CAKE VR

Design a socialVR tool for remote co-design of customized cakes

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Design a socialVR tool for remote codesign of customized cakes.

Mater thesis

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Enjoy reading!

Summary

Nowadays, co-design is progressively popular in the area of customized retail services. Co-design involves users and potential customers into the whole process of product design, from ideation to final design, and thus, has a great potential in offering a personalized customer experience based on the individual needs and behaviors. However, usually co-design requires face-to-face communication, which might be difficult especially in the current corona time. Additionally, it is a challenge for the customer, the non-expert designer to equally collaborate with professional designers. Therefore, a tool is needed to support remote co-design actions and empower the non-expert users for an equal cooperation with designers.

We propose that socialVR, an emerging mediated social interaction technology in the medium of Virtual Reality, has a potential in supporting remote and interactive co-design activities. Social VR technology enables users in different locations to interact with virtual avatars of other users in a collaborative Virtual Environment. Additionally, socialVR allows users to communicate with each other through diverse communication cues (i.e., 3d visual, audio, haptic), and hence, supports intricate social and physical interactions in co-design.

In this project, we aim to explore how socialVR can facilitate co-design, and understand how socialVR influences people's experience and behavior in remote collaborative design tasks. To find out the answers, we follow a research-through-design methodology. Firstly, we choose a specific use case of collaborative cake-making between cake-makers and clients for the purpose of customized retail. Then, based on the current interaction between baker and clients, we designed and developed a medium-fidelity VR prototype, which allows two users collaboratively design cakes in VE wearing head-mounted displays (HMDs). After that, we performed a VR test for user evaluation, so as to investigate the impacts of socialVR on social and collaborative behavior, as well as validate the functionality and interaction techniques of this prototype. The results offer abundant insights for us to understand how design non-experts experience interacting with professional designers and design systems in socialVR, and how their experience influences their behavior.

Table of Content

1. Literature Review

This part starts from the introduction of co-design in the field of product design. The basic methodology of co-design and the challenge of customers transforming into co-designers will be elaborated. After that, the use case, co-design in customized cake making, will be described. Finally, the current state of socialVR, as well as its application in supporting remote collaboration and design tools will be explained. This part gives a common ground understanding of the possibilities and challenges of applying socialVR to supporting co-design in the specific context of co-designing customized cakes.

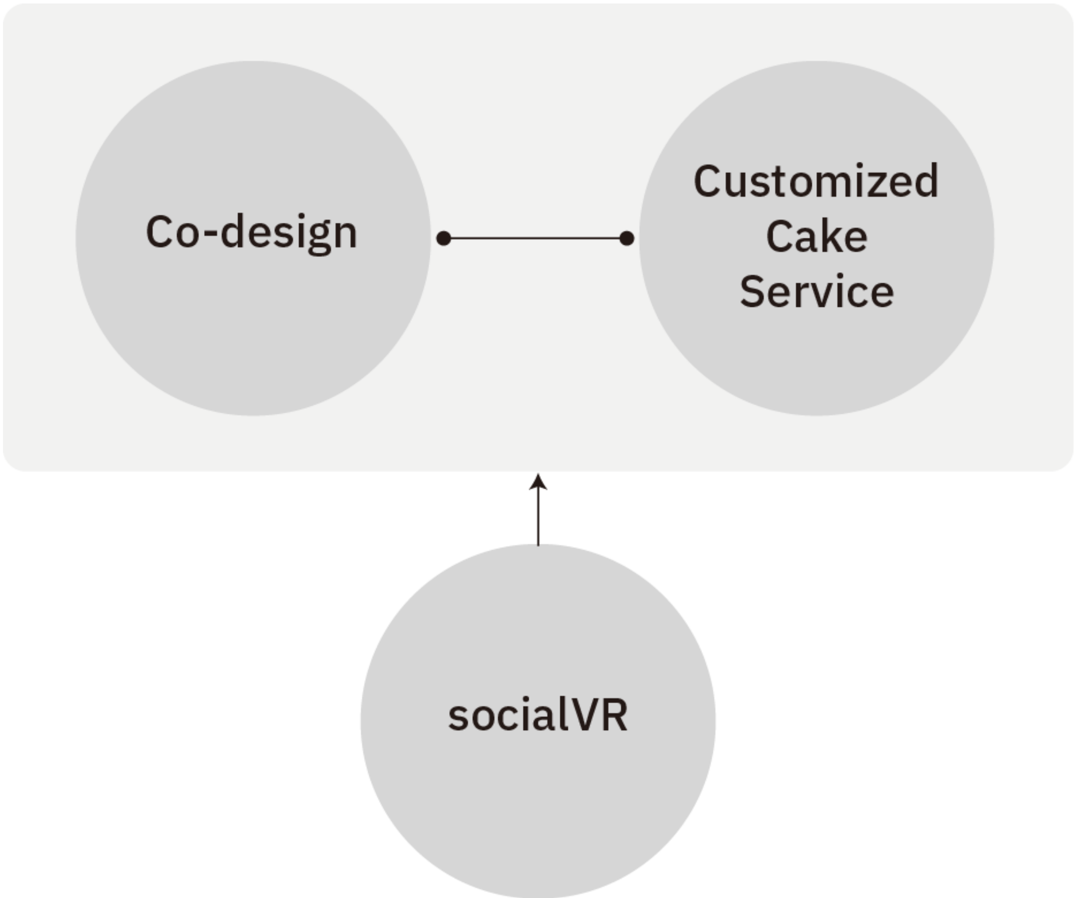


Figure 1. Scope of this project

1.1 Customers as co-designers

1.1.1 Co-design: what & why

Design is an activity undertaken by all humans instead of people who call themselves designers [1,2]. This principle is proved to be effective and pervasive in the domain of product design. Nowadays, consumers are involved in the design process and final decision-making of product development. This idea is endorsed as a powerful new tool for product promotion and innovation [3]. The traditional consumer-supplier idea that a product is fully defined by designers, standardized by manufacturer, and then purchased by consumers, is not the only valid model nowadays [4]. Instead, consumers are now empowered to adapt and modify the products by expressing their own preferences (i.e., form, usage, personal experience) of a product, even though they are not professionally trained in the design domain [5].

In this way, the front-end design process is more efficient in identifying consumers' needs from consumers' point of view [6], and the design outcome is more likely to achieve higher user satisfaction, since users are the "expert of their own experience" [7]. Trischler et al. had conducted an empirical study on comparing the design outcome of a team solely made up of designers and another team including both users and designers. The results indicated that the concept generated by the second team which involved end-users achieved a much higher score in user benefit and novelty [8]. Therefore, the design outcome is more likely to fit users' needs and behaviour, with consumer participation in the design process.

1. 1. 2. Methodology and theory of co-design

Consumer participation in product development has shifted the consumers' role from "passive consumers" to "proactive producers" [9]. However, designing a product is not merely finished by consumers themselves, this process is usually facilitated and supported by professional designers. Customers collaborate with professional designers to explore the best solution for a product. This practice is defined as "co-design". Stappers and Sanders defined "co-design" as a form of collective creativity that is based on the assumption that all people can be creative [7]. According to Prahalad et al., co-design is a business strategy whereby the value of a product is created by consumers together with designers [10].

In co-design, the roles and tasks of consumers and designers change. "Co-design" requires that the professional designers should have a "design-with" mindset [11], perceiving end-users as partners or collaborators, instead of the conventional restrictive roles such as clients or consumers. Hence, customers transform into "co-designers", who bring with them their tacit and contextual knowledge to help reshape the design towards the most meaningful solution in a collaborative environment [12]. In addition, designers' task is totally different from the traditional narrow idea which is "helping to give form and order to the amenities of life" [13]. Besides working on design outcomes, their focus extends to creating a collaborative design process for the co-designers. They are redefined as "facilitators", who characterize activities, processes, and objectives in design practices, so as to build creative environments that allow users to act as designers and be creative [14]. Equipped with their expertise in design and research, they sensitize the end-users [7] and convert promising new ideas into viable concepts [8].

One of the most commonly used methods in co-design activities is ContextMapping. ContextMapping is defined as "mapping the dynamic factors that influence users' interaction with products" [52]. With this technique, designers and researchers are able to uncover tacit knowledge and latent needs which cannot be discovered with conventional user study techniques such as interviews and observations. The basic principle of this technique is to let people make designerly artefacts (i.e. collage, drawing, physical models) related to a specific context and then tell a story about what they have made [52], under the proper guidance and facilitation of designers or researchers. These actions enable participants to build up context awareness and share the contextual knowledge by storytelling. The outcome of ContextMapping is a bunch of topic-related stories and anecdotes told by the participants. Such qualitative data is diverse and inspiring, but fragmentary and multi-layered. So it needs to be reorganized by researchers and designers. Audio records of stories are transcribed and the most inspiring and topic-related quotes are selected. After the data is distilled, a context overview is created by categorizing these quotes based on their topics and exploring the patterns. This overview offers rich contextual information to the design team to develop design concepts in the following design process.

To summarize, ContextMapping enables a design team to combine two sets of knowledge: customer insights into latent user needs and designers' expertise in design, creative facilitation [33] and user research. This principle also works in other co-design methods [8]. Therefore, co-design activity can be defined as an interactive process of learning together [15], in which co-designers and facilitators exchange and integrate their knowledge for a common design goal: the product to be designed [16].

1.1.3. Challenge of Co-design

As mentioned above, co-design resembles a collaborative learning process including extensive knowledge exchange and social interaction. Thus, co-design is still confronted with several challenges regarding social interaction and communication between designers and customers.

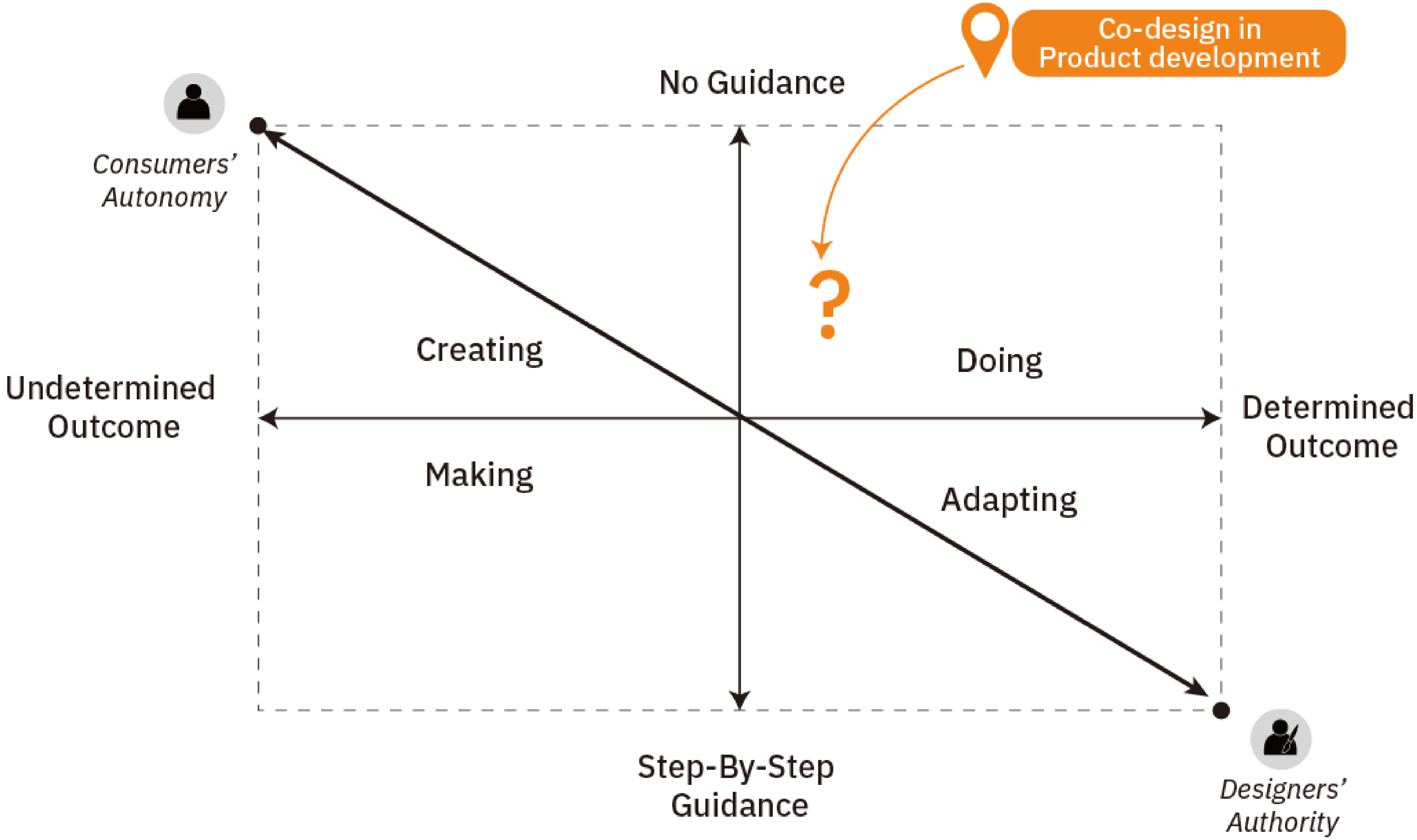


Figure2.The design-space model. Adapted from Dahl & Moreau, 2007 & Stappers & Sanders (2008)

First, a metric is needed to deal with the trade-offs between designers' authority and customers' autonomy in a collaborative design process. (Figure 1) Even though the co-design practice is expected to be an equal collaboration in which all the participants share equivalent agency, there is still a tension between customers and designers, because they have different backgrounds, interests and perspectives on the design practices [17,18], as well as the methods and techniques they are able to utilize [19]. This tension is perceived as the the balance between freedom of co-designers and constraints set by designers in a creative task. The level of constraint is determined by two factors: (1) the extent to which a target outcome is dictated and (2) the amount of instruction or direction available [5]. These two factors are determined by designers, and in this way, designers create a "design space", which includes all the imaginable and viable design solutions [5]. These two factors serve as a "boundary" of the "design space". Ideally, customers are expected to actively self-explore product solutions inside a "design space", without sacrificing a structured design process and viability of the design outcome. A properly-confined "design space" is significant because customers value constraints in the design process [20]. However, if the designers delineate the "design space" strictly, they might let their own ambitions and ideas drive the final outcome. This has a big impact on customers' motivation and experience of creative practices. According to Dahl and Moreau, autonomy and competence are the most significant motivations for consumers to undertake creative tasks [20]. Competence means anticipated satisfaction derived from completing a creative task successfully, while autonomy is the enjoyment stemming from the flexibility to choose and modify the design process as well as the creative outcome [20]. Competence and autonomy work together to create an overall sense of personal achievement and creative experience. However, in a creative context, factors that are designed to boost perceptions of competence (i.e., instructions on material selection given by designers) may ironically decline feelings of autonomy (i.e., freedom to change the material of products for aesthetics) [20]. Therefore, more research is needed in exploring the balance between the agency of designers and customers in the design process, so as to achieve the optimal combination of competence and autonomy for the best customers' creative experience. Figure 1 indicates a design space model, a two-dimensional coordinate system with the variables of outcome and guidance. All kinds of creative practices can be defined in this model regarding to what extent the design process is guided and the design outcome is flexible. The main question about co-design is : Where is "co-design" supposed to be placed in this coordinate system? To what extent the consumers' autonomy and designers' authority need to be achieved?

Second, a tool for remote co-design is needed, to support tacit communication in co-design. There is an increasing need for remote cooperation between geographically separated collaborators, due to the growing globalization, complexity and mobility of the current world. Likewise, tools for remote co-design are necessary, due to a wider range of stakeholders involved [21]. However, according to Stappers, collective creativity is best in face-to-face interaction [7]. Co-design is perceived to be "a process of investigating, understanding, reflecting upon, establishing, developing, and supporting mutual learning between multiple participants in collective 'reflection-inaction'" [22]. Hence, co-design activity includes complicated information exchange and cooperative practices, which require considerable tacit communication. Tacit communication includes nonverbal cues such as body gesture, facial expression, eye contact and voice quality [23]. These cues are essential in collaborative interaction and help to build the shared contexts for all the collaborators [24]. For example, in co-design activities, participants usually utilize role-play to agilely establish a shared understanding of a design concept [7]. In addition, in co-design activities, these cues are useful data for researchers to investigate the tacit and latent knowledge of users needs, which are not recognized by users themselves and hard to be expressed in words. Tacit communication is prevalent in real world interaction when people are physically collocated. Due to its reliance on tacit communication, co-design mostly requires participants to be physically collocated. However, it might be challenging to support tacit communication in current social media products (i.e., Skype, whatsapp) because such communication is highly context-related and too subtle to be explicitly encoded like the language system [23]. It is a challenge to enable geographically separated users to encode and decode nonverbal messages in a natural way while cooperatively undertaking creative tasks.

Co-design is defined as a team-based process in which consumers and designers contribute to the design process and content with shared knowledge [16,25]. It requires physical co-presence of participants, as well as the agency balance between designers and customers (Figure 3). These bring challenges for remote co-design with growing complexity. Recently, social virtual reality (socialVR), an emerging social interaction technology mediated by immersive media, is creating new possibilities. This new technology enables people in different locations to "meet" in a shared virtual world and interact with each other. It is believed to be able to bridge the gap between mediated social interaction and face-to-face interaction [26], and support more sophisticated social interaction in co-design.

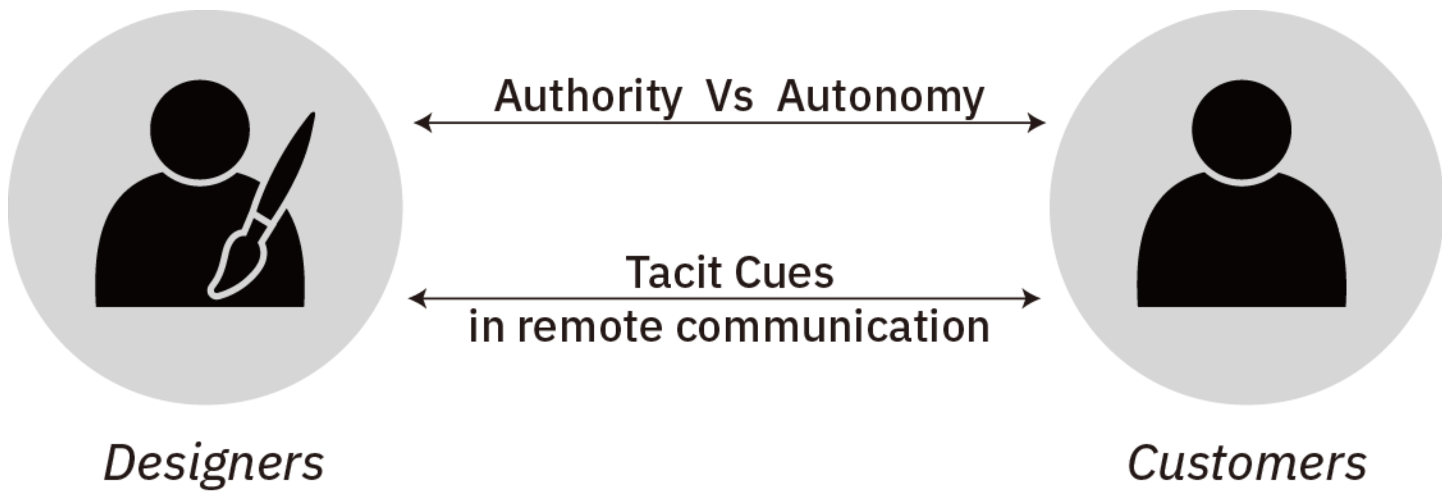


Figure3. Challenges of co-design in designer-customer communication

1.1.4 Customized Cake: beyond a piece of cake

Mass customization

In this project, the application of socialVR in supporting co-design activities will be explored in a specific use case: co-design of the customized cakes, between a cake maker and a client . This use case is embedded in the concept “mass customization”, which means that customers actively configure a product to meet individual needs. The term “Mass customization” had been first coined in the book Future Perfect by Stan Davis (1987, p. 272). Even though this concept has existed for more than three decades, it is indicated that consumers are far from being a “very creative consumer” [51] and customer integration is insufficient in customization [34]. Most consumers are still buying made-to-order products manufactured in a mass production system [34], and seldom spend spare time in personalizing their unique products. Ideally, in mass customization, customers are integrated in the process of value creation by defining and modifying their personal solutions out of predesigned components and inspiring tools offered by designers. Therefore, co-design practices, performed in the form of knowledge exchange and integration between designers and customers, are the necessary prerequisite of mass customization [34].

