayed on the screen as products that physically exist in reality.

3) To optimize the interaction gestures, a drag-to-move gesture replaced the old gesture, which becomes helpful when moving large objects (digital room) in Pocket Home in a more intuitive and easy way. Users are able to adapt to move a virtual room around themselves and adjust the placement of products precisely

The content of these proven effective iterations can serve as a great reference for further research and improvement of this project in the future. Figure 6.1 shows the diagram about how the iterative design improved the user experience.

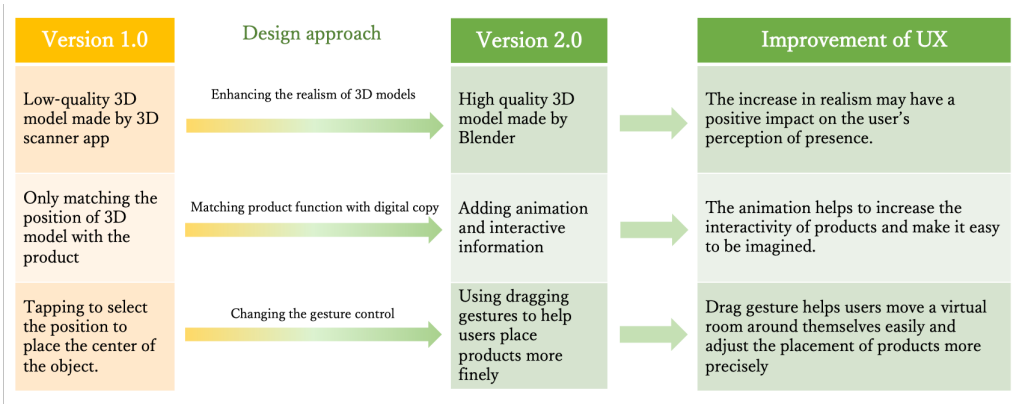


Figure 6.1: The effective design approaches

6.1.2 Findings on Cognitive Aspects

In the experiment, by evaluating the user experience in aspects of physical experience, ease of imagination, presence, a series of conclusions about how users perceive the use of Pocket Home and Pocket Furniture were learned. Besides, the result of perceived valueperceived risk about how users value the two types of AR applications and what kind of privacy concerns did they have were also discussed. Conclusions obtained are as follows.

1) Products which give users haptic feedback, can have good performance in aspects of physical experience and ease of imagination when tested by Pocket Home.

2) However, when haptic feedback focuses the user's attention on the product itself, it may reduce the sense of presence of the virtual environment.

3) Lack of interactivity between the product and the environment can lead users to distrust the authenticity of the scenario.

4) Products that focus on the audio-visual experience can be better integrated with the virtual space. It can give users a stronger sense of presence and realistic information of products with Pocket Furniture.

5) The ability to experience the product from multiple perspectives (e.g., from third-person to first-person) when using Pocket Home may be key to improve the user experience, especially in aspects of physical experience and imagination of use.

6) Users prefer to use Pocket Home for offline shopping and use Pocket Furniture for online shopping. Therefore, users' value judgment of these two types of AR app will change depending on the usage scenario.

7) Both types of products face privacy issues: Pocket home requires uploading the user's private room data before use, while Pocket furniture requires real-time video recording while in use. Therefore, the privacy issue cannot be ignored in the next development and application in the market and we to find a reasonable strategy to protect user privacy.

The correspondence of these conclusions with the discussion in the previous sections is shown in Figure 6.2.