Customized food: I create what I eat

The trend of mass customization influences the food industry, and promotes popularity of customized food products. Customized food service enables people to personalize the food in shape, color, flavor, texture and even nutrition, by means of social media technology, 3D food printing technology and digital gastronomy technique [44]. People expect customization in food because their food choices can be quite personalized and diverse. Previous research indicated that the food choice process model is made up of sensory perceptions, monetary considerations, health and nutrition beliefs and concerns, convenience, social relationships and quality of food [45]. These factors vary a lot from person to person. Therefore, food customization service is so popular because it can deliver food with sufficient variety and personalization which people find almost exactly what they want [46].

No celebration without a cake

Cake is a sort of baked food which is usually served on celebratory occasions, such as weddings, anniversaries and birthdays. The cake conveys two layers of meaning: edible art and ceremonial symbolism. Certainly, cake is an edible confection with gustatory and nutritional functions. A well-decorated and sculpted cake is perceived to be a form of edible three-dimensional art. Mary Douglas had compared baking to architecture and photography as a genre of applied art [50]. However, the purpose of serving a cake in an event is not only for eating or viewing, but, more significantly, “marking an event at which it appears as a memorial and special happening” [47]. In this sense, the function of cakes goes beyond an edible decoration, to a symbolic artifact of a monumental occasion. Although food cultures vary in different countries, it is true that, in most countries, the cake plays a vital role in events marking the progress of time or the transition from one stage to another [48]. Since there is a strong association between celebration culture and cakes, the meaning of “cake” is extended to social relations, emotions, social structures and behaviours [49]. A lot of social practices emerge during cake eating and sharing in a specific event, in this way, participants collaboratively construct a unique meaning around that event, for the purpose of leaving an unforgettable memory or creating a ceremonial atmosphere. For example, it is a typical cake-related social practice, for brides and grooms to cut wedding cakes together at their wedding ceremonies. This ritual stands for their mutual support in future life. In summary, the meaning of cake has been no longer limited to the narrow scope of food, cakes are firmly associated with enriched social meaning and social practices.

Customized cake services

As mentioned above, cake is both food and art, with strong social meaning underlying that. Therefore, when designing a cake, a cake maker should not only take aesthetic and gustatory elements into account, but also consider the social meaning, context of the event, emotion and food practice related to this cake. The good thing is that, cake design is not the exclusive work of cake makers or bakers, more and more people participate in the design process for a unique cake, with the growing popularity of customized cake services. Nowadays, there is a growing market for customized cake products, most of which are usually designed and made by trained food artists [44]. Usually, people can personalize their unique cakes by expressing their preference in flavor, mouthfeel, material, size and aesthetic styles to cake makers. Currently, most customized cake services mainly focus on the flavor and appearance of cakes. Thus, it is meaningful to consider the “cake context” (the scenario in which the clients will enjoy the cake) and convert this element into feasible cake design concepts. This idea has the potential in adding value to current customized cake service and improving food experience.

Currently there are some digital cake customization services. Havi Proprel Cake Configurator (Figure 4) is a web-based tool offered by a bakery, for customers to configure the cake based on their preferences [59]. It provides step-by-step guidance for clients to personalize each component of the cake, from the cake body, filling, side icing, top decoration, printed text and size. Then the final price can be automatically calculated based on customers’ choices. When customers do any operation on cake configuration, the altered outcome is immediately presented to users in 3D renderings. The rendering shows the color and composition of cake, but without cake texture and scale. People customize their cakes with limited options, most of which are the preset elements made by cake makers in advance. This might restrict customers’ creativity in exploring, expressing and embodying their ideas when customizing the cakes.

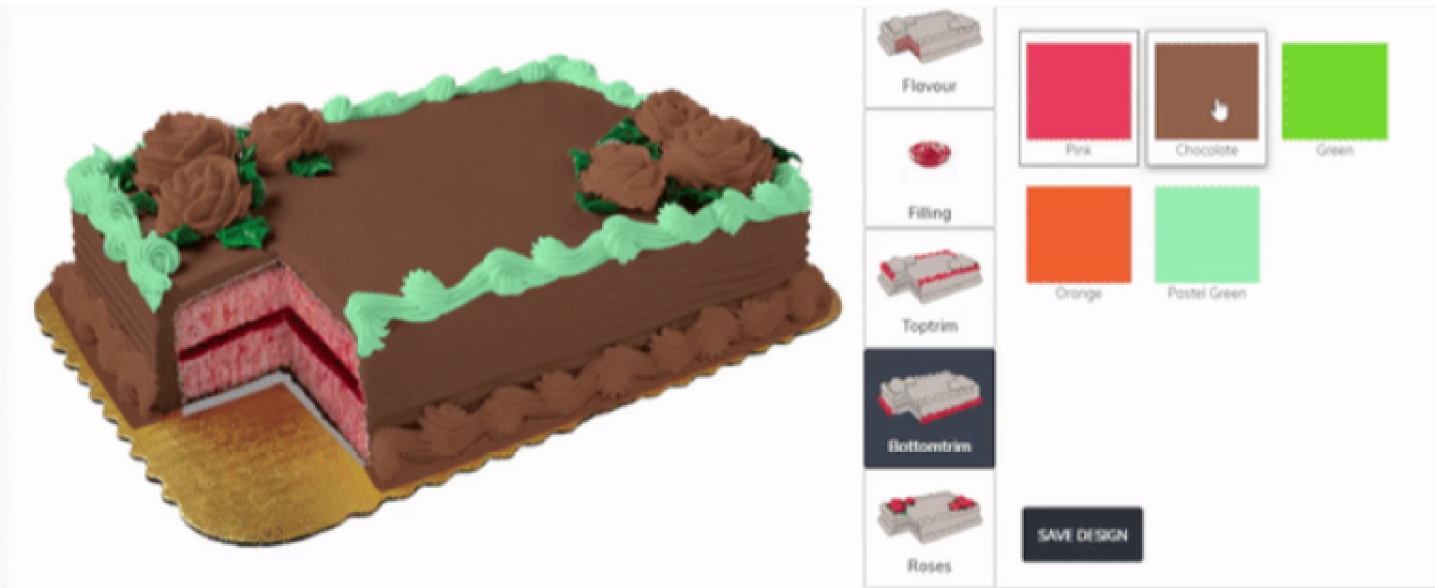


Figure4. Interface of Havi Proprel Cake Configurator

1.2. SocialVR: enabler of remote co-design

SocialVR can be described as the transformation of virtual reality into a type of social medium [27]. It enriches the future social environment and the way people cooperate and share experiences [28]. **SocialVR is a web-based social interaction technology, which allows multiple users who are physically separated to interact with virtual representations of each other in a shared virtual environment.**

1.2.1. Appromixing face-to-face social Interaction

Social VR allows users to better communicate with each other in the medium of real-time audio, 3D visual and haptic cues, with a maximized immersive experience. For example, in the most cutting-edge socialVR platform such as Facebook Horizon [35], the facial expression, voice, eye orientation and body gesture of one user will be collected and then mapped to the three-dimensional virtual avatar of that user in real time (Figure 5).

Figure5. Virtual avatar in Facebook Horizon

SocialVR achieves articulated behavior and avatar realism, enabling interactants to communicate non-verbally in a natural way. First, subtle nonverbal cues can be precisely simulated in virtual reality. Balaam et al. had proposed a computer algorithm driven agent-avatar system which is able to mimic participants' side-to side head movements at approximately 12 Hz [37]. This gesture is perceived to be a signal of visual attention in real-world social interaction. Second, sophisticated avatar embodiment enables participants to intuitively give tacit cues to other interactants. It is indicated that the interaction quality in VE is contingent on participants' acceptance of the avatars as the representation of "self" and "others". This "acceptance" highly depends on the quality of avatar embodiment and behavior realism in VE [37]. Only if participants are persuaded that the avatars they see are themselves, they can truly feel "being there" and have nonverbal communication in a natural way.

As mentioned above, socialVR is capable of supporting tacit communication, which helps to convey 65% of information in face-to-face interaction [38]. Simulation technology in socialVR achieves remarkable behavior realism which is essential in social presence [28,29,30]. Therefore, soicalVR is believed to have the potential in simulating face-to-face interaction regarding closeness, richness and intuitiveness. Previous research [31] has proposed that socialVR can closely approximate face-to-face interaction, in the context of co-present photo-sharing, since it provides a high level of social presence and conversation patterns which remarkably resemble face-to-face interaction [32]. Therefore, we propose that socialVR is promising in supporting co-design activities for geographically separated collaborators and facilitating intricate interaction in the process. Even though currently there is no systematic research in how to apply socialVR technology in co-design activities, it is still possible to gain insights from virtual reality's application in supporting remote collaboration and developing design tools.

1.2.2. Remote collaboration in socialVR

SocialVR technology has been applied in the field of remote collaboration for the purpose of business, education and healthcare. It allows a team to collectively undertake a task in the same Collaborative Virtual Environment (CVE), which is a distributed virtual reality system supporting multi-user collaborative practices [24]. Within a shared CVE, collaborators in different locations can share and process information together. SocialVR adds extra value to the information exchange process in remote collaboration, compared with conventional mediated social technology (i.e., video conference in Skype). First, socialVR increases the types of information to be shared in remote collaboration. It offers complicated cues for interaction and for establishment of shared contexts [24]. For instance, in socialVR, users can easily exchange spatial information which is hard to express in texts or speech. Inside a malleable virtual world, users can freely use pointers or add visual objects as spatial cues, so as to express spatial references in target identification or navigation tasks. Müller et al. claimed that shared spatial cues in VE are able to reduce the amount of deictic speech for users to describe spatial positions [53], and decrease the workload of individual spatial memory. Second, socialVR allows flexible and efficient information collection and storage in remote collaboration. Collaboration involves extensive information exchange, process and retrieval. SocialVR offers various interaction techniques for users to collect information during collaboration. For example, socialVR applications like Facebook space and Expo allows users to capture images as well as record videos inside the VE [35,36]. These functionalities help users to record the signification visual and audio information in VR communication efficiently. In addition, Expo enables users to use Google Drive to store information inside the VE [81]. Third, socialVR allows flexibility and individuality in the design of shared data representation for different contexts. It is true that collaborative tasks include many levels of information and many layers of contexts. In different contexts, collaborators might have diverse preferences in information representation regarding visualization styles, level of details and information highlights. In aid of socialVR, perception of shared data is no longer confined to "objective view" mode [24], in virtual presentation keep the same all the time. Instead, flexible representation is viable in socialVR since there is no intrinsic or fixed appearance for abstract data [24]. Embodiment can be tailored based on a specific collaboration context (i.e., task requirements, personal goals , intended interaction between collaborators). For example, Facebook space allows diverse presentation of images. A collection of images can be presented on the virtual screen for users to better share contents in the context of formal discussion, and users can manage the images by screen interaction (Figure 6). But in some casual contexts such as story sharing, pictures can be presented as physical pictures floating in the 3d space, so that users can physically interact (i.e., move, rotate, resize) with them in the virtual world [35] (Figure7).

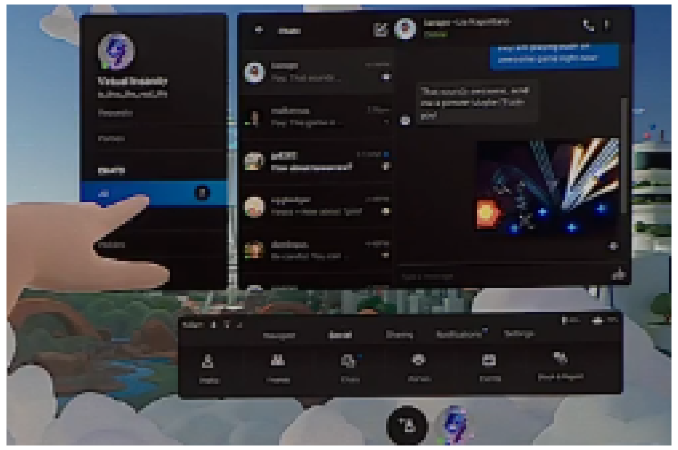


Figure6. Presentation of picture on screen

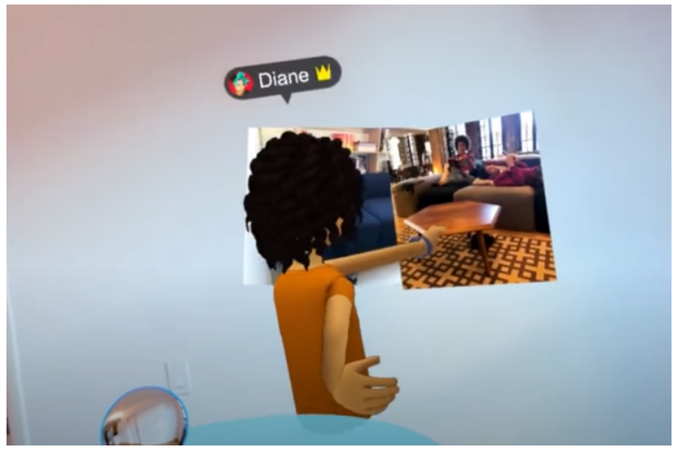


Figure7. Manipulation physical pictures

Therefore, socialVR optimizes user experience with regards to information representation and management in collaborative tasks, and optimally deals with the information complexity in collaborative communication.

When designing the CVE for remote co-design, designers need to consider how co-design participants negotiate and what kind of product to be designed. CVE should be designed with explicit consideration of the intended task to be achieved, and the intended users' behavior [24], because the task contexts can vary a lot. Collaboration is a highly complex interpersonal interaction with substantial negotiation. Negotiation plays a vital role in collaboration since it enables team members in different backgrounds to build up a shared understanding in current tasks. Previous research proved that teams vary a lot in the negotiation strategies [39], caused by the differences in the scale of teams, the type of tasks and the work accomplishment progress. Thus, CVE of collaborative tasks can be very diverse with regards to divergent task contexts.

1.2.3. Virtual Reality in 3d design

Virtual reality is perceived to be an ideal medium for 3D artifact design tools. VR empowers users to freely generate, manipulate and perceive virtual three-dimensional artifacts inside the VE, due to its proficiency in supporting spatial orientation and awareness [40]. In general, VR facilities 3d design work from two perspectives: immersive 3d modelling and perception of design concepts.

Immersive modelling system

3D shape generation and manipulation is perceived to be the core of putting a 3d design idea into practice. VR enables an immersive modelling system in which users can freely realize their wild ideas. Immersive modelling system is defined as a computer-aided design (CAD) tool in combination with virtual reality technology as a visualization medium and immersive interaction enabler [55]. Compared to traditional desktop CAD tools (i.e., AutoCAD, Solidwork), it promotes 3d artifact design process from three perspectives.

First, it allows more intuitive 3d manipulation interaction with gesture-based cues, in aid of motion capture technology. Previous research claimed that gesture-based interaction is an intuitive interaction metaphor in 3d modelling, because people mostly interact with 3d artifacts with their bodies in the real world[63]. Gesture-based modelling interface enables people to learn quickly, model efficiently, and communicate with computers and peers about the models in a natural way. Nevertheless, the premise is that the gesture commands should be memorable and usable. Previous research claimed that an intuitive gesture-based interaction should be based on empirically determined gestures elicited from the users [63,64]. Several works address the hand gesture commands elicited by users when interacting with 3d models [63,64,65], and reveal intuitive patterns in the gestures for embodying creative ideas. For instance, Kahn et al have developed a set of user-elicited gesture grammar (Figure 8), for CAD modelling techniques [63].

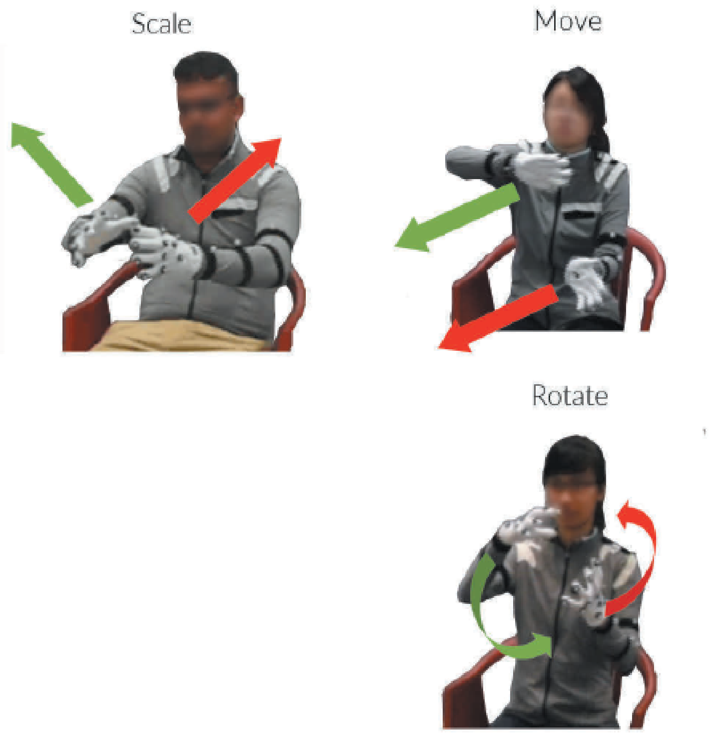


Figure 8. user elicited hand motion for 3d manipulation(Kahn et al.)

Second, it enables free 3d sketching, in which people can directly transfer their design intent into digital 3d representations [76]. This technique achieves higher creative freedom and interaction between human, system and space. Virtual modelling systems (i.e., FacebookSpace, FreeDrawer) enable people to freely draw 3d curves in the 3d space, in aid of hand motion tracking devices [35, 76] (Figure 9). Users can also freely manipulate what they draw by moving, scaling and rotating it, or changing the color and texture. In this way, users can directly embody their mental images in the 3d space. When making virtual 3d sketches, users develop and evaluate design ideas by “playing with the space” with their bodies. Previous research has claimed that users in 3d immersive modelling environment are more proactive to interact with the virtual designed artifacts [55]. For example, users tried to sit down on the 3d-sketched virtual chair, to evaluate their design concepts [55].

Figure 9: 3d sketch in Facebook Horizon

Third, it supports modelling in one-to-one scale. Unlike the desktop CAD tool, of which the scales of 3d models are limited by the screen sizes, immersive modelling environments such Google Blocks and Facebook Horizongs provide infinite 3d landscapes for users to perceive the designed artifacts in one-to-one scale [35,55,77]. In such wise, users have more precise understanding of the artifacts’ properties with regards to scale, proportion and spatial impacts [55].

Ubiquitous perception: from physical to contextual

VR enables product designers to get a precise and realistic view of the design concepts [41] from two perspectives. First, VR offers designers an explicit visual perception of the physical characteristics of a 3D artifact, by presenting the 3D models with high-quality interactive 3D graphics, or even photo-realistic cloud point cloud visualization [28]. Aided by VR simulation, designers can perceive the size, shape, material and texture of a 3D model with realistic visual feedback. Previous research has claimed that visual cues (i.e., illuminance distribution, color density, color identity, visual texture) exerts a crossmodal influence on the overall sensation of a certain project exerts a crossmodal influence on the overall sensation of a certain product [78, 68, 79, 80]. As Sutherland has claimed, virtual reality makes the “mathematical wonderland” look real, sound real and feel real [42]. Second, the simulation in VR reproduces the possible future scenario [43], for designers to experience how this product will be used in the proposed context. Contextual characteristics (i.e. light effect, spatial scale) can be proficiently simulated and integrated in VE. Such virtual environments can be generated efficiently by 360-degree cylindrical panoramic photos[75]. In this way, VR allows designers to be “placed in an activity or a context” with the designed artifacts [43] and to understand how the design outcomes make a difference in the future scenario from the perspectives of target users. By means of an immersive interaction and a sensorily realistic scenario, designers are able to stand in the shoes of the future users and explore their experience and emotion when interacting with the designed artifacts. This enables designers to gain meaningful insights for design iteration with prompt sensory feedback, before anything has been built physically. This way, the cost of late modification can be significantly reduced [41].

2. User reseach

In this chapter, we will investigate how clients and cake makers communicate about the personalized cake, in order to collaboratively make design decisions. To delve deeper into the context, semi-structured interviews were performed. After that, a qualitative analysis is conducted to reveal the general information and workflow of the client-baker communication. Then, based on the analysis results, we will discuss how ideas and design decisions come into being, as well as the concerns and latent needs of clients and bakers. These findings will inform the design requirements of the socialVR tool (Chapter 3).

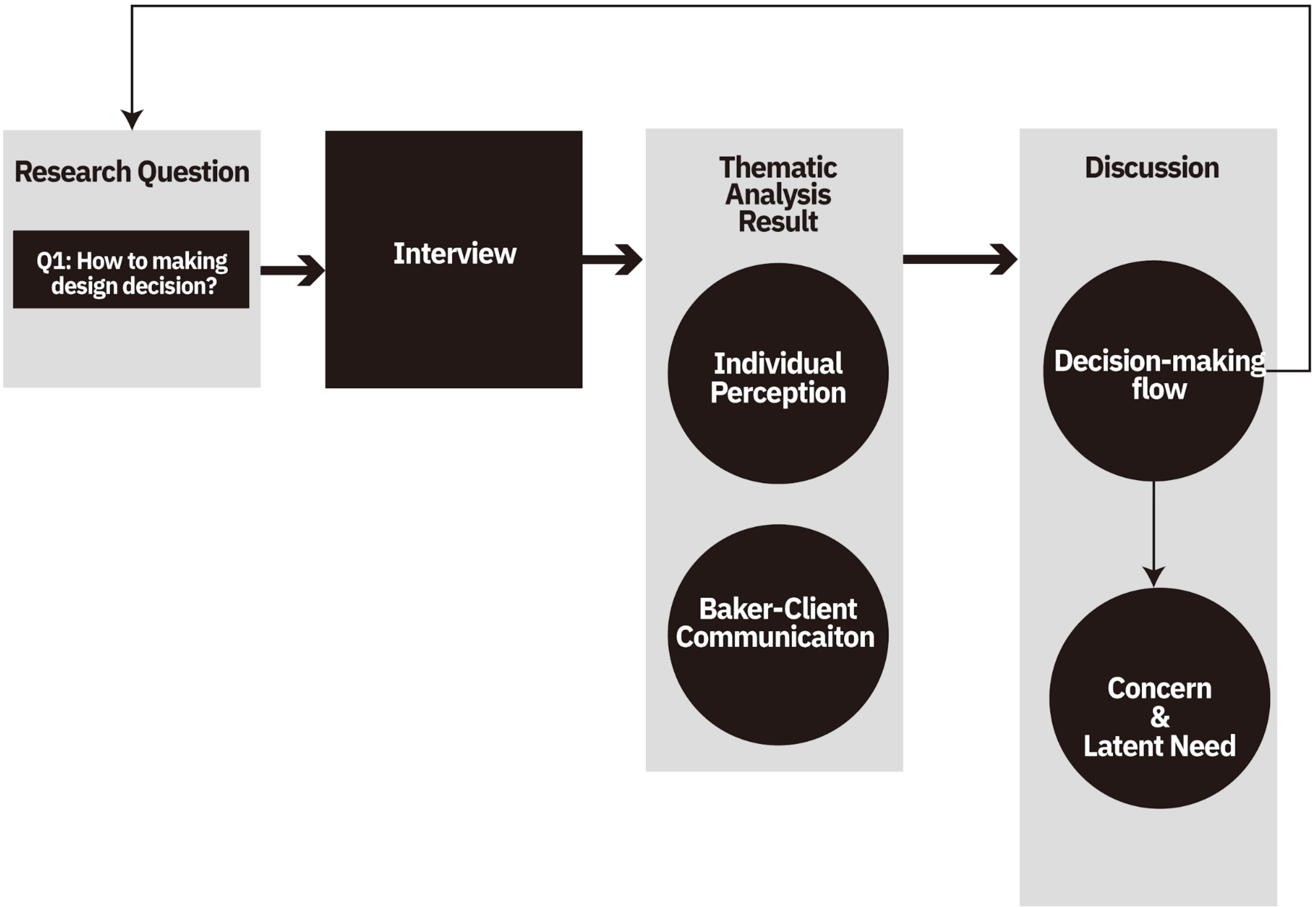


Figure 10. Structure of this chapter

Research Question:

How do clients and cake makers generate ideas and make the design decisions?

Method

The study was conducted in the form of semi-structured interviews. Based on the research question, two sets of interview questions (Appendix) were designed separately for cake makers and clients. They were asked to describe their most memorable experience about customized cakes. After that, interviewees were inspired to tell more about their stories and opinions with regards to customized cakes. The aim of the study is to understand how clients and cake makers communicate about customized cake.

Participants

5 cake makers and 4 clients with varied nationalities (Chinese, Dutch, United States) participated in the interviews. Two out of the five cake makers were male and the other three were female. All of them were the owners of their bakeries, and had abundant knowledge in cake making. Among the four clients, all of them were female. Three of them customized cakes for their weddings, while the other one ordered the cake for a friend's birthday party. Three of them are amateurs of cake making, while the other one have no experience at all. The age of all the interviewees ranged from 20 to 40, and all of them had experience in communicating about personalized cakes.

Participant List (Cake maker)

No.	Age	Gender	Bakery name	Main Focus in cake making	Location
B1	30-40	F	Cake Researcher	Mainly focus on customized cake, with a few services of regular cakes for cafe	Delft
B2	30-40	M	SugarLips	Mainly focus on customized wedding cake, with a few services of regular cakes for cafe	Utrecht
B3	30-40	F	Round & Round	Mainly focus on regular cakes for cafe, with a few customized cake cases	Rotterdam
B4	30-40	M	Jans Delft	Mainly focus on regular cakes for cafe, with a few customized cake cases	Delft
B5	40-50	F	IS Mooi & Lekker!	Merely focus on customized cakes	Den Hoorn

Table 1: Participant list (cake maker)

Participant List (Customer)

No.	Age	Gender	Reason for customizing a cake	Location
C1	30-40	F	wedding	Hague
C2	30-40	F	wedding	Rotterdam
C3	30-40	F	wedding	Rotterdam
C4	20-30	F	A friend's birthday	Shanghai

Table 2: Participant list (customer)

Setting

All the interviews with cake makers were performed face-to-face in their bakeries. Communicating with the cake maker in the bakery helps the interviewer to gain more deep insights, compared with the telephone interview or the face-to-face interview in another place. First, cake makers feel more relaxed and active in the bakery, a workplace which he or she is very familiar with. In this scene, they are proactive in expressing personal ideas or sharing stories. Second, in the bakery both the cake makers and interviewers have easier access to the cakes and baking tools. These nudge cake makers reflect deeply on their experience, and serve as triggers for interlocutors to easily start a relevant conversation, telling more stories and anecdotes. Additionally, the cakes or tools act as vivid references for cake makers to convey some cake-related ideas which are difficult to express in words (i.e., aesthetics style, size, texture).

Two interviews with clients were performed face-to face-at their home while the other two were conducted via telephone.

Data collection
Each interview session was audio recorded. Then, the audio records were transcribed. Additionally, pictures of some cakes and tools were taken, under the permission of interviewees. In general, all the data collected in this session is qualitative data.

Data analysis
Filtration
All the transcription was read several times. Significant quotations were picked out.

Classification & Generalization
Selected quotations were first coded using deductive reasoning into three groups: clients' perspectives, bakers' perspectives, client-baker communication. Then, inside each group, quotations were recoded with inductive methods, based on which themes they were related to. After that, new themes come into being.

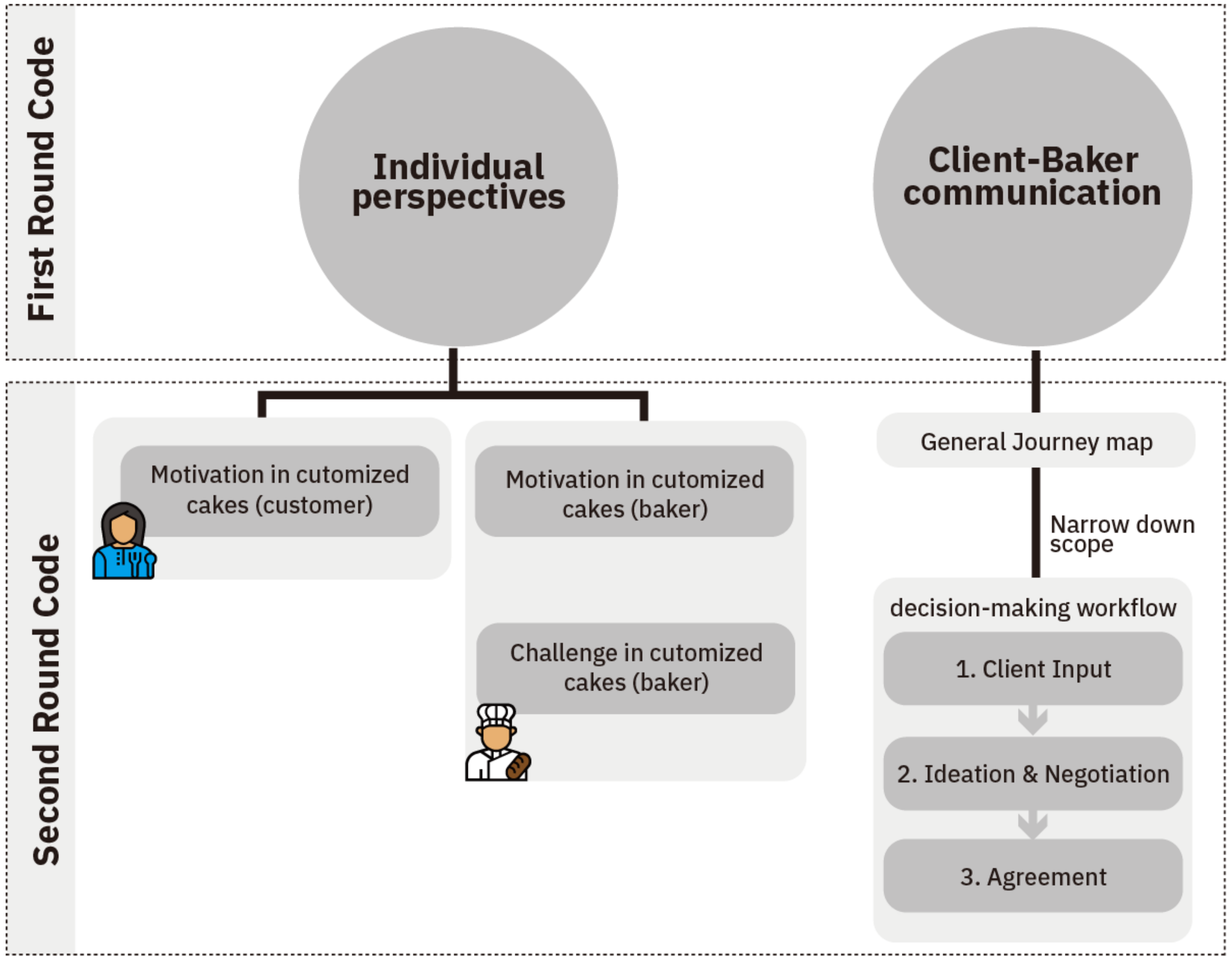


Figure11: Data analysis process

2.2 Study Result

The study results are categorized into three parts. The first part is about how clients and bakers individually perceive the activities of ordering or making personalized cakes. The second part is client-baker communication workflow of making design decisions.

2.2.1 Individual perspectives

Customer: motivation to order personalized cakes

Self-identity. Self-identity is one of clients' motivations to personalize cakes. In the area of creative tasks, self-identity is defined as "desire to reinforce and enhance self-perception in creativity" [20]. It stems from engagement of the design process and uniqueness of the design outcome. For example, C2 designed a unique graphic pattern for the wedding cake, and she was proud of it and said "I don't think anyone else in the world has the same wedding cake like mine." Hence, the uniqueness of a personalized cake stands for the personal taste and creativity of the cake owner.

Make sense of an event. For the view of customers, the customized cake is perceived to be a supporting part of a well-organized and meaningful event. According to interviews, all the people purchased personalized cakes for special ceremonies (i.e., wedding, birthday party, baby shower, company anniversary). They usually personalize the cake design based on the event. For example, one of B2's clients asked to make a fondant yacht figure on the cake because he ordered this cake to celebrate his purchasement of a new yacht. In general, a personalized cake makes a special occasion more formal and memorable

Convey emotion. It is common that cake owners take cakes as vehicles of their emotion, so as to strengthen the social bond. Since emotional messages can be quite personalized and contextual, the cakes should also be specially designed in order to convey a certain emotion. For instance, B5 mentioned about one of her cases that one couple visualized all the important moments of their love journey (i.e., the first dating, the first time to live together) on the wedding cake. They recollect and symbolize their happy memories on the cake, and, in this way, to express love to each other..

Cake maker: motivation to offer customized cake services

Self-identity. Crafting a unique and novel cake reinforces a cake maker's self-identity with regards to creativity, value, personal styles and professional skills. For example, B5 only focuses on making personalized cakes, and she is proud of her career: "I only make unique cakes, if people want to buy normal cakes they can just go to HEMA."

Self-achievement. The sense of self-accomplishment after overcoming challenges is another essential motivation for bakers to make personalized cakes. Customized cakes are usually more difficult to make than regular cakes. Cake makers sometimes need to step out of their comfort zone to make a unique cake which no one had done before. They might do some experiments and explore new techniques. For example, B2 mentioned that she had tried some architectural materials to craft articulated 3d cake shapes. "It is funny that you sometimes find the weirdest tool to make a cake", as he described. In addition, cake makers gain a great sense of achievement after overcoming difficulties and putting their wild ideas into practices. B2 has told us that "I am surprised at how we managed to do it. Some designs give big headaches, but it always works out in the end."

Cake maker: challenges in making customized cakes

Time-consuming. Making customized cakes is usually time-consuming. Firstly, cake makers need to spend a large amount of time communicating with customers. Generating a novel idea for a unique cake can take a long time. For instance, B3 has said: "Some customers don't know what they want, so I need to spend some time asking them questions". In addition, it is a tedious process to iterate ideas. B4 has mentioned that customers could change their ideas every five minutes. Besides, decision-making can also be an arduous task. B3 told us that it was difficult to make decisions because customers were sometimes overwhelmed by so many options. Secondly, making a customized cake takes more time than making a regular cake. Usually customized cakes require more advanced techniques than the regular cakes. So cake makers need to invest more effort in trial-and-error and crafting the cakes. For instance, B5 has described her experience about spending a whole week crafting a novel 3D shape which she has never tried before.

Less financial benefit. As mentioned above, making customized cakes cost a great deal of time. The time cost should be transformed into the expenses of cakes. Thus, customized cake is more expensive than normal cakes. However, most clients are not willing to pay a large sum of money for a cake. B5 has said: "People only want to pay for the material of the cakes. They don't want to pay for the time and effort of cake makers." Therefore, it is mostly impossible for cake makers to convert all the time cost into the price of cakes. To some extent, making customized cakes is not a good bargain.

Viable novelty. From the perspective of the cake makers, there is always a tension between viability and novelty. Viability refers to realizing a certain cake idea within constraints. Novelty is defined as the creative freedom of the cake design regardless of external restrictions. The tension is caused by several factors. First, the external environment (i.e., temperature, physical distance between baker and event location) set limitations on cake making. For example, B1 said:" I cannot serve my cakes for outdoor events in summer, because I only use light cream, and it will easily melt in such a hot environment." Second, the availability of resources (i.e., money, time, equipment, transportation) offered by customers and cake makers is also perceived to be a constraint to the freedom of cake ideas. Both clients and cake makers have to carefully consider how much resources they are willing to invest in the business cases. For example, B2 has said, "I will not specially buy an expensive silicon model just for making one cake." In addition, C1 mentioned that she wouldn't pay too much money on the wedding cake because it is just a certain part of the whole wedding. Third, cake making techniques limit the practicality of a cake idea. For example, B1 has described one of her experiences: "One of my clients asked for a purely dark cake, but it is impossible to do that. Even though you add a great deal of edible black pigment into the white cream, what you can get is the dark grey color."

3D Craft. Cake making is always a 3d work. Sometimes it is a big challenge for cake makers to realize a cake idea with regards to complex 3d structures. First, building an articulated 3d shape usually requires 3d mathematics calculation. Sometimes cake makers might make wrong calculations, which lead to unnecessary cost. For example, B1 said that, "I bought a circle-shape supporter for my 'cake tower', I figured out the right diameter, but I made a mistake on the thickness. So I have to buy another one, and I have to pay for my mistake." Second, sometimes cake makers need to do mental transformation between 2d shapes and 3d shapes, in order to realize 3d cake ideas. For example, when making a cake roll, cake makers usually bake a 2d "cake blanket", and then roll it into a 3d cylinder shape. If there are some special patterns on the roll, cake makers need to metally 'unwrap' the roll to figure out how the patterns looks like on the 2d "cake blanket."

Conflict between timeliness and time abundancy. Making customized cakes requires reasonable time management. Cake makers always try to find a balance between timeliness and temporal abundance. 'Timeliness' means that the cake maker needs to make the cake right before the delivery time to ensure that the cake is fresh when the customer receives it. For example, B4 said that he needs to make the cake several hours before delivery, so that the cake can keep fresh when customers enjoy it. However, the conflict is that the cake maker needs to spend sufficient time in making a good-quality cake. For instance, B1 has mentioned she used to spend seven hours making a single small fondant decoration. Therefore, a reasonable time management is important to achieve the freshness and good quality of a customized cake.

Uncertainty. It is impossible to control every detail of a cake, because cake making is a process full of uncertainty. Some nuances (i.e., ingredient quantity, timing, temperature, air humidity) in the baking process might have some impacts on the finalized cakes. Therefore, it is difficult to finalize a cake which is exactly the same with the mind image. For example, B3 has said:" One client wants to know the exact height of her cake, but it is impossible (for me to precisely control the height). " In addition, B2 has mentioned: "Some clients are unsatisfied because 'the pink is not pink enough'." Therefore, cake makers sometimes need to make their clients understand and accept the tiny unpredictability of cake making.

2.2.3 Client-Baker Communication

Firstly, we will introduce general information about client-baker communication, with regards to time, location and general flow. After that, we will specifically describe how they communicate to reach a final design decision. The workflow is grouped into three parts, aligned with the temporal sequence: client input, ideation and negotiation, agreement.

GENERAL INFORMATION: when, where, how

when
The overall communication between clients and cake makers lasts for two months to six months, from getting in touch to giving customer feedback. The time span is contingent on the price and size of the cake, and the intended workload of cake-making.

where
Clients and cake-makers usually have one face-to-face meeting in the bakeries, for negotiating about the cake ideas and making a decision. At other times, they usually communicate remotely via email or whatsapp.

how
Figure 12 presents the overall process of client-customers communication about customized cakes, from getting in touch to giving customer feedback.

	Get in touch	Initial communication	Formal Negotiation	Confirmation	Post negotiation Cake Making	Delivery	CakeTime	Feedback
Common Goal	Build up businiss contact	Availability confirmation	Make collaborative decisions on cake design and related services	Agreement for common decision making	Refine or alter cake idea	Offer a finalized cake in the event location	Share cakes	
Task	* Present personal style and skills	* Check availability * Arrange an appointment	* Prepare for cake tasting * Reveal client needs * Generate and refine cake idea * Decide the cake price	* Record all the cake ideas and business information * M*ake an agreement	* Alter cake idea based on client input * Make the cake * Update the working prog-ress	* Transport the cake * Assamble the cake on site		
Task	* Select a preferred bakery * Start contact	* Give basic information	* Give detailed requirement * Tell personal preference * Tell budget limit * Generate and refine ideas	* Check the agreement * Pay	* Inform cake makers the chage of the event informa-tion	* Transport the cake * Support cake makers to set up cakes on site		* Give comment on the cake
Value		* Schedule availability * Interest in this case	*** Viable novelty * Profitability**	*** Inclusiveness of info * Traceability of info**	*** Constancy of cake idea * Sufficency of work time * Freshness of cake**	**Offer a finalized cake in the event location**	* Client's satisfac-tion on cake	* Give comment on the cake
Value	* Style match		* Affordablbility * Fulfilment of requirement * Uniqueness	* Inclusiveness of info * Credibility of info	* Promise-keeping of cake makers * Flexibility of cake design	* Transport the cake * Support cake makers to set up cakes on site	* Cake sharer's satisfaction * Successful event	* Give comment on the cake
Interaction								
Communication tool								
Media								

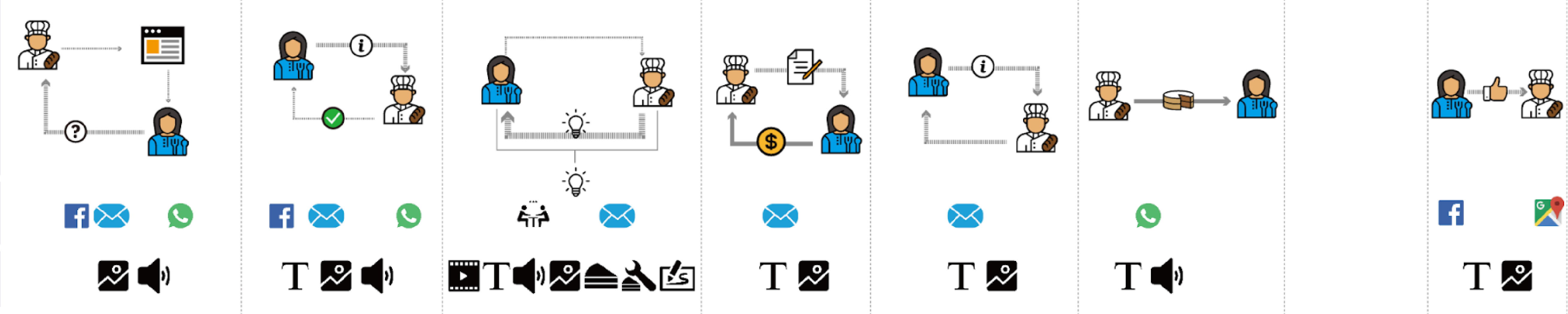


Figure 12. Journey map of client-baker communication

1. Get in touch. Clients select a preferred bakery on the internet. Then they contact the baker by leaving a message on the website or directly sending messages on social media applications. This is the first step for them to build up the business relationship.