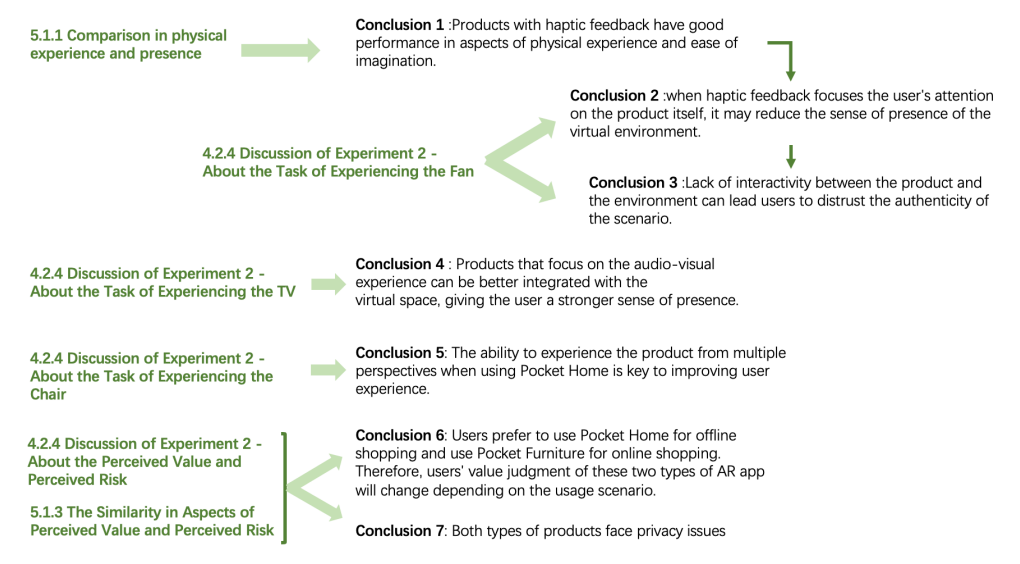


Figure 6.2: the connections between discussion and conclusions

6.2 Limitation

There are some limitations to this study. First, the experiments in this study were conducted in an experimental environment. Therefore, the participant needed to play the role that was set in the experiments and complete the tasks through empathy. The data from participants may not be exactly the same as the real customer in the shopping place. This limits us to get real feedback from the customers (online shopping or offline shopping). Second, the experimental device used in this study was a smartphone. It was selected because smartphones are the most popular smart devices that can provide AR functions for general users. The participants were able to use smartphones skillfully to complete the experiment. However, the size of the smartphone may not fully support the display of the virtual environment and influence immersion. In addition, the 3D model in Experiment 2 was created using Blender. It has more detail and is easy to make interactive animations. But, it gives users a more digital feeling when compared with models in Experiment 1 which had realistic texture. This may affect the user's sense of immersion as well as presence.

6.3 Future Work

6.3.1 Updates of Pocket Home

For Pocket Home, firstly, we can further improve the quality and interactivity of the product and environment modeling and the matching of the animation to the product through the experience of previous iterations. Secondly, through the discussion of the results and the analysis of the interview transcripts, I think the following features can be expanded for Pocket Home in the future.

1) Add a function of 3D scanner to Pocket Home to help users get 3D models of products and rooms easily and quickly. And the 3D scanner function should be able to provide better high-quality 3D models

2) Some users want to have the freedom to switch between the room model preview view and the first-person experience view when experimenting with Pocket Home. This would help users to plan their own room design.

3) Since real customers tend not to pick just one product when shopping offline, Pocket Home could support multiple products in the scene at the same time in a future version.

4) Pocket home can be transformed to an application for HMD devices in the future. This will bring better simulation to Pocket home and free up the user's hands for more physical interaction chances.

6.3.2 Updates of Experiments

For the experiments in the study, the next phase is to test it in a real shopping environment to get feedback from real customers. This will greatly increase the credibility of the data. In addition to this, more types of products should be included in the collection of products in Pocket Home/Pocket Furniture, and after testing a large enough number of products, categorize the products according to the feedback from the user experience. The proper products should be summarized as a list and contribute to the marketability of Pocket Home. What's more, when people go shopping, they usually not only buy products for one room but for multiple rooms. So in the next experiment, the prototypes can be tested multiple rooms with different interior design goals, which may lead to different user experiences.

6.3.3 Imagination of future application

In this study, I focus on some common furniture and products used in the home or workplace. One commonality of these products is that the placement is based on the horizontal plane. Therefore, when using AR technology to recognize products, the information and digital content can be displayed more accurately. But in the future I will make Pocket Home support more products. Through my experiments, I learned that products with haptic feedback are better suited to be experienced with Pocket Home. According to this conclusion, things like bedding, fitness products, clothing, etc. could be added to the Pocket Home support list in further version. These products are more frequently purchased and have more physical feedback which may leads to better shopping experience.

In addition to update the digital contents of Pocket Home, We can do more with Pocket Home in the future. Pocket Home was designed to help users focus on the product itself and the future scenario of using the product. Unlike AR technology that adds more information to the real world, Pocket Home uses AR technology to block out ineffective information in the shopping scenario, helping users focus on the information they more care about: the performance of product and the scenario where they are going to use it. The future I'm picturing is a world that everyone can take the real thing into the virtual world. With Pocket Home, people are not limited by the spatial constraints of the reality or by the lack of sensory feedback in the virtual world. They can experience the sensory stimulation of interacting with real objects, but also enjoy the freedom of switching between virtual environments. The Pocket Home is the first step, and the experience of developing and testing it can be a great reference of designing the type of mobile AR application which combines digital environment with real products.