2. Initial communication. After getting in touch, clients generally describe the basic information about what they want to the cake makers. If cake makers confirm the availability regarding time or workload, they will book an face-to-face appointment for further negotiation. In this phase, the business relationship is initially confirmed.

3. Formal negotiation. Formal negotiation is usually in the form of a face-to-face meeting. It takes about one hour. In this phase, clients and customers collaboratively make a design decision, regarding the cake features (i.e., color, flavor), cake-related service (i.e., delivery time, transportation) and cake price. This is the most interactive part of the overall client-customer communication, as well as the most essential part to the design decision.

4. Confirmation. After the face-to-face meeting, cake makers draft a contract with regards to their design decisions. Then they send the digital contract to clients via email, to make sure both sides reach an agreement. Only after clients agree with the contract, the business can continue and bakers can start making the cakes.

5. Post-negotiation. After they reach a consensus on the contract, they keep infrequent contact with each other on email or social media. They communicate in several situations (i.e., clients change ideas, clients ask working progress). During this period of time, bakers are working on cake making.

6. Delivery. After the bakers finish cake-making, the cake is delivered to the clients. Sometimes if the cake is too large to be delivered, cake makers will set the cake apart into several pieces to be transported, and then assemble them on site. Usually, this is the first time that clients see the cake.

7. Cake time. Clients and the event guests enjoy the cake.

8. Feedback. After the cake is consumed, the clients usually give feedback to cake makers via social media, bakery's website or Google Maps. This is the formal ending of the client-customer communication.

As mentioned above, the client-customer communication on the personalized cakes is perceived to be a long-term interaction, involving several types of communication, in different contexts and for various purposes. **In this project, I will focus on the cake co-design activities regarding idea generation and decision-making, thus, I will narrow the scope into the two phases: "formal negotiation (3)" and "confirmation (4)",** which are most relevant to the co-design activities and decision-making. Therefore, in the following writing, the "communication" refers to client-customer interaction in these two phases.

Communication for the design decisions

In this sense, the "communicate" refers to the interaction in which the clients and bakers form the cake ideas and make design decisions, in the two phase mentioned above: ***formal negotiation and confirmation.*** Usually, this communication is in the form of a face-to-face meeting lasting for about one hour in the bakery, together with some ensuing online communication via email. The communication is generally divided into three phases, aligned with chronological sequence: ***client input, ideation and negotiation, agreement.***

PHASE 1: Clinet Input

Usually, the conversation starts with clients offering input to cake makers. Firstly clients discover what they want about the cake, including mandatory requirements and personal ideas. Then, they use verbal description and image to express their thoughts to cake makers.

Requirements
The requirements refer to "what the cake should be." They must be met and included in the final design decision, because they are firmly based on the clients' needs. Clients set requirements from two aspects: personal preference and objective constraints. Personal preference refers to the clients' subjective likings for certain cake features (i.e., flavor) which is not highly relevant to cake concept design. Objective constraints are related to the context in which the cake will be consumed, and they cannot be changed by subjective preferences. For example, clients usually give some constraints with regards to the amount of guests (cake sharers), allergie information of guests, delivery time and delivery methods. In general, clients' requirements are taken as priority in the client-baker communication, because clients are the owners of the cakes.

Ideas
Besides requirements which are not significantly relevant to cake design, customers also explore cake design ideas, which is defined as "what the cake might be." Clients develop their creative thoughts in three ways: **define cake properties, fit the cake-context, symbolize emotion to be conveyed.**

First, **customers sometimes directly define the intended physical characteristics of the cakes.** For some clients who cannot design something from scratch, they usually refer to an existing design paradigm. They obtain these design templates by searching for reference images on the Internet (i.e., Pinterest, bakery's website). Reference images offer existing cake design examples to people. Clients usually appropriate the preferred cake features from a certain example, and then redesign it to fit their own preferences. For example, C1 defined the color tone of the cake from a reference image. In addition, reference images can be an existing graphic paradigm such as themes (i.e., Mickey Mouse) or a predefined graphic pattern (i.e., mosaic). For instance, one of B5's clients showed her an image of Netherland windmill pattern and asked to apply it to the cake surface. Additionally, for clients who are able to imagine and create a design element, they can originally self-define what they want. For example, C2 originally came up with a graphic pattern in which she defined the shape and color, in order to decorate the cake outer layer.

Second, customers gain inspiration from the context in which the cake will be shared, by reflecting on the **physical environment, social value and purpose of the event.** For some clients, they usually extract visual information of the physical environment (i.e., wedding setup), and set it as a guideline for cake design, so as to achieve visual consistency between the cake and event setup. For example, one of B1's clients asked for a red cake because his/her party would be held on a red yacht. C3 asked to decorate her wedding cake with English roses because she also used this type of flower in the bridal bouquet. In addition, clients hope the cake to be socially valued, thus the cake sharers opinion and experience will be taken into consideration. For example, C1 mentioned that, when designing the configuration of the cake, she focused a lot on how to make it easier for guests to share and take. Additionally, some clients envision how people interact with the cake based on the purpose of the event. For example, one of C1's clients (a couple) wanted to order a cake for guests to guess the gender of the coming baby in their baby shower party. Their idea is based on the purpose of that event: expecting a new life into the world. Third, customers reflect on what kind of emotion they want to convey via the cake, if the cake is served on an emotional occasion (i.e., a dinner for confessing love). The consumers usually extract emotional cues from the personal stories, memories, love quotes or the personality of the person to whom they will express emotion. Such cues will be taken as intangible design elements of the cake. For example, B1 mentioned that one client wanted to "build a forest" on the cake to express his feelings to a girl, because the girl was fond of forests. Here, "forest" is a sort of emotional cue regarding the boy's love and care for that girl.

Expressing thoughts

After clients identify what they require and what they dream of about the cake, they need to convey these requirements and ideas to cake makers. **They mostly use verbal description to express their requirements, and utilize images to convey their ideas.**

Requirements can be easily expressed and understood in words. Requirements are usually in the form of numerical or temporal information (C3: "I want a six-tier cake for 160 guests". C4: "The cake should be delivered at dd-mm(her friends' birthday)"). In addition, the requirements can be some descriptive words with very simple semantic meaning (C1: "I want a matcha cake"). "Matcha" can be easily understood just in words because it is a kind of general knowledge which everyone knows.

When expressing ideas, clients usually use images as the primary media, because cake ideas can be very abstract and visual-based. The way people express ideas with images can be defined as two dimensions: concrete or abstract, original or referential. The first dimension, "concrete or abstract", indicates how specifically and detailedly customers can describe their ideas. Clients can describe their ideas in a very concrete way, clarifying the exact physical characteristics of the cake which they want. They usually specifically point at a visual element inside an image, and take it as a reference to express the intended physical design. For example, C2 drew a graphic pattern of which she defined the shape and color, and asked to apply this pattern to the cake surface. On the other hand, some convey ideas can also be very abstract concepts. In this sense, people refer to the general style of the image to describe the "feel" of the desired cake. For example, C1 referred to a cake picture and told her baker: " I want an Asian style cake like this." The second dimension, "original or referential", implies whether the visual materials which they use to express ideas are original or referential. Some customers are able to generate graphic materials by themselves, because they are skilled in painting. For example, one of B1 clients made a sketch by herself to tell what kind of 3d configuration and decoration she wanted. But most clients don't have such ability. Instead, they utilize reference images to embody what they want. They usually show the images in their mobile phones as reference and describe their design ideas, or sometimes, verbally refer to a well-known visual paradigm which everyone knows how it looks. For example, one of B5' clients said:"I want a Lego cake".

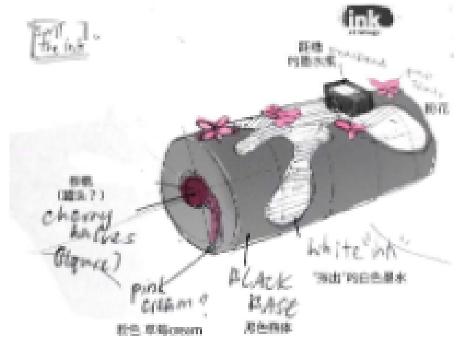
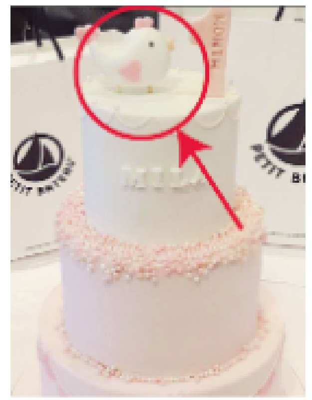
	Original	Referential
Concrete	*"I want a cake roll on which an ink bottle is pouring"* 	*"I want that little chicken figure on my cake. "* 
Abstract	-	*"I want an Asian style cake, like this"* 

Figure 13

PHASE 2: ideation & negotiation

After clients express their requirements and ideas, they collaborate with cake makers to develop a cake idea and make a collaborative decision. In this stage, I discover that they develop the design decision through three activities: **1) synthesize clients' thoughts into design 2) embody cake information 3) give professional advice.**

1-Synthesize clients' thoughts into design

Clients' input is the primary factor informing the cake design, because they are the owner of the cake. As B5 has described :" The customer's requirements are the most important, because it is his/her cake, he/she must like it.". In this sense, cake makers collaborate with clients to translate their thoughts into certain cake components (FIXME) which are tangible, edible and doable.

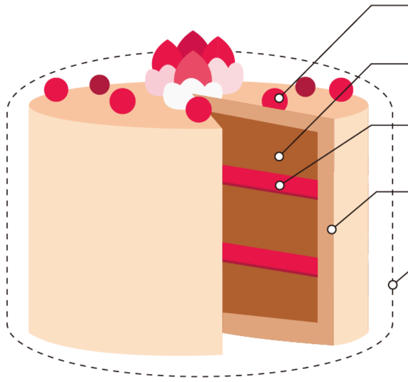


Figure 14. cake component

Usually, they will first make a connection between an intangible idea with a certain cake component (FIXME), and then physically modify (FIXME) it in order to achieve the intended visual effects. For example, C2 wanted a cake with a lot of colorful triangle shapes, so she and the baker(B1) decided to apply this visual element to the cake outer layer as a graphic pattern. Then, B1 decided to use a specially made material for the cake outer layer, instead of the commonly used cream, so as to apply that colorful pattern on the cake surface.

Component	Frequent Adaptation
Cake dough	flavor, color, material(for mouthfeel)
Filling	Flavor, color, cream material
Outer Layer	Flavor, color, cream material, graphic pattern, texture
Decoration	material
3D configuration	Size, 3d shape

Table 4. Information exchange in baker-client communication component

Usually, cake makers and clients develop the design concept through three actions: ***adaptation, creative combination, creation.***

Adaptation. "Adaptation" refers to **redesigning a certain component of an existing cake template to fit the requirements.** This action doesn't have a big impact on the creative concept of the cake. As B3 has mentioned: "Sometimes designing a cake is similar to adapting the pattern of blanket covering a bed. It doesn't make too much difference because after all the bed is still a bed." Usually, clients choose a preferred example cake presented in an image, from the bakery's website, then **redefine the parameter** (i.e., diameter of a round cake) or **physical characteristics** (i.e., color, ingredient) to fit their needs and preferences. For example, one of B3's clients designed her cake by selecting a cake template from the bakery menu and reducing the size to the half.

Creative combination. "Creative combination" is defined as the process in which **people freely mix and match the diverse existing design elements to generate their own cake ideas.** Most of the design elements stem from the existing design paradigms displayed in the reference images which clients offer to bakers. As B5 has said: " Some clients showed a collection of pictures and told me 'I like the topping of this cake, I like the decoration of that cake.' Then, we combined them into a new cake." In addition, the visual materials can be derived from the context where the cake will be consumed. For example, C3 chose English roses as the wedding cake decorations which are also included in her wedding bouquet.

Creation. Creation implies the process of **integrating clients' personally-generated novelty into the cake design.** Such novelty can be **self-defined physical properties of cake.** For example, C2 used computer sketching tools to design an original graphic pattern, which would be applied to the cake surface. In addition, creation can be inspired by the context where the cake will be served (i.e., purpose of the event). For instance, one of C1's clients (a couple) came up with a blue cake with a white outer layer, for their baby shower party. This cake would let guests guess the gender of the coming baby. The novelty of this idea is that the action of "cutting the cake and revealing the color inside" would be taken as the indication of the baby's gender (if it is blue, the baby is a boy; if it is pink, the baby is a girl). They generate the ideas by envisioning how the cake sharers interact with the cake to achieve a surprising experience. What's more, the original idea can also be informed by the intended emotion conveyed via the cake. For example, one couple (B5's clients) wanted to record their love journey and express their love to each other, so they asked to visualize their first-time dating (they watched a film) on the cake. Then they came up with an idea about printing the film picture on the cake with edible pigments, and making two fondant minifigure characters who are "watching the film" to recreate that scene.

In general, these three creative strategies are usually interwoven in a design process. In other words, people usually employ more than one strategy in one single case. It depends on what kind of input the clients offer, and the creative motivation of cake makers and clients.

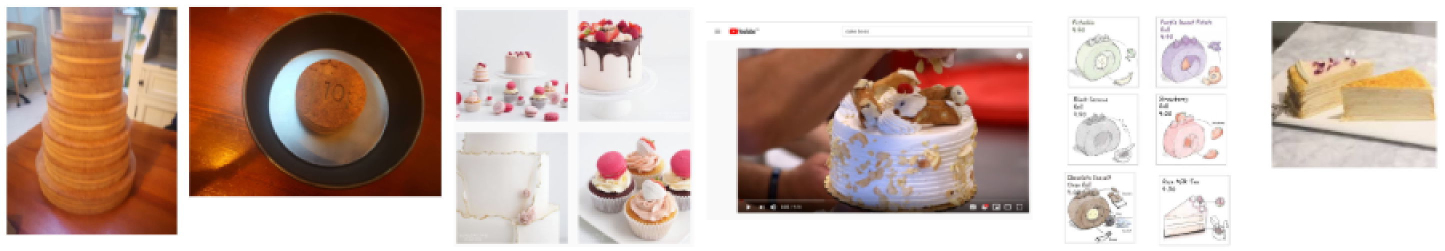
2-Embody and exchange cake information

When collaboratively forming the cake ideas, cake makers and clients extensively exchange their thoughts, regarding the physical characteristics of their cake, as well as the event in which the cake will be served. In face-to-face meetings, both cake makers and clients utilize various media to embody and convey information, so as to efficiently make the other one understood. While some information can be easily conveyed via words, some need to be presented by means of visual, physical and bodily cues. For example, B4, B5 often use dummies to explain the size of the cakes, and B1 presents that with body gestures. B1, B2, B5 usually present the 3d configuration and color of the cake by sketching. In addition, as mentioned above, clients usually describe their aesthetics preferences or the event setup with images. Table 4 indicates the information which frequently emerges in the client-baker conversation, nine of the fifteen are usually conveyed in nonverbal medium.

Figure 15 shows the most frequently-used nonverbal media used in cake ideation. While images and videos can be exchanged via online communication, some of them are exclusive in face-to-face meetings. Such media includes body gestures, or

ABOUT	INFORMATION	MEDIA
	Aesthetic style	Image,Text
	Color	Text, Image
	2d graphic pattern, texture	Image, Sketch
	Flavor	Text, Real Cake
	Material & Ingredient	Text
	3d configuration	Image, Sketch
	Available technique	Video
	2d/3d Detailed decoration	Image, Sketch
	Size (the whole & each slice)	Body gesture, Dummy, Real Cake
Cake	Price	Text
	Event spatial set-up General spatial layout Dessert table setup	Image, Sketch
	Event visual style	Image
	Delivery time	Text
Event	Delivery method	Text

Table 4. frequent modification of cake component



Dummy Baking tool Photo Video Sketch Sample cake

Figure 15. Media for information exchange

physical items in the bakeries where the face-to-face meetings usually take place. For example, B1 uses her fingers to form a triangle shape, to tell clients how large each cake slice will be. Also, B4 usually explains the 3d configuration and size of the cake by assembling the dummies. Such media is only effective when the interlocutors are physically co-present, so that they can perceive these media one-to-one scale in the flesh, and physically interact with these media.

3- Give professional advice
When developing the creative solutions for the cake, cake makers sometimes give professional advice or explain cake-making knowledge to clients. They do so for three purposes.

Firstly, they want to improve the cake quality by giving recommendations from the professional perspectives. For example, C3 has said that the bakers asked her not to add too many design elements into her wedding cake or it would look garish. B1 told her customer that the matcha cakes easily turn yellow in hot summer and might undermine the aesthetics. In this sense, clients choose whether to follow the bakers' advice, depending on their own willingness. For example, C3 followed the baker's advice and reduced the decorations, then she thought it truly worked. However, B1's clients still chose the matcha cakes because they placed more value on flavor than aesthetics.

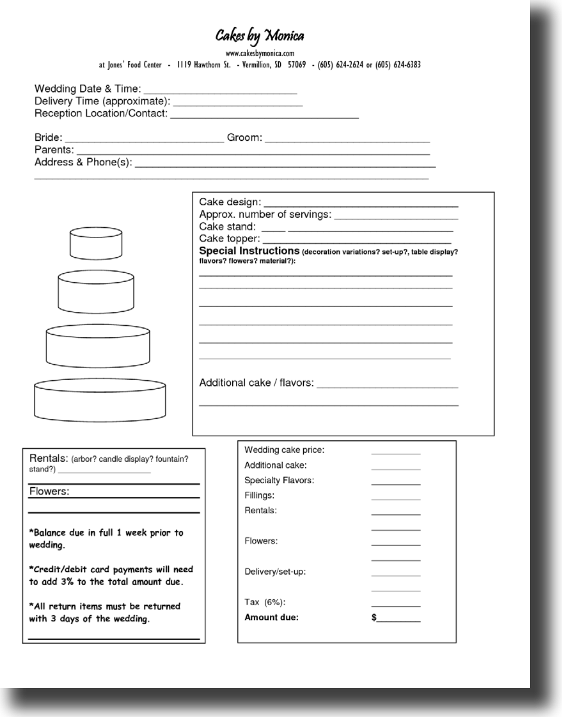
Secondly, cake makers give professional recommendations in order to stick to their own "philosophy" in cake making, so that the cake can meet the requirements from their own perspectives. In this sense, "philosophy" is defined as cake makers' personal principles or pursuits in cake making (i.e., natural food materials only). It is derived from a cake maker's self-identity in creativity and profession. For example, B1 and B3 only use natural food material with low sugar and fat for the purpose of health. B2 always tries to modernize the aesthetic style of the cake. B5 places great value on the uniqueness of the cake and never makes regular cakes.

Thirdly, cake makers sometimes convey professional suggestions or knowledge to clients, in order to fix the understanding gaps and reach a consensus. They sometimes have different understandings in a certain issue, because they have different knowledge levels and roles with regards to customized cake makings. Thus, they need to negotiate to settle the differences, so as to make a decision which both are satisfied with. The most significant understanding gaps are about cake value and viable novelty. For the cake value, clients sometimes cannot perceive the effort, time and creativity invested by cake makers. They evaluate the cake expense merely based on how much food material is used. As B5 has mentioned: " They just want to pay for the material and ingredients, they don't want to pay for the time and design." In this situation, the cake makers usually give professional advice to modify the cake ideas, in order to make a decision within the comfort zone of both sides. For example, B2 described that one of his clients had a fancy idea but with a limited budget. So they tried to generate another symplified idea which resembles the general style of the original one but requires less expenses. Additionally, clients and clients have different ideas on the viability of a certain cake idea. As mentioned before, viability of a cake idea is influenced by three factors. However, understanding these three factors require professional knowledge in cake making, which most clients don't have. So sometimes customers might come up with an idea which is perceived to be impractical by cake makers. In this situation, the cake maker usually explains relevant knowledge to the customer in order to partially bridge the knowledge gap. Then, cake makers try to persuade clients to give up this idea, or choose another viable option. For example, B3 explained to her client that it is impossible to make a three-tier sponge cake, because sponge cake is too soft to support such a structure. Then, B3 offered two alternatives, telling the client that she can use supporting tools or choose the butter cream cake.

PHASE 3: Agreement

After forming a cake idea through ideation and negotiation, cake makers and clients need to confirm their common decision and reach an agreement. Usually, cake makers need to document the design decision and confirm that with clients, after the face-to-face meeting. Based on the interview, I discover that they confirm the agreement through three actions: **1) converging the information. 2) presenting the outcome. 3) convey the common decision.**

1-Converging information
After the decision is finalized, cake makers need to collect all the information about the finalized cake idea, and record them on a contract. However, such information can be very fuzzy, fragmentary and diverse, because they are conveyed via different media (i.e., image, body gesture, video). Thus, cake makers turn all the information into texts and images, tabulate them, and then store the information in a pdf file or a physical paper. From my investigation, cake makers set up the purpose for three purposes. First, traceability of information is important.


Cakes by Monica
www.cakesbymonica.com
at Jones' Food Center - 1119 Hawthorn St. - Vermillion, SD 57069 - (605) 624-2624 or (605) 624-6383

Wedding Date & Time:
Delivery Time (approximate):
Reception Location/Contact:

Bride: Groom:
Parents:
Address & Phone(s):

Cake design:
Approx. number of servings:
Cake stand:
Cake topper:
Special Instructions (decoration variations? set-up?, table display? flavors? flowers? material?):

Additional cake / flavors:

Rentals: (arbor? candle display? fountain? stand?)
Flowers:

*Balance due in full 1 week prior to wedding.

*Credit/debit card payments will need to add 3% to the total amount due.

*All return items must be returned with 3 days of the wedding.

Wedding cake price:
Additional cake:
Specialty Flavors:
Fillings:
Rentals:
Flowers:
Delivery/set-up:
Tax (6%):
Amount due: $

Figure 16: replica of B5's contract template

First, the source of decision details should be identified, so that the bakers and clients can recall and examine how the final decision comes out. Because the contract is taken as a proof of clients' participation and agreement in the final decision. For example, B2 and B4 usually document clients' quotations which lead to a certain aspect of final decision when talking with clients. Second, the inclusiveness of the information should be focused. All the details regarding the design decision should be documented. For example, B2 told that he tried to include as many pictures as possible in the contract, to illustrate every decoration detail of the cake. In this way, cake makers can check all the details during cake making, and make sure that they fulfil all the clients' requirements. In this sense, the contract serves as a cake-making guideline for bakers. Third, the accuracy of the information is significant. The design decisions should be precisely described and consistent to the intended outcome, in order to avoid miscommunication. For example, B5 described that one of her clients ordered a cake but they forgot to accurately clarify the color. Then the client was unsatisfied with the cake because she thought the color was not bright enough.

2-Presenting the outcome

In the contract, cake makers also visualize the intended cake, informing clients of what they will get. From my investigation, cake makers usually present cake ideas in two methods: 1) bottom-up 2) top-down (Figure 17). Firstly, the bottom-up method involves all the details of the cake, usually in the form of photo collages. This method is time-efficient, and is able to realistically visualize the texture and gustatory quality of cakes. Based on interviews, B1 and B4 always collect photos to present ideas in order to save time, for saving time. However, clients cannot perceive what the cakes will look like as a whole. It might be inconsistent with the finalized cake ideas because people usually do redesign based on the reference photos but they cannot present their renovation on those fixed photos. Secondly, the top-down method presents the whole cake picture regarding the 3d configuration and spatial composition, as well as the design intervention made by co-designers. The typical top-down method is sketching. However, it cannot comprehensively and vividly present the details and texture of the cake. For instance, C2 mentioned that the baker made a line sketch to present the cake but didn't apply the color. After the cake was delivered, she found that there was a mismatch of the color layout between her expectation and the real cakes. Besides, this method might be time-consuming, because cake makers need to visualize everything from scratch. According to interviews, B1, B3 and B5 only made sketches for expensive customers cakes, which are worth time investment.

The presentation is an essential factor to customers' satisfaction in the finalized cake. Because clients expect consistency between the presentation and the real cake which they would get. According to interviews, C1, C3, C4 claimed that they were satisfied with the cakes, because the real cakes generally looked the same with what they had expected, based on the presentation made by the cake makers. C3 mentioned that there were some nuances between her expectation and real cakes, because the idea presentation didn't cover those details, but generally she was satisfied with that cake.

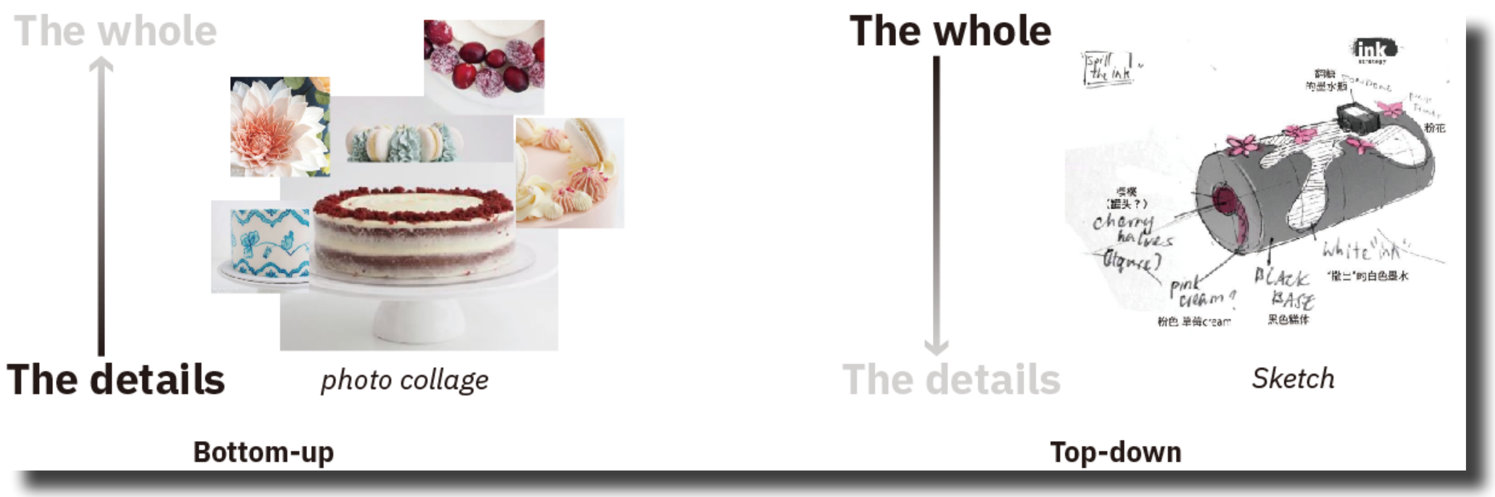


Figure 17. Two way of presenting design results

3- Conveying the common decision

After finishing the contract, clients usually share the digital version with clients via email, so that clients can go through all the details of the contract and respond to the cake makers for confirming the contract or making some tiny adjustments. An interesting insight is that, B2, B3, B4 and B5 stressed that they liked using email to convey the information about the final design decision. First, email offers a feeling of control for cake makers to manage a large amount of information. Bakers usually need to deal with several business cases at one time, and email helps to categorize and trace extensive information, and give a clear information overview. As B5 has said: " I have a lot of orders, it's easier for me to have everything in email." Second, information exchanged via email is more effective to decision-making, compared with online chat or F2F talk. Email is perceived to be a formal tool for communication, so people usually take their words seriously. For example, B2 said that:"I prefer to use email because clients will think it over before typing something. When they talk, sometimes they say something without consideration."

2.3 Discussion

In this section, we will investigate how the design decision is made by clients and bakers. After that, we will discover users' concerns and latent needs of their communication and decision-making.

2.3.1 Workflow of design decision making

Based on the user study results, I investigate that the process of idea formation and decision making is divided into three phases (Figure 18).

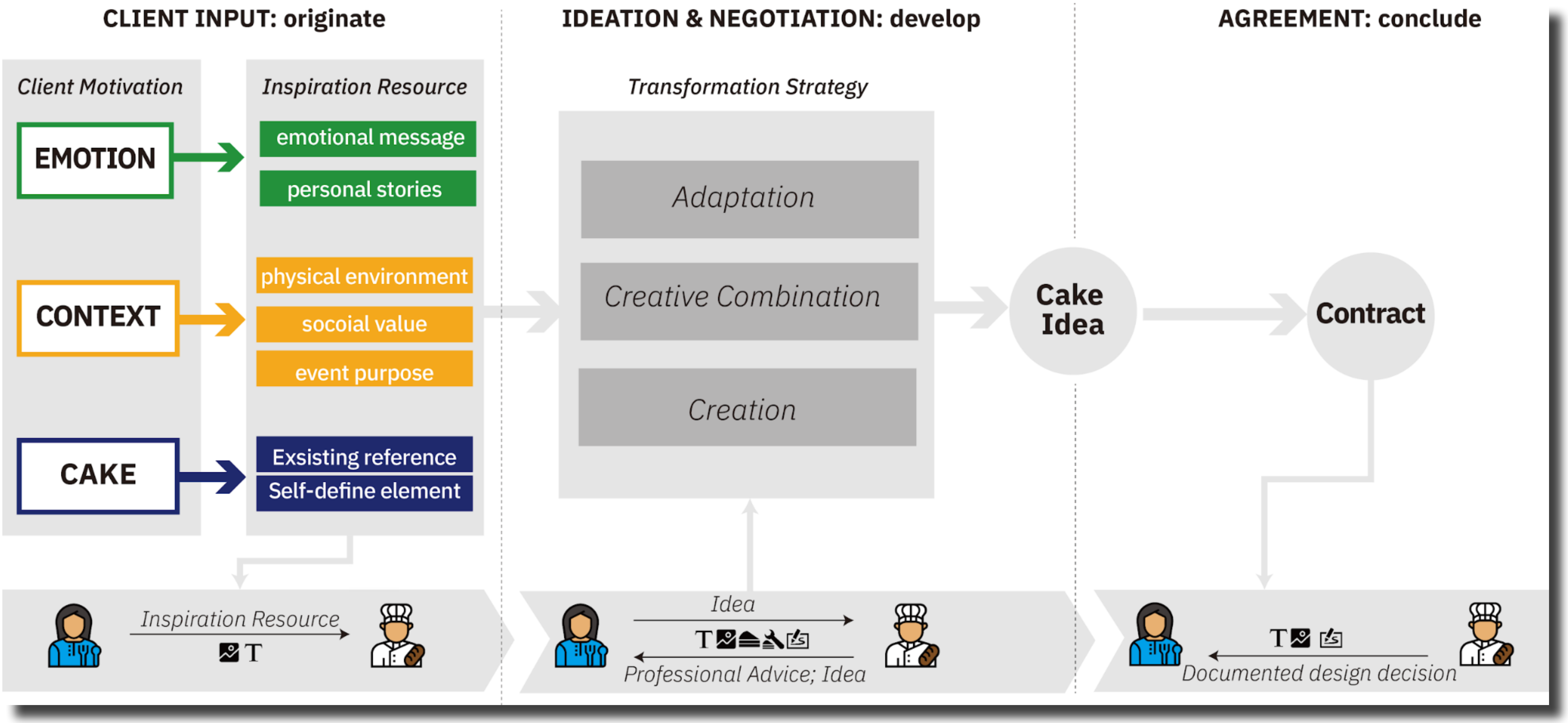


Figure 18: 3 phases of idea formation and decision making

How does the idea originate?
Ideas originate from the phase of "client input", in which clients reflect on their preference, limitations and imagination, and visually transmit these information to cake makers as the inspiration resources. Usually, clients reflect on what they need from three perspectives: cake, context, emotion. This is firmly based on their motivation to order a personalized cake: achieve self-identity (own a unique cake), make sense of an event, convey emotion (2.2.1). Cake-oriented perspective refers to the process that clients directly define the desired gustatory property and physical characteristics of the cake. Context-oriented perspective involves the features of physical environment, social value and the purpose of the event where the cake will be consumed. Emotion-oriented perspective requires clients to think about what kind of emotion message or personal story can help to convey the intended emotion to someone via the cake. Usually, a client might not employ all the three perspectives at one time, they choose one or two depending on the intended "use" of the cake. Through these three perspectives, clients generate the necessary information which will inform the cake design. I define such information as "inspiration resources".

After the inspiration resources are generated, they are conveyed to the cake makers by clients. They present their thoughts by **developing a narrative or description in aid of a collection of images.** They use images to describe the intended physical properties of the cake, the general aesthetic style they want and the visual elements which can be appropriated. Such information is hard to express in words.

How is the idea developed?

After cake makers are informed of clients' input, they help clients to turn these inspiration resources into tangible cake design by **synthesizing the client's input into cake component design in aid of professional cake-making knowledge.** As mentioned above, they develop the cake ideas through three actions: adaptation, creative combination and creation.

Adaptation implies appropriating or redesigning the existing design paradigms derived from reference images, by changing the parameter or modifying the physical properties. **This design process is basically centered on reference images.**

Creative combination is defined as freely combining existing design elements to generate a creative solution. These combined resources are derived from existing design elements of an example cake, pre-designed graphics, and visual elements related to context including the surrounding environment of the cake and cake sharers. **This information is usually in the form of reference images and photos in the design process.**

Creation refers to transforming self-generated creative ideas into cake components design. These ideas can be some self-defined 2d or 3d shapes, created from scratch. Additionally, people come up with original ideas from the physical environment, social value and purpose of the context where the cake will be consumed. The cake is designed to fit the "cake context" sensorily and socially. In addition, cake creation can be emotion-oriented, they define a symbol or token to represent some emotional messages or personal stories, and apply that to the cake. **Usually, people embody these original ideas in images, sketches, body languages or verbal description.**

Besides ideation, clients and cake makers extensively exchange other information including personal constraints and professional advice, so as to iterate the ideas. **They transfer their thoughts by embodying these information in aid of verbal, visual, spatial and gestural cues.** In this way, the cake idea is built up brick by brick.

How is the idea concluded?

After the ideas are collaboratively formed by the clients and cake makers, the cake makers usually need to conclude the design decision as a proof of their agreement.

In this process, they need to **texualize all the design details and document this information into a static media such as a paper contract or a pdf file.** This information should be traceable, for people to check by whom a certain detail is determined in order to achieve credibility of this document. This documentation should be inclusive, covering all the details of the final decision, so that cake makers can take it as a cake-making guideline. Also, the contract should illustrate the decision as precisely as possible, in order to avoid miscommunication and keep consistency between what clients expect and what bakers will make. Besides documenting the details, **cake makers visually present the finalized cake ideas to help clients build up an expectation of the design output.** They usually utilize two representation methods: photo collages(bottom-up) and hand sketch (top-down). The former one is more time-efficient, and presents vivid details and textures but fails to flexibly give an overall picture of the cake. The latter offers a whole image of the cake and flexibly presents how the cake is composed, but cannot illustrate the realistic details and food texture of the cakes. Also, it can be time-consuming and skill-demanding.

2.3.2 Concerns & Latent needs

From the user results, I investigate several concerns and latent needs of client-baker communication.

First, there is a lack of **integration of multiple media in the design process.** We have discussed that clients and customers utilize imagery, spatial, gestural cues to develop ideas . They have different functionalities for idea embodiment. Reference images offer design examples for people to appropriate and redesign, especially in adaptation and creative combination. Photos of the event venue help people to design a cake visually harmonious to its surrounding environment. Some images are directly taken as a decoration by edible printing techniques or being placed on the cake physically. All the images are usually displayed digitally on mobile phones or tablets. Besides, sketching on paper usually helps to present some self-graphics. In addition, tangible dummy and intangible body gestures help to define the 3d configuration and size of the cake. In general, the media mentioned above are in different dimensions (2d or 3d), different scales, and different mediums (digital or physical). In the physical world, these media can not be well integrated to support ideation and presentation. For example, C3 mentioned that the cake maker used line sketches to present the spatial layout of the decorations, then she needed to imagine the final effect by mentally complementing the texture and detail of the decorations derived from the reference images.

Second, **there is a lack of immediate and direct perception in the effects of their design intervention, because the media (i.e., image, dummy) they use to generate ideas is static and non-interactive.** This implies that they cannot directly modify the design elements (i.e., a pattern in a reference image) to implement their design intervention, to see the "before and after". Thus, they cannot simultaneously perceive the visual and spatial impacts of their design actions in the design process. Lacking simultaneous perception of design impacts might lower the efficiency of decision-making. For example, cake makers sometimes give aesthetic recommendations and offer other alternatives to clients, but it is difficult for clients to make a choice because they cannot perceive the expected impacts of cake makers' advice .

Third, **a time-efficient method is needed for cake makers to embody the cake ideas.** Time efficiency and management is an essential concern for cake makers in offering customized cake services. So they try to reduce the time in presenting the cake ideas in order to decrease the temporal investment. This is why some cake makers like using photo collages to visualize the finalized idea. For some cake makers who sketch, they also mentioned that sketching was time-consuming, and they only sketch if that cake was expensive.

Fourth, **there is a need for presenting the finalized idea both with vivid details and an overall image.** As mentioned above, the two frequently used methods, photo collages and sketches, have their own pros and cons . Photo collages can present the details and food textures realistically, but cannot provide a whole picture of the cake and visualize design intervention. Sketch can accurately present the overall sense of the design concept, and flexibly show the design intervention made by bakers or clients, but it fails to visualize the vivid details and cake textures. Missing an overall image or vivid details might lead to clients' misunderstanding in the design decision and inconsistency between the presented cakes and real cakes. Hence, it might undermine the customer satisfaction.

Finally, **cake makers need a more efficient way to manage the decision information so as to conclude design the final decisions.** Cake makers place a great value on the contract because it is a formal proof of the business agreement as well as a cake-making guidelines. They make an effort in preparing for the contract through the design process. For example, B1, B2, B4 mentioned that they always take notes to record clients' quotations relevant to the design decision, when talking with clients. Additionally, B2, B3, B5 mentioned that they spend extra time organizing the design decision information into a text file, after the face-to-face meeting.

2.4 Conclusion

This section reveals how cake makers and clients collaboratively generate a design decision on the personalized cakes, through three phases: ***originating from client input, developing by ideation and negotiation, concluding for agreement.*** Then I conclude the concerns and latent needs of client-customer communication. In the next chapter, I will combine these findings with literature review, to conclude the design requirements of the socialVR co-design tool.

3. Design proposal

The previous chapter investigates how cake makers and clients collaboratively generate ideas and make design decisions. In this chapter, the design requirements of the socialVR co-design tool will be concluded, based on the user research results and literature reviews.
These design requirements will inform the design decisions, regarding the intended interaction of the socialVR tool. Then, the three main design decisions will be introduced. Finally, the overall user experience will be elaborated in the use scenario.