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Appendix A

Measures of Evaluating User Experience

1. **Physical experience** [18]
   1) I can have physical experience while using the application.
   2) I can confirm the quality and performance of products.
   3) I can try the product to see whether meeting my needs and expectations or not.
2. **Ease of imagination** [28]
   1) It is easy for me to imagine how the product would be.
   2) It is easy for me to picture myself using the product.
   3) it is easy for me to picture myself enjoying the product.
3. **Presence** [28]
   1) In the application, I had a sense of "being there".
   2) During the time of the experience, I often thought that I was actually in the virtual world.
   3) There were times during the experience when I felt that the virtual world became my reality.
   4) During the experience, I often thought that I was really standing in the virtual world.
4. **Handheld Augmented Reality Usability Scale** [15]
   1) I think that interacting with this application requires a lot of body muscle effort.
   2) I felt that using the application was comfortable for my arms and hands.
   3) I found the device difficult to hold while operating the application.
   4) I found it easy to input information through the application.
   5) I felt that my arm or hand became tired after using the application.
   6) I think the application is easy to control.
   7) I felt that I was losing grip and dropping the device at some point.

8) I think the operation of this application is simple and uncomplicated.
9) I think that interacting with this application requires a lot of mental effort.
10) I thought the amount of information displayed on screen was appropriate.
11) I thought that the information displayed on screen was difficult to read.
12) I felt that the information display was responding fast enough.
13) I thought that the information displayed on screen was confusing.
14) I thought the words and symbols on screen were easy to read.
15) I felt that the display was flickering too much.
16) I thought that the information displayed on screen was consistent.

5. **Perceived Value** [18]
   1) The time I spent for using this application is worthwhile to me.
   2) The effort I spent for using this application is worthwhile to me.
   3) Overall, the application delivers better value into my shopping experience.
6. **Perceived Risk** [18]
   1) The products or services purchased via the application are riskier in quality, size, performance, and genuineness than other methods of shopping.
   2) Privacy information may more easily be exposed to the use of the application comparing with other shopping ways, such as personal information, sensitive information, and so on.
   3) Overall, I can feel risk if I use this app to shopping products for my personal space.

Appendix B

The Result of Evaluation

The Result of Evaluation

1. Questionnaire results of Physical Experience, Ease of Imagination and Presence

	7-points Likert Scale[1]						
	Strongly disagree	Disagree	Somewhat disagree	Neither agree nor disagree	Somewhat agree	Agree	Strongly agree
Physical Experience							
I can have physical experience while using the application.	0/0/0; 1/1/2	0/0/0; 2/0/3	0/0/0: 3/1/0	0/2/1; 0/3/0	6/8/0; 6/5/3	11/10/10 : 8/5/7	8/5/14; 5/10/10
I can confirm the quality and performance of products.	0/0/1; 2/1/1	0/1/0; 2/1/2	0/2/0; 2/4/2	1/1/0; 2/4/0	5/4/0; 6/2/4	13/7/9; 9/6/7	6/10/15; 2/7/9
I can try the product to see whether meeting my needs and expectations or not.	0/0/0; 0/0/0	0/0/0; 1/1/2	0/1/0; 3/2/2	1/2/1; 2/0/1	2/7/1; 5/6/4	14/8/9; 10/5/6	8/7/14; 4/11/10
Ease of Imagination							
It is easy for me to imagine how the product would be.	0/0/0; 1/0/0	0/0/0; 0/1/0	0/0/0; 1/0/2	0/1/1; 0/1/1	3/4/1; 3/6/5	9/12/10; 12/10/9	13/8/13; 8/7/8
It is easy for me to picture myself using the product.	0/0/0; 0/0/0	0/0/0; 2/0/1	0/0/0; 3/2/3	0/1/0; 0/2/0	1/6/2; 7/3/3	13/11/8; 9/10/7	11/7/15; 4/8/11
It is easy for me to picture myself enjoying the product.	0/0/0; 2/0/1	0/1/0; 4/1/3	0/1/0; 1/3/0	4/2/1; 2/1/1	2/4/4; 5/6/1	10/12/9; 6/6/10	9/5/11; 5/8/9
Presence							
In the application, I had a sense of "being there".	0/0/0; 0/1/0	0/0/0; 0/0/1	0/0/0; 2/2/2	0/2/1; 3/2/0	5/7/4; 5/4/4	8/10/10; 7/9/12	12/6/10; 8/7/6
During the time of the experience, I often thought that I was actually in the virtual world.	0/1/0; 1/1/0	0/0/0; 3/1/3	1/2/4; 3/4/1	2/4/0; 2/5/2	8/4/7; 10/4/7	7/6/7; 2/6/7	7/8/7; 4/4/5
There were times during the experience when I felt that the virtual world became my reality.	1/0/1; 2/2/1	1/0/0; 1/0/2	1/3/2; 3/2/2	2/1/0; 0/3/1	7/8/8; 10/7/9	5/9/7; 5/4/5	8/4/7; 4/7/5
During the experience, I often thought that I was really standing in the virtual world.	0/0/0; 1/2/0	0/0/0; 3/0/2	1/1/1; 2/3/4	5/3/1; 3/3/2	4/6/6; 7/4/6	8/11/7; 4/8/5	7/4/10; 5/5/6