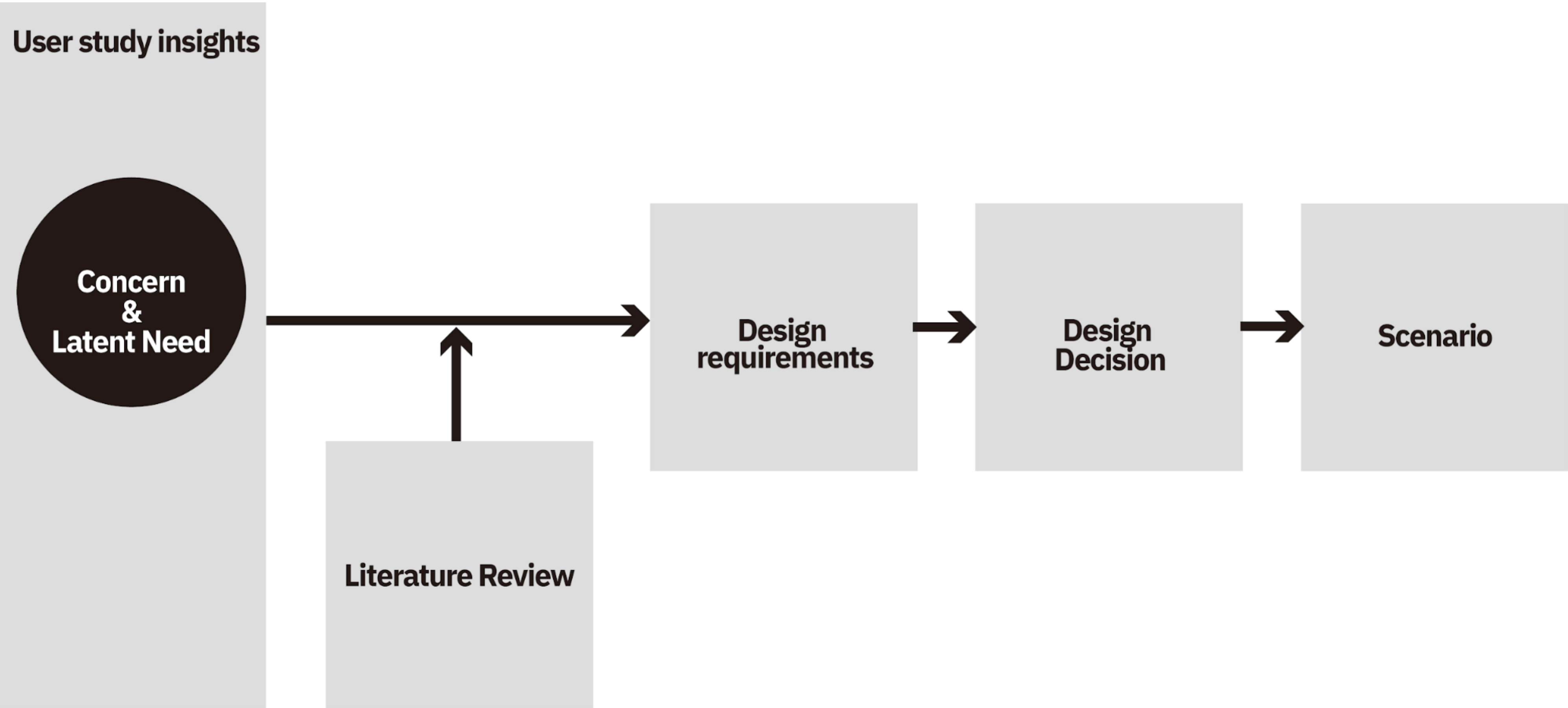


Figure 19. Structure of this chapter

3.1 From research to design

From user research, some significant insights were concluded, with regards to current interaction as well as users' concerns and expectations. Then, I will discover how socialVR technology helps to fix the problems or fulfil the needs, based on literature review. After that, these insights will inform the design requirements of the social VR co-design tool.

3.1.1 User research result

Concern & Latent need

1. There is a lack of integration of multiple media in the design process.
2. Participants lack immediate and direct perception of the effects of their design intervention.
3. A time-efficient method is needed for cake makers to embody the finalized cake ideas.
4. There is a need for presenting the finalized ideas including both vivid details and an overall image.
5. Cake makers need a more efficient way to manage the decision information so as to conclude design decisions.

3.1.2 SocialVR opportunities

Based on the latent user needs and concerns, we will explore the opportunity of socialVR in dealing with these issues, based on literature review (chapter 1). We will conclude design requirements regarding functionalities and interaction techniques of the co-design tool, on the basis of the current state of art in socialVR and virtual modelling techniques.

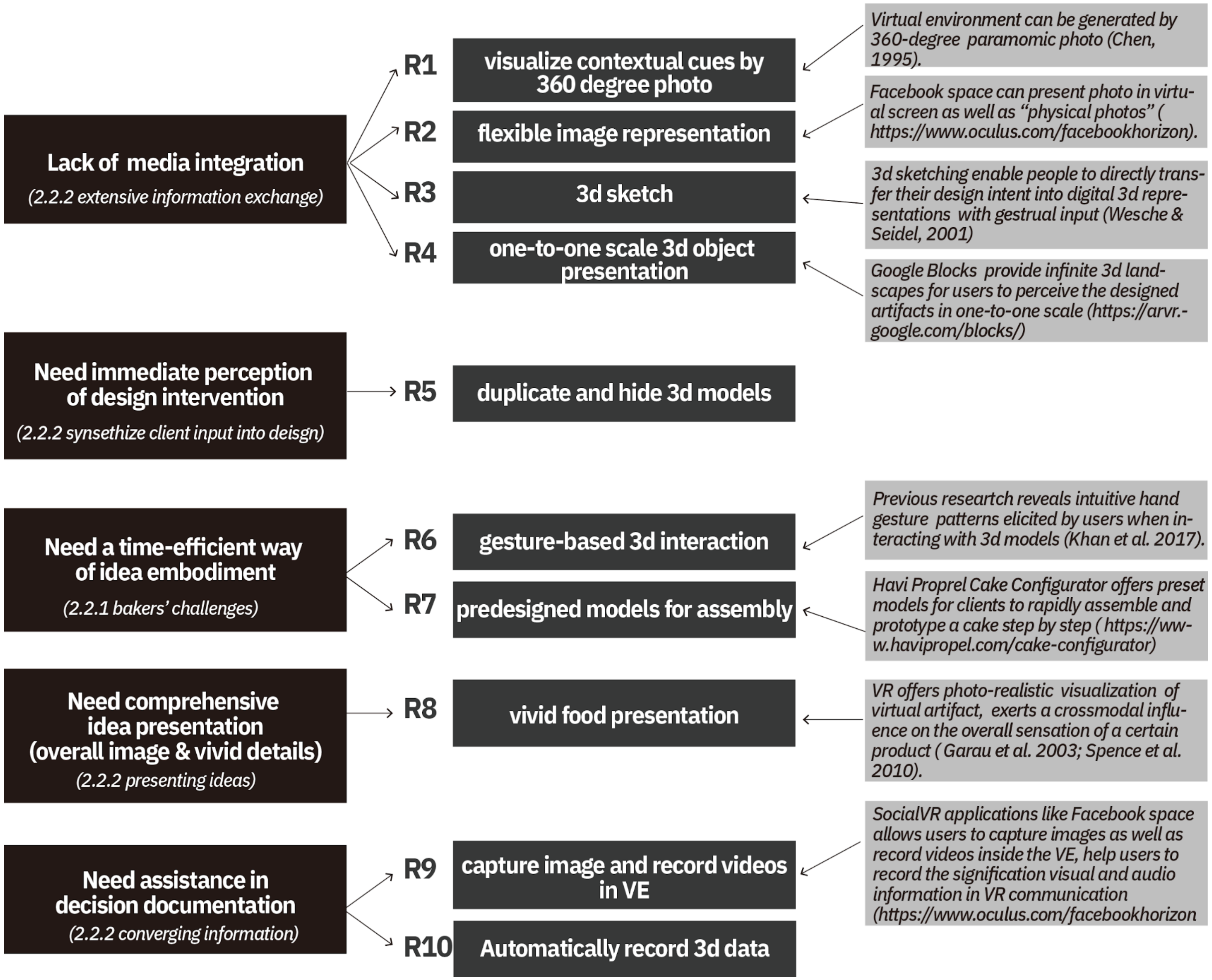


Figure 20. design requirements based on user research and literature review

3.1.3 Design requirements

1. The tool should integrate the various media used in ideation and presentation by (Figure 21):

R1: Transforming panoramic photos into the immersive virtual environment.
R2: Presenting the images in two forms: physical photos floating in the 3d space; digital pictures presented in the virtual screen.
R3: Allowing users to draw 3d curves in the 3d space
R4: Allowing users to manipulate 3d shapes in one-to-one scale

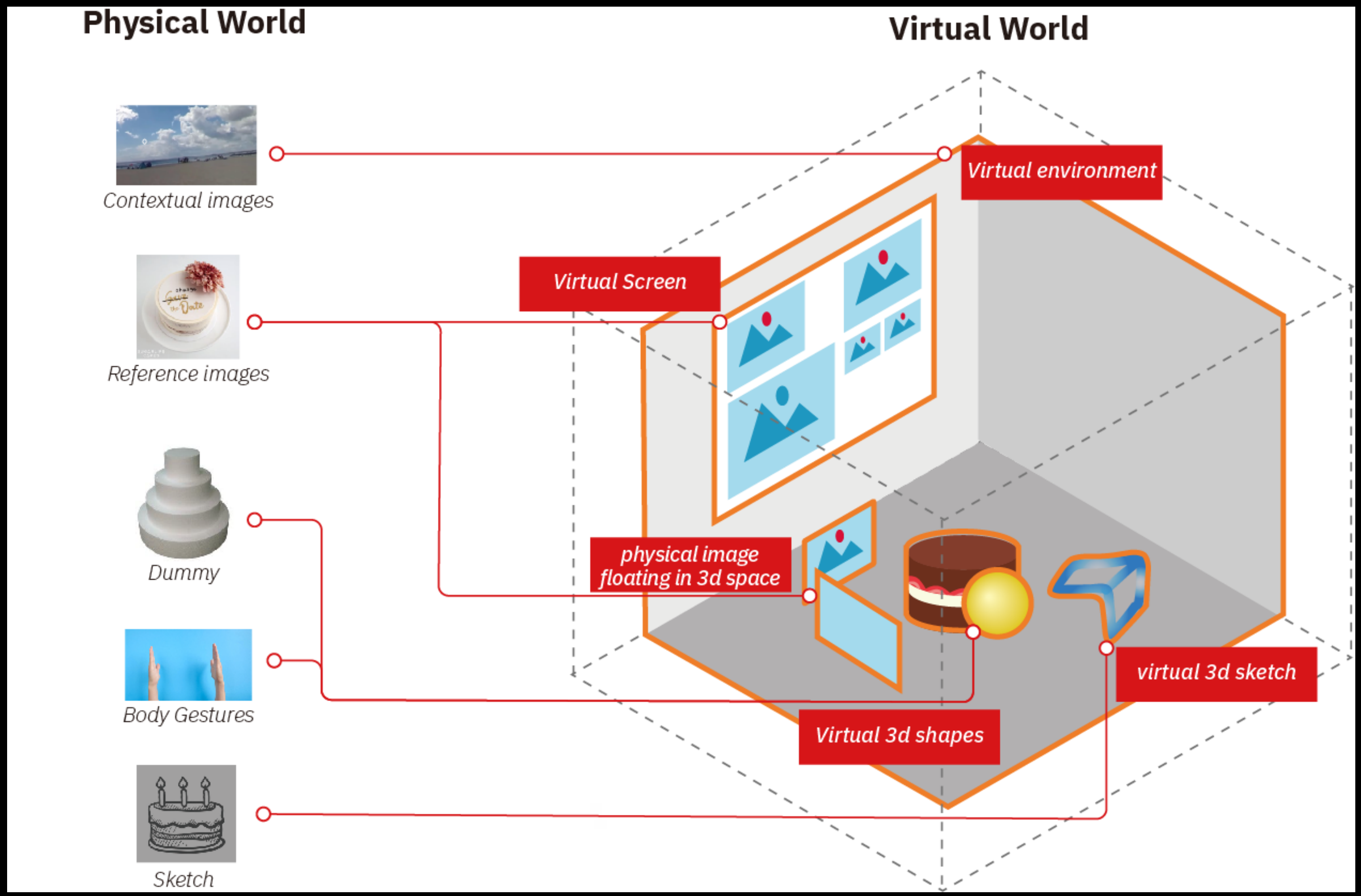


Figure 21. Media integration

2. The tool should enable users to perceive the effects of their design intervention by:

R5: allowing users to duplicate and hide the 3d geometries.

3. The tool should improve time-efficiency of generating and presenting ideas by:

R6: enabling users to use intuitive and easy gestural inputs to manipulate virtual objects.
R7: offering pre-designed models of the most commonly used cake components

4. The tool should comprehensively present the cake with both the overall images and details by:

R8: giving vivid visual cues (i.e., glosiness, color identity, color density, visual texture) of the virtual cake.

5. The tool should assistant cake makers in documenting the final decision by

R9: allowing users to capture images and record videos in VE
R10: automatically calculating and archiving the 3d data of the virtual cake

3.2 Design of socialVR tool

Based on design requirements mentioned above, we will elaborate three design decisions of the socialVR tool. After that, we will describe the overall user experience in use scenario.

3.2.1 Design decisions

In this part, three design decisions will be introduced: **virtual design world setup, preset model database, 3d manipulation grammar.**

Virtual design world setup

FIXME indicated the basic spatial layout of the virtual design world. The clients and cake maker sit shoulder by shoulder, to communicate and design. They are sitting in front of a virtual table. On the table, there is a 3d modelling window which would accommodate the virtual model. A virtual toolbelt is positioned on the edge of the table, for users to get access to creative materials or 3d manipulation tools. A virtual screen is floating in front of users, so that they can share visual information.

Additionally, we propose that users are able to seamingly switch between two design modes: Design-in-context and Design-in-workshop (Figure 22). They can freely shift the setup of the virtual environment to facilitate creative work. "Design-in-context" is defined as embodying the virtual cake in the intended cake context, so that users can perceive the mutual impact between the finalized cakes and the event environment. However, realistic contexts might bring visual information noise to co-designers when they are operating 3d shapes, so we propose an alternative design mode: Design-in-bakery. This mode enables clients and bakers to communicate and co-design in the virtual bakery of the cake makers. We assume that cake makers will be more proactive and enaged in their daily working contexts. The setup of the bakery will be tweaked a little bit to offer an neat viewport with a reasonable amount of contextual information (i.e., unnecessary interior decoration), so that users will not be disturbed by excessive visual noise.

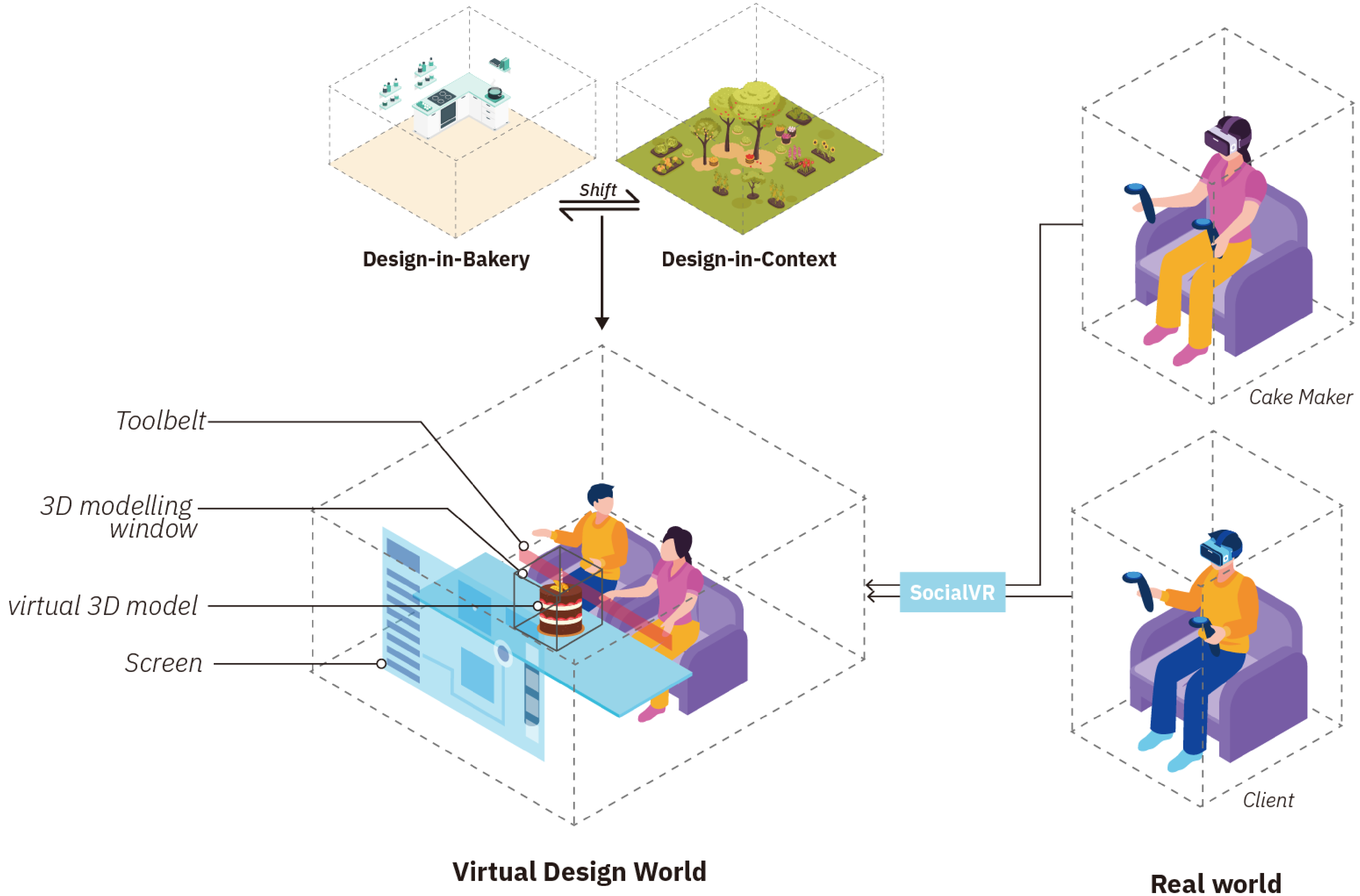


Figure 22. Virtual world set-up

Preset model database

Based on the cake pictures offered by interviewees, we discover the most frequently used objects or 3d geometries for cake decorations and configurations (i.e., flowers, cream icing, macarons, cylinder, sphere). So, I propose a 3d material database including the most commonly used cake components, so that users can directly derive these models to do rapid assembly or redesign works. These models include:

Common cake component:

- cream icing and common dessert
- plant,
- fruit

Primitive shapes:

- numbers
- letters
- basic 2d shape (circle, square, triangle)
- basic 3d shapes (sphere, cube, cone, cylinder, pyramid)

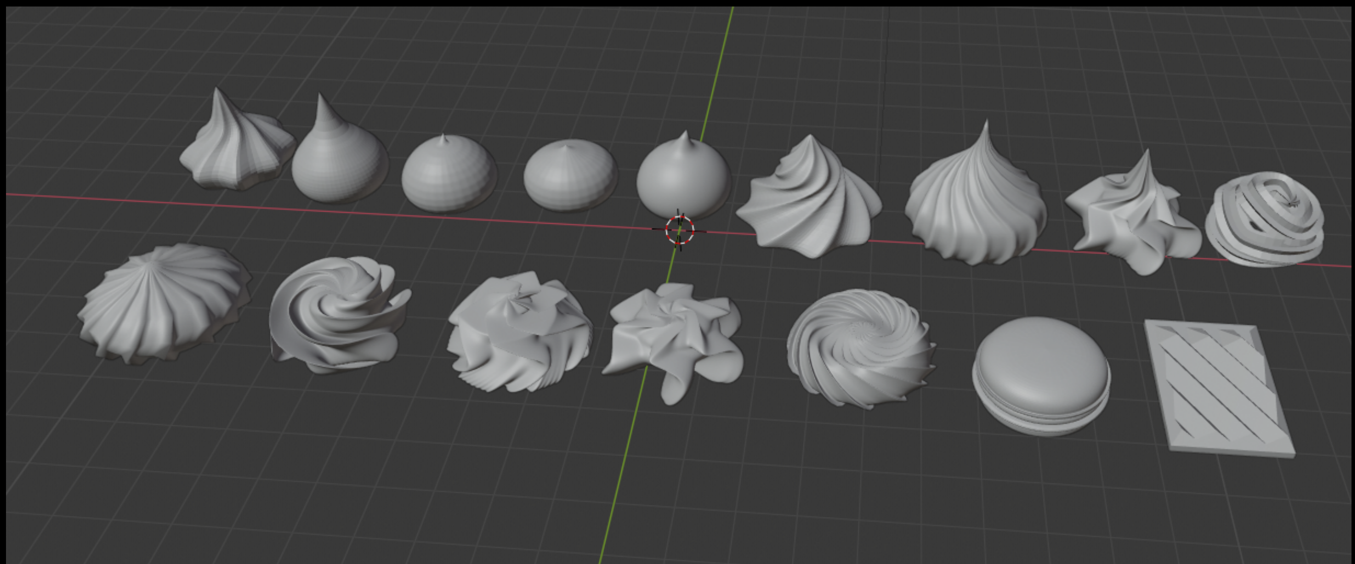


Figure 23. examples of preset models

3d manipulation grammar

For the purpose of easy use and quick learning, we chose to apply basic 3d operation without direct shape deformation: translation, rotation and scaling. In addition, we assume that these three operations are powerful enough to cake design. Below is the subdivision list of all available 3d operations.

- ***Translation: x-axis, y-axis, z-axis***
- ***Rotation: x-axis, y-axis, z-axis***
- ***Scaling: x-axis, y-axis, z-axis, proportional scaling***

In this project, we will initially develop the hand gesture commands based on user-elicited gesture grammar developed by Kahn et al (Figure 24)[63]. We will focus on the bimanual motion, including the movement of hands and relative motion between two hands. The motion and position data can be captured by Oculus touch and Oculus motion sensors. We will iterate and adapt this interaction paradigm in the ensued prototyping implementation and user tests.

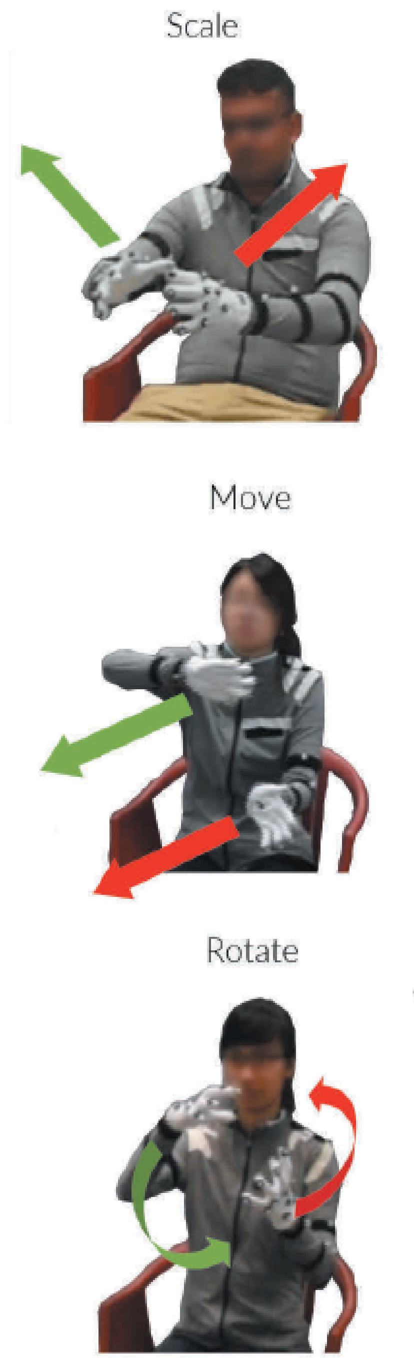


Figure 24: user-elicited gestural command for 3d manipulation (Kahn et al., 2017)

3.2.2 Scenario

The design decisions will be elaborated in the form of use scenario (Figure 25), describing the experience and interaction of co-designing the customized cakes. All the de

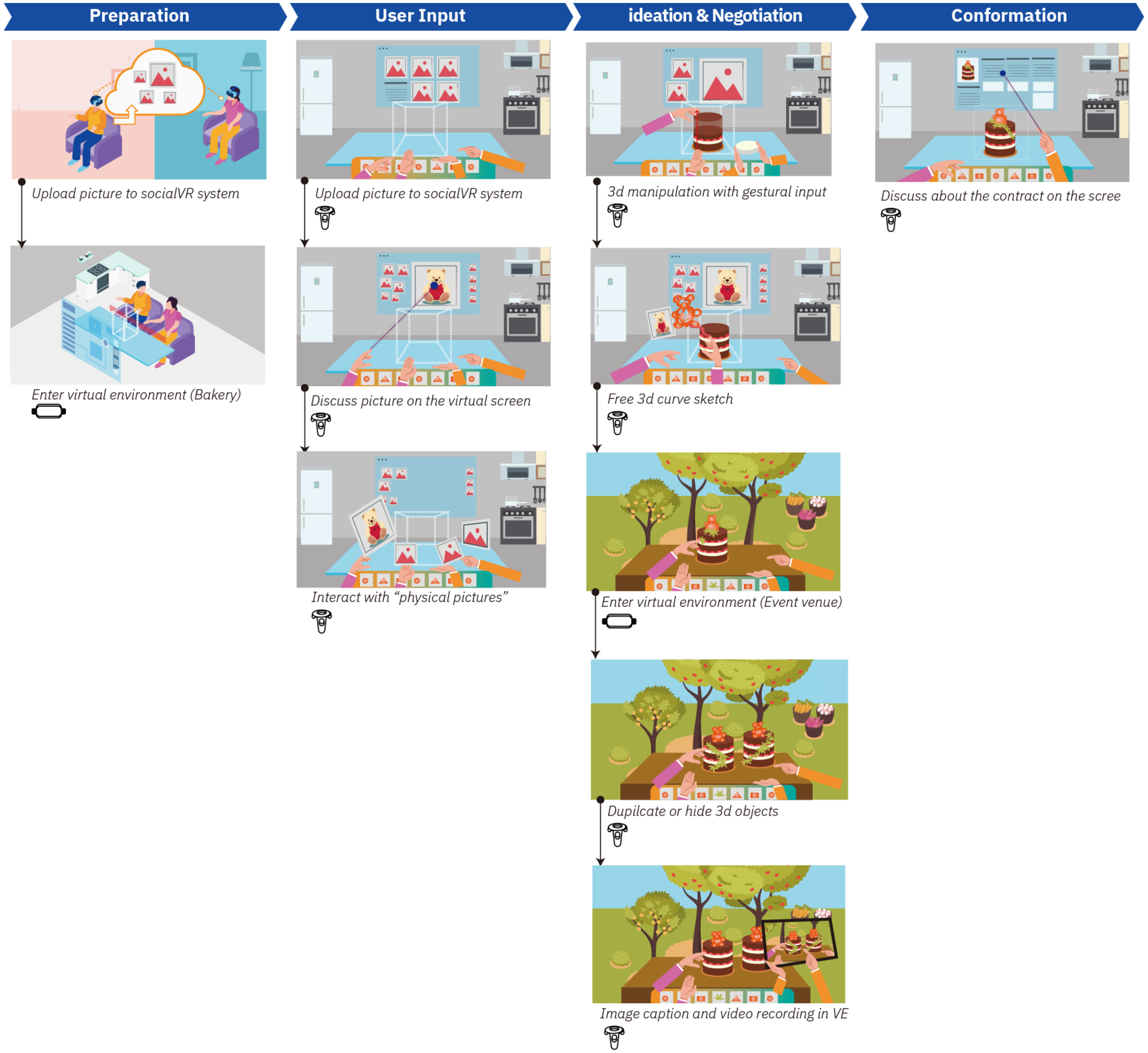


Figure 25. Storyboard

Ben was going to customize a cake for his wedding. He contacted Lisa, a cake maker who is living far away from him. Thus, they choose the socialVR tool to discuss cake ideas, so that they don't need to commute. Today, they would have a socialVR meeting to ideate the wedding cake.

Before the meeting, Lisa asked Ben to collect several pictures which are relevant to his cake ideas, and upload them to the socialVR cloud. Ben collected a set of pictures including: reference cake photos, the panoramic photo of his wedding venue, photos of him and his wife. In addition, Ben typed in his basic requirements: number of wedding guests, preferred flavour, event location and delivery date.

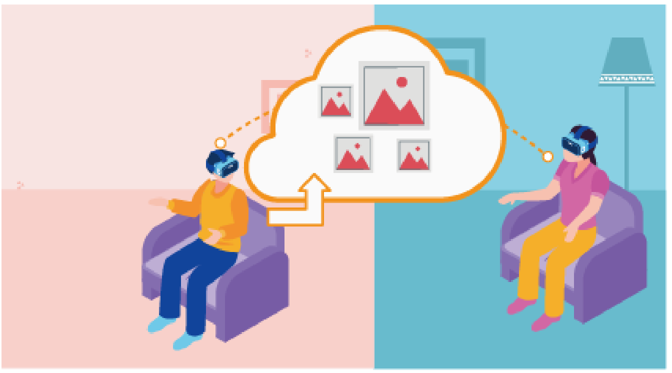


Figure 26

After uploading, the formal meeting started. Ben entered the virtual bakery, and sat with Lisa shoulder by shoulder. He can see a table, a toolbox bar, and a big screen. The screen was presenting the images which Ben uploaded before.

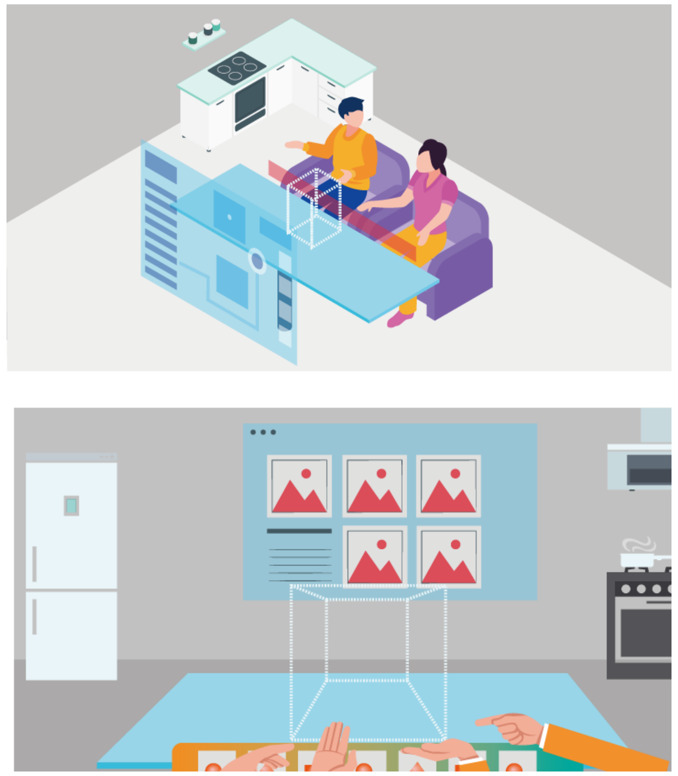


Figure 27

The conversation started by discussing these images. They used the pointers to refer to the images presented on the screen.

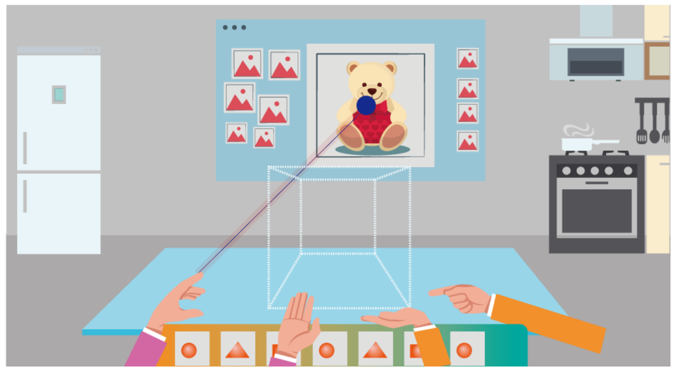


Figure 28

After this discussion, they selected the most relevant pictures by clicking with pointers. Then, the image "came out of the screen" and became physical photos floating in the 3d space. Ben and Lisa can physically interact with the pictures, to deeply discuss how to integrate the images into cake design **(R2:Presenting the images in two forms: physical photos floating in the 3d space; digital pictures presented in the virtual screen)**. Ben talked about a picture of a teddy bear toy. He said that it was the first gift he sent to his wife and then they fell in love, so he wanted to make a bear figure on the cake, to record their happy memories. So he wanted to add a teddy-bear decoration on the cake.

Then, they scanned the preset model database, and selected the 3d shapes which they can use to embody the cake ideas **(R7: offering pre-designed models of the most commonly used cake components)**. They moved their hands to move, resize and rotate the 3d shapes, and assemble the virtual cake rapidly **(R6: enabling users to use intuitive and easy gestural inputs to manipulate virtual objects)**. They easily decided the size of the cake, because they perceived the virtual cakes on a one-to-one scale **(R4: Allowing users to manipulate 3d shapes in one-to-one scale)**. Then, they adapted the color, flavor and ingredient of the cake. The texture of the cake and cream is vividly presented on the 3d geometries, Ben could totally perceive what the real cake would look like **(R8: giving vivid visual cues (i.e., glosiness, color identity, color density, visual texture) of the virtual cake)**.

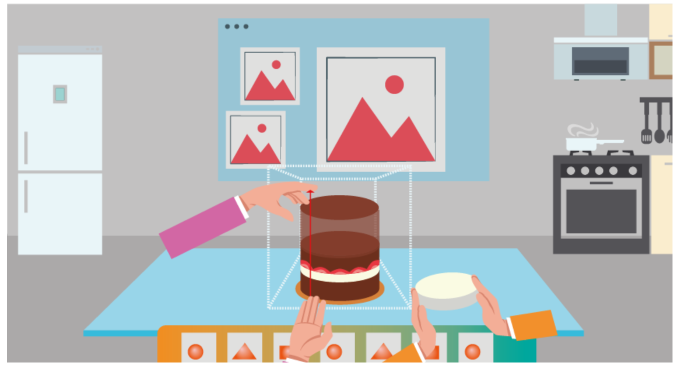


Figure 29

Then, they used the 3d sketch to draw a virtual teddy bear, based on the reference image, then he resized the sketched object, and put it on the top of the cake as decoration **(R3: Allowing users to draw 3d curves in the 3d space)**

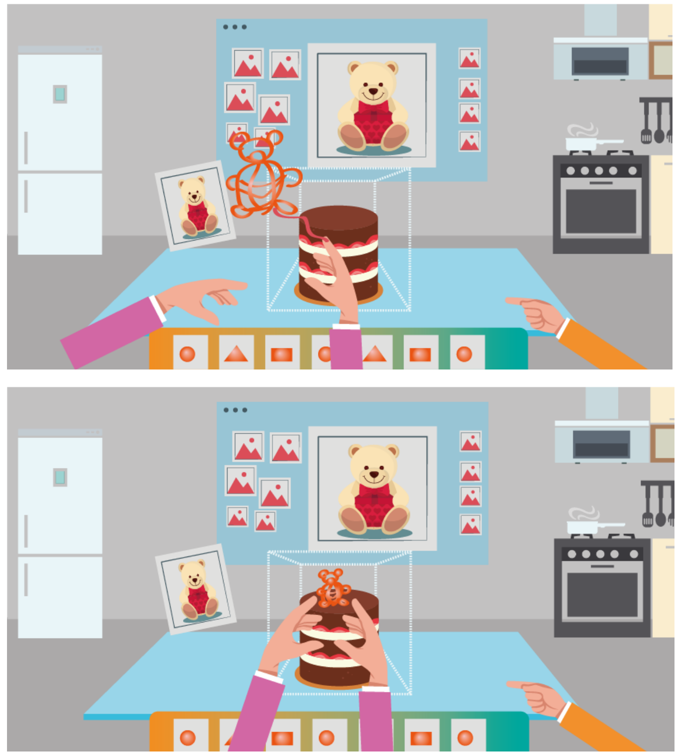


Figure 30

Then, Ben shifted the virtual environment into the garden where his wedding would be **(R1: Transforming panoramic photos into the immersive virtual environment)**. He found that there were a lot of plants in the garden, so he derived a leaf model from the preset model database, and decorated the cake with some leaves.

Figure 31

They explored the proper spatial layout of the leaves, so they duplicated the cake and tried another way of organizing these leaves. Then they make a decision by comparing these two cakes. Additionally, Lisa suggested that the leaves were too much and made the cake look garish, so she hid some leaves and told Ben that it would look better **(R5: allowing users to duplicate and hide the 3d geometries).** Ben agreed with Lisa. During this process, Lise recorded their action by video recording, in order to document how the decoration is made and decided **(R9: allowing users to capture images and record videos in VE)**.

Figure 32

Ben is satisfied with his artwork, and captured the picture of the virtual cake. Lisa also felt happy that the cake is creative but doable. All the cake information was automatically recorded in the system, including the cake 3d numeric data, visual data, basic requirements, information of delivery and basic information of clients **(R10: automatically calculating and archiving the 3d data of the virtual cake)**. The system automatically organized the information and generated a contract. The contract was presented on the big screen in VE. Lisa and Ben checked the information of the contract, and reached an agreement.

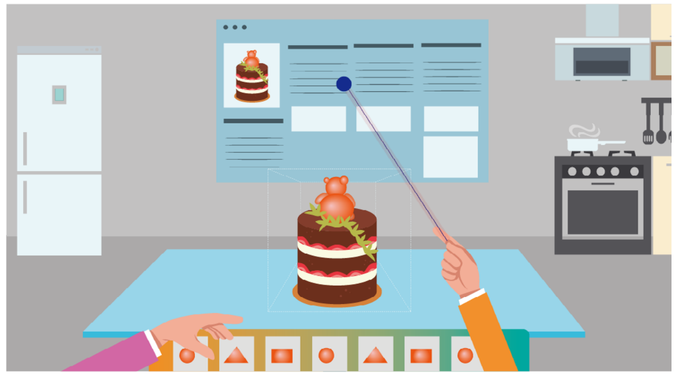


Figure 33

4. Implementation

In the previous chapter, the design requirements and decision decisions of the socialVR tool are clarified. In order to discover whether these requirements are able to facilitate the co-design activity of cake makers and clients, a medium-fidelity prototype is developed. It is a social virtual reality application for two users to communicate and co-build customized cakes. Thus, in this chapter, we will introduce the process of prototype implementation. Firstly, the implementation scope will be elaborated, indicating which design requirements will be fulfilled. After that, we will introduce the hardware and software used for application development. Finally, the interaction techniques of the prototype will be described, based on the sequence of the user journey.

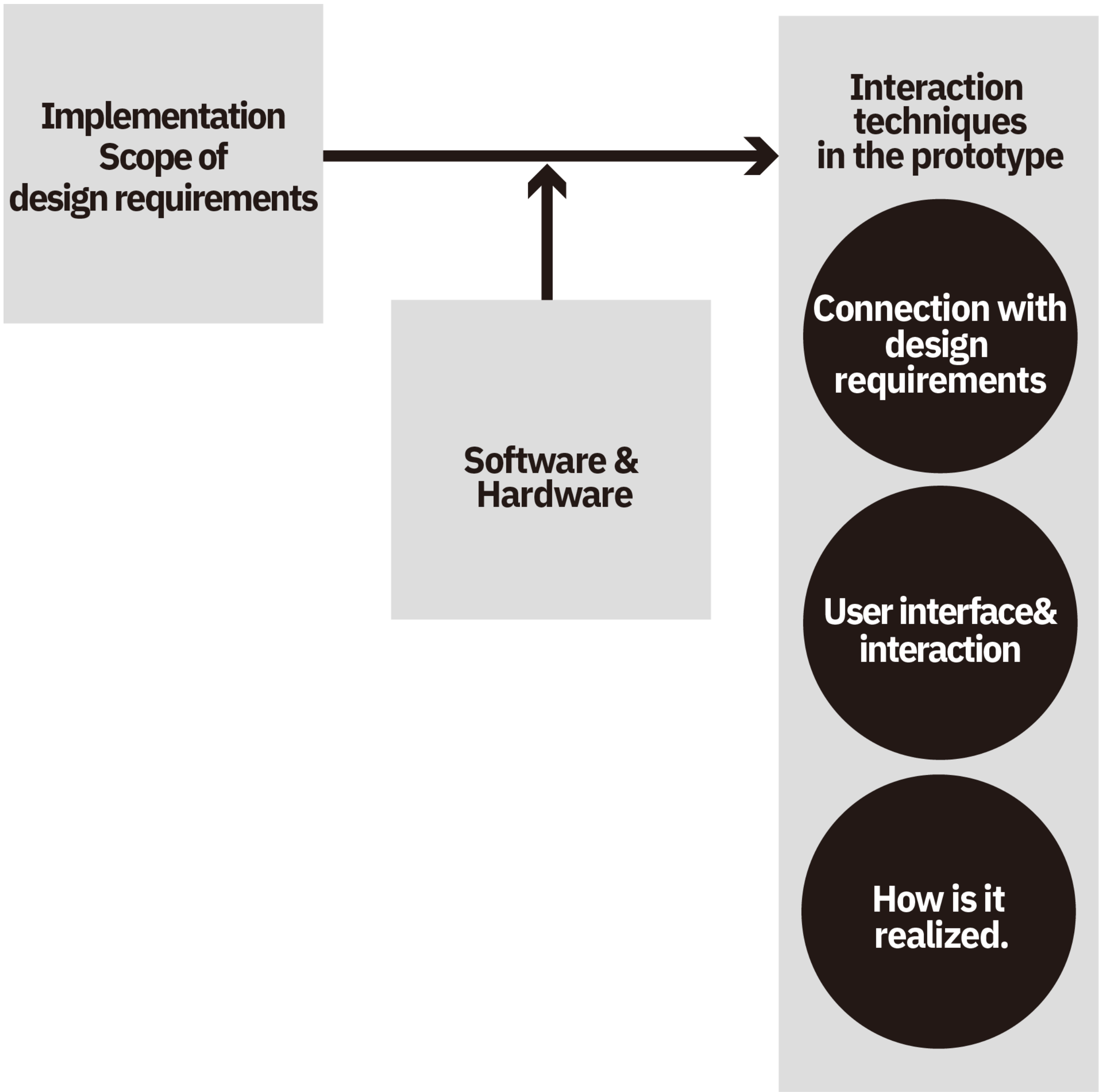


Figure 34. Structure of this chapter

4.1 Implementation Scope

In this project, I will focus on the first two phases of client-baker communication: client input, ideation & negotiation, because this part involves the most essential social interaction between interlocutors. Hence, I decided to implement the eight (R1-R9) of the ten design requirements, because they aim to fulfil users' latent needs in these two phases.