[1]PH-Chair/PH-TV/PH-Fan;
PF-Chair/PF-TV/PF-Fan. Unit : frequency
(PH = Pocket Home ; PF = Pocket Furniture)

2. Questionnaire results of Handheld AR Usability Test, Perceived Value, and Perceived Risk.

	7-points Likert Scale[2]						
	Strongly disagree	Disagree	Somewhat disagree	Neither agree nor disagree	Somewhat agree	Agree	Strongly agree
Handheld Augmented Reality Usability Scale							
I think that interacting with this application requires a lot of body muscle effort.	3(5)	10(14)	8(1)	1(0)	2(3)	1(2)	0(0)
I felt that using the application was comfortable for my arms and hands.	0(0)	0(1)	0(1)	3(4)	10(2)	7(15)	5(2)
I found the device difficult to hold while operating the application.	5(4)	10(13)	4(0)	5(3)	0(4)	1(1)	0(0)
I found it easy to input information through the application.	0(0)	1(1)	2(0)	2(1)	5(7)	12(13)	3(3)
I felt that my arm or hand became tired after using the application.	7(8)	10(13)	3(0)	3(1)	2(2)	0(1)	0(0)
I think the application is easy to control.	0(0)	0(0)	3(2)	0(3)	7(5)	10(10)	5(5)
I felt that I was losing grip and dropping the device at some point.	7(7)	5(7)	7(1)	5(8)	1(2)	0(0)	0(0)
I think the operation of this application is simple and uncomplicated.	0(1)	0(0)	1(1)	2(4)	4(4)	14(9)	4(6)
I think that interacting with this application requires a lot of mental effort.	3(4)	9(10)	3(2)	7(5)	3(4)	0(0)	0(0)
I thought the amount of information displayed on screen was appropriate.	0(1)	2(3)	1(2)	3(2)	8(7)	8(7)	3(3)
I thought that the information displayed on screen was difficult to read.	5(6)	13(11)	6(5)	0(2)	1(1)	0(0)	0(0)
I felt that the information display was responding fast enough.	0(0)	1(0)	1(1)	2(2)	11(7)	7(11)	3(4)
I thought that the information displayed on screen was confusing.	4(6)	10(9)	5(5)	3(3)	2(1)	1(1)	0(0)
I thought the words and symbols on screen were easy to read.	0(0)	0(0)	1(1)	3(1)	4(6)	10(11)	7(6)

I felt that the display was flickering too much.	7(9)	5(5)	6(6)	5(2)	2(1)	0(2)	0(0)
I thought that the information displayed on screen was consistent.	0(0)	0(2)	2(1)	3(2)	7(11)	10(6)	3(3)
Perceived Value							
The time I spent for using this application is worthwhile to me.	0(0)	0(0)	0(1)	2(3)	5(5)	10(9)	8(7)
The effort I spent for using this application is worthwhile to me.	0(0)	0(0)	1(2)	1(2)	5(6)	12(9)	6(6)
Overall, the application delivers better value into my shopping experience.	0(0)	0(1)	0(0)	1(1)	5(7)	7(6)	12(10)
Perceived Risk							
The products or services purchased via the application are riskier in quality, size, performance, and genuineness than other methods of shopping.	2(2)	8(8)	5(3)	2(5)	6(6)	2(0)	0(1)
Privacy information may more easily be exposed to the use of the application comparing with other shopping ways, such as personal information, sensitive information, and so on.	3(3)	4(6)	3(3)	3(3)	4(6)	8(3)	0(1)
Overall, I can feel risk if I use this app to shopping products for my personal space.	4(4)	6(7)	5(3)	3(2)	4(5)	1(2)	2(2)

[2]Pocket Home (Pocket Furniture). Unit: frequency

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