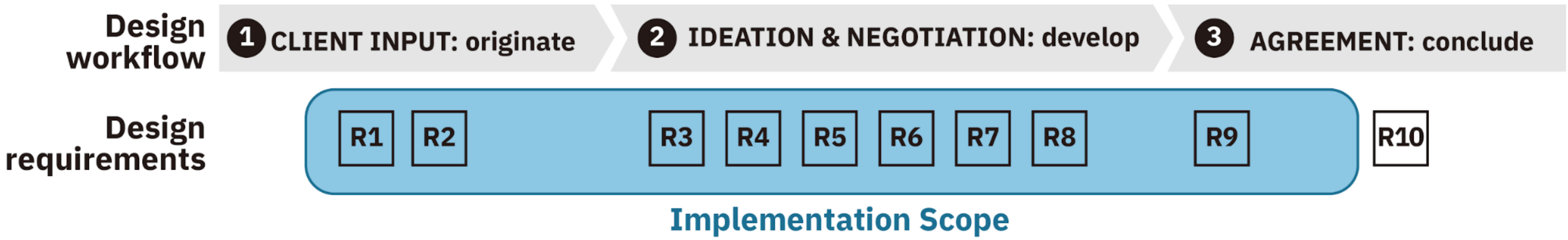


Figure 35. Implementation scope

1. ***The tool should integrate the various media used in ideation and presentation by (FIXME):***
   R1: Transforming panoramic photos into the immersive virtual environment.
   R2: Presenting the images in two forms: physical photos floating in the 3d space; digital pictures presented in the virtual screen.
2. ***The tool should enable users to perceive the effects of their design intervention by:***
   R3: Allowing users to draw 3d curves in the 3d space
   R4: Allowing users to manipulate 3d shapes in one-to-one scale
   R5: allowing users to duplicate and hide the 3d geometries.
3. ***The tool should improve time-efficiency of generating and presenting ideas by:***
   R6: enabling users to use intuitive and easy gestural inputs to manipulate virtual objects.
   R7: offering pre-designed models of the most commonly used cake components
4. ***The tool should comprehensively present the cake with both the overall images and details by:***
   R8: giving vivid visual cues (i.e., glosiness, color identity, color density, visual texture) of the virtual cake.
5. ***The tool should assistant cake makers in documenting the final decision by***
   R9: allowing users to capture images and record videos in VE

4.2 Software & Hardware

The 3d shapes and food textures of virtual cakes are made in Blender, a CAD tool which is proficient in 3d animation and interactive graphics. After that, the virtual 3d models with texture are exported into Unity3d, a game and XReality development software. In Unity3D, The socialVR tool prototype is developed, with regards to setting up the overall virtual environment and creating virtual interaction with C# coding. Then, Unity is connected to the Oculus VR hardware in aid of Oculus Integration, a plug-in in Unity3d. In this way, users can experience the socialVR prototype with Oculus Rift HMD (Head-Mounted Device) for virtual display as well as Oculus Touch for giving user inputs.

4.3 Interaction Techniques

Each interaction technique is designed to fulfil a certain design requirement. The interaction techniques will be elaborated with regard to technology implementation and user interface. We will introduce them based on the intended storyline of the bake-client co-design activity.

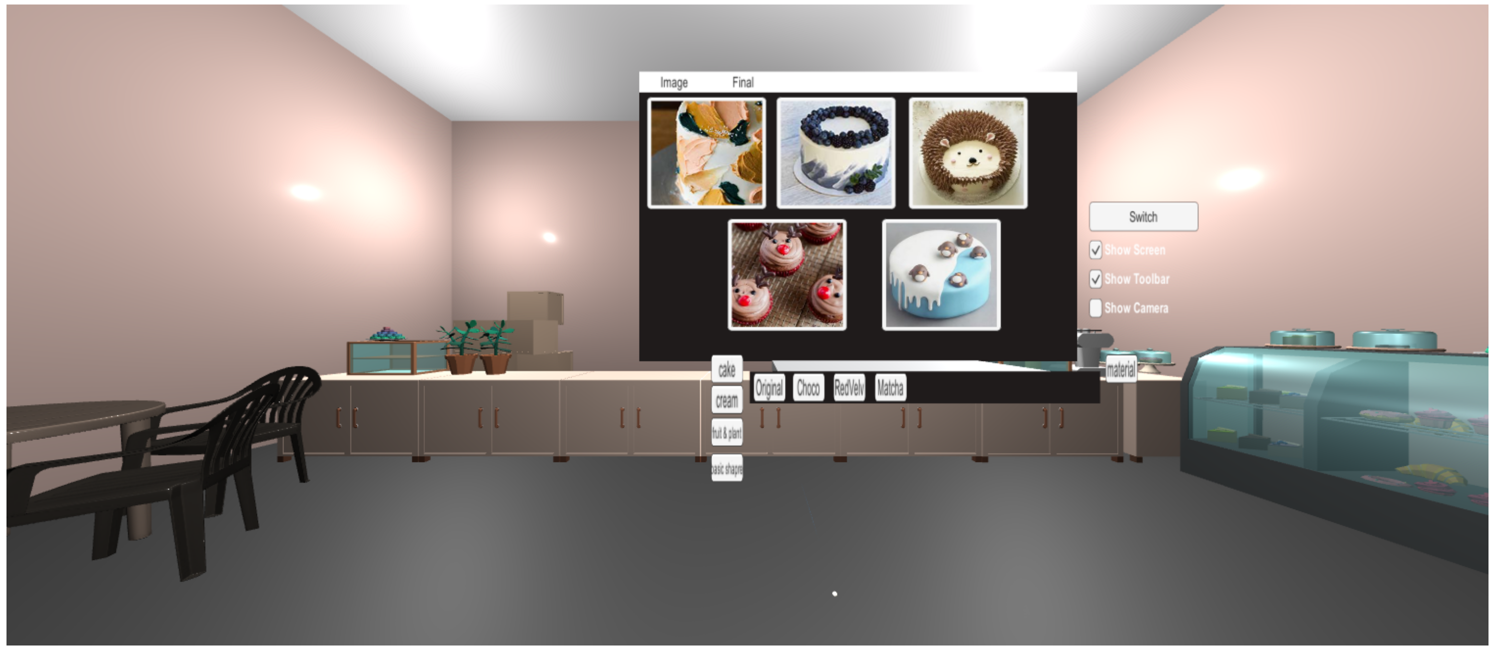


Figure 36. photo of virtual bakery

Enter the Virtual Design World

Switchable virtual environment (R1). The co-design activity starts with entering the virtual environment: virtual bakery and virtual cake-context. The virtual bakery is built up with 3d virtual models in Unity3D. As for the virtual cake-context, it is generated by applying a panoramic photo as the "skybox" component of the VR camera in Unity3D. This method can simulate a realistic virtual environment without consuming much computer power. In this VR prototype, users can seamlessly switch the virtual environment by clicking the "switch" button with a virtual laser pointer.

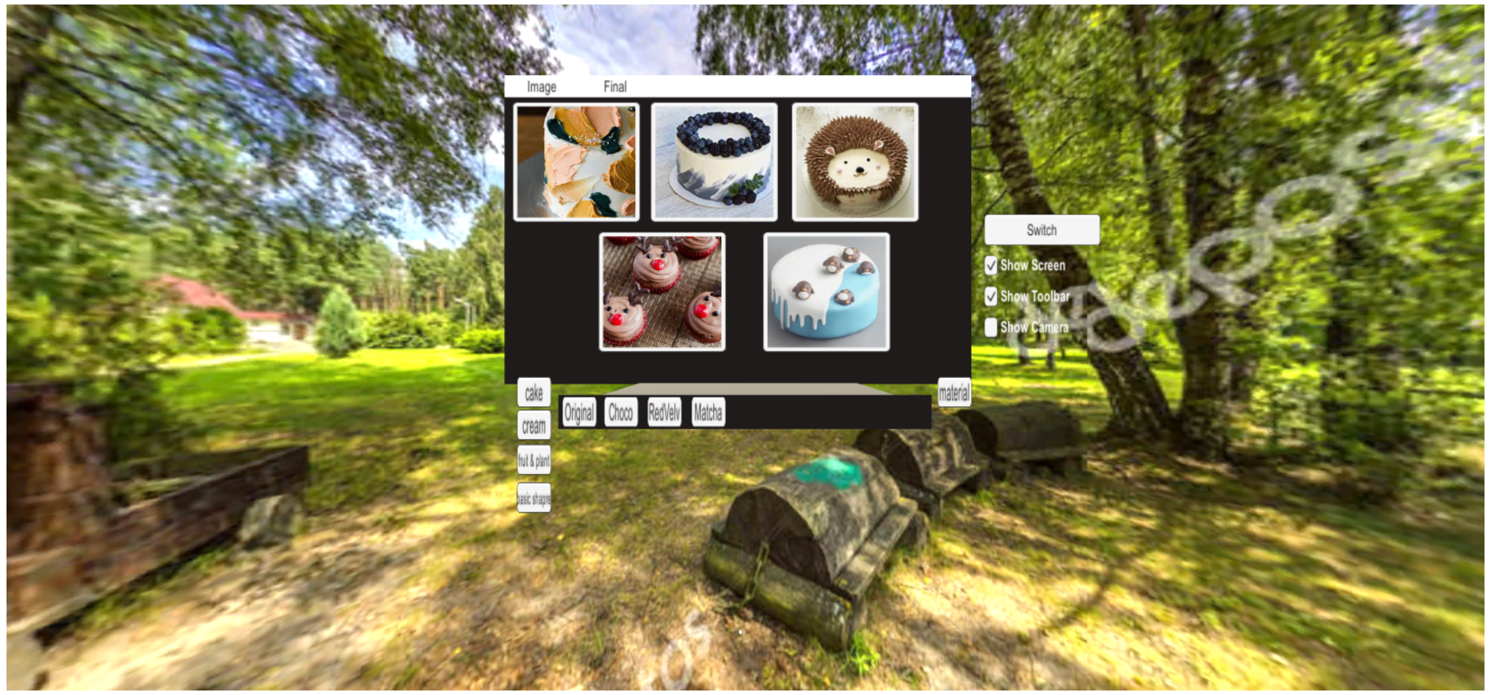


Figure 37. photo of virtual bakery

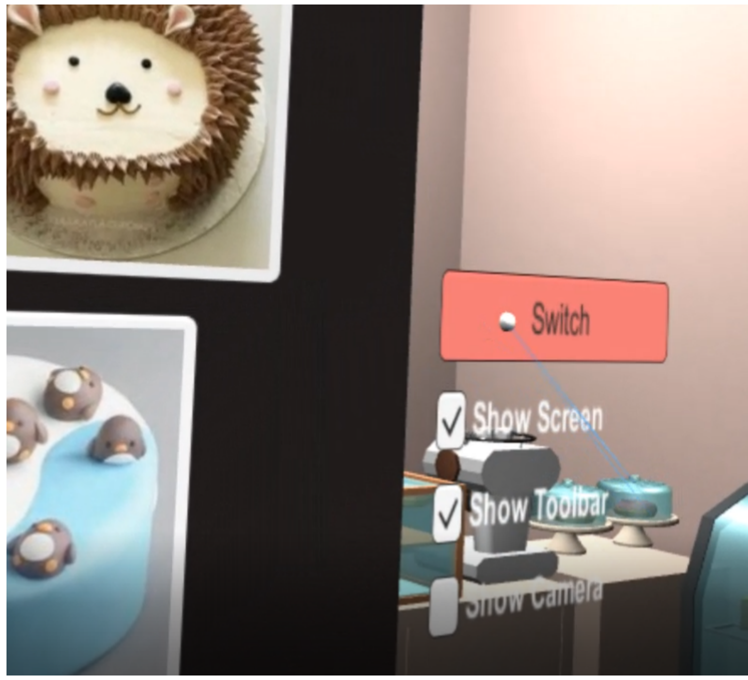


Figure 38. switch button

Virtual avatar. After the two users enter the shared virtual environment, they can see and interact with each other represented by virtual avatars. The virtual user avatars are visualized as low-poly human upper body figures in a cartoonish style, because of the limited computer power. Users can control the movement of head and arms of the avatar, in aid of the motion capture of VR headsets and handels. “Animation Rigging” plug-in in Unity3d is employed for organizing the skeletal animation of the human figure.

Figure 39. virtual avatar

Giving client input

Image sharing (R2). Before the co-design activity starts, customers need to convey their thoughts to bakers by sharing a collection of images. In this prototype, images are flexibly presented in two ways: slideshow and virtual “physical photo”. All the images uploaded by clients are presented on the virtual screen, and users can remotely refer to the photo with a laser pointer. When the laser pointer is hovering on the certain image, the outline of the images will turn red as an indication of selection. When people click the selected image by pressing the X button, a physical version of that image will appear, floating in the 3d space. Users can do basic 3d operation (translation, rotation, scaling) on the virtual physical photo, with the virtual hands.

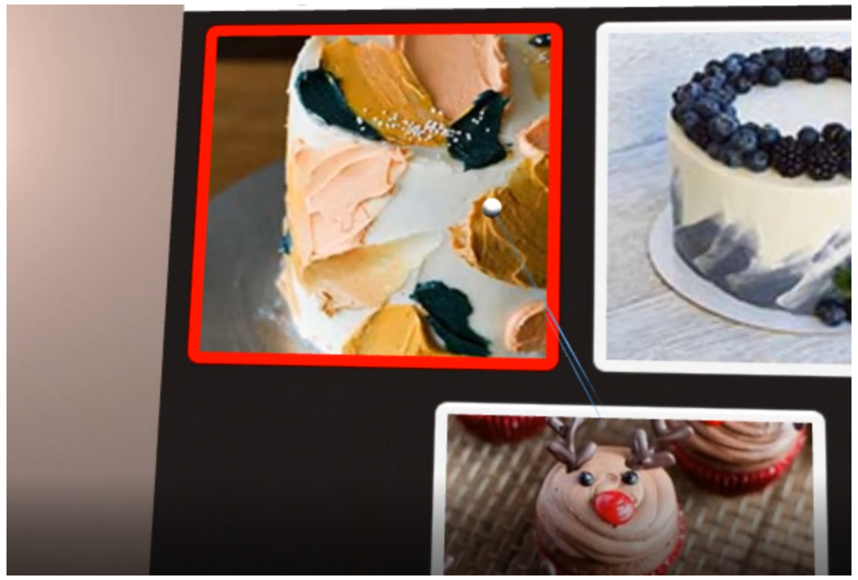


Figure 40. select image with laser pointer

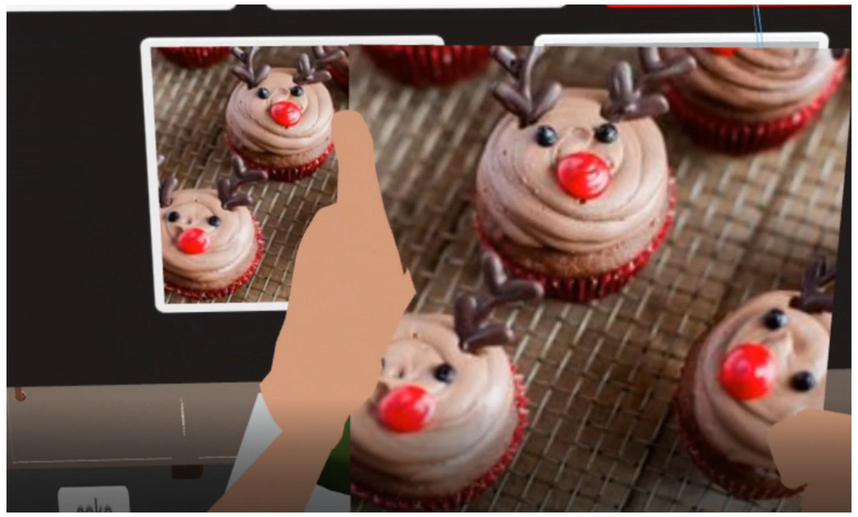


Figure 41. transforming slide image to “physical photo”

Ideation & Negotiation

Based on customers' input, cake makers and clients ideate and negotiate to develop the cake idea. During this process, they freely interact with the virtual objects and environment, in order to embody their ideas. They can do free 3d sketching, derive vivid preset models from the system database, and play with the model with their hands in a natural and intuitive way.

3D sketching (R3). Users can freely draw 3d curves in the virtual space to self-defined 3d shapes. The 3d sketch interaction is realized by tracking the motion of Oculus Touch. When the X button is pressed, users leave a collection of spheres on the trace of the moving hand. In this way, a 3d curve is generated by users. By tilting the left thumbstick, users can adjust the strokeweight of the 3d brush while drawing. After finishing the 3d sketch, people can do basic 3d manipulation (translation, rotation, scaling) of what they draw in the 3d virtual space, with the virtual hands.

Figure 42. do 3d sketch with changeable strokeweight

Figure 43. 3d interaction with 3d shapes produced by sketching

Predesigned model database (R7). For quickly building up the cake ideas, users can also derive the 3d models of the most commonly used cake components from the preset model database. They can get the 3d shape they want by clicking the correspondent button of the virtual toolbar with a laser pointer. These 3d shapes are built in Blender3d, then imported into Unity3d.

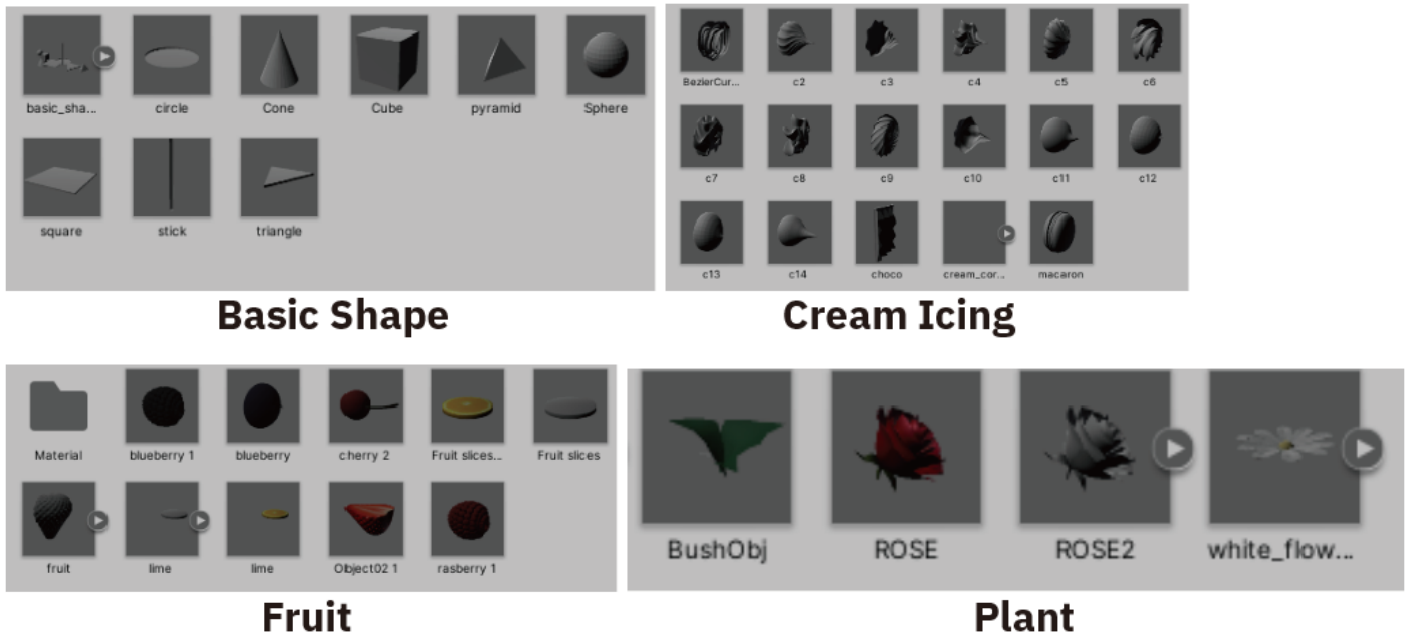


Figure 44. preset cake component models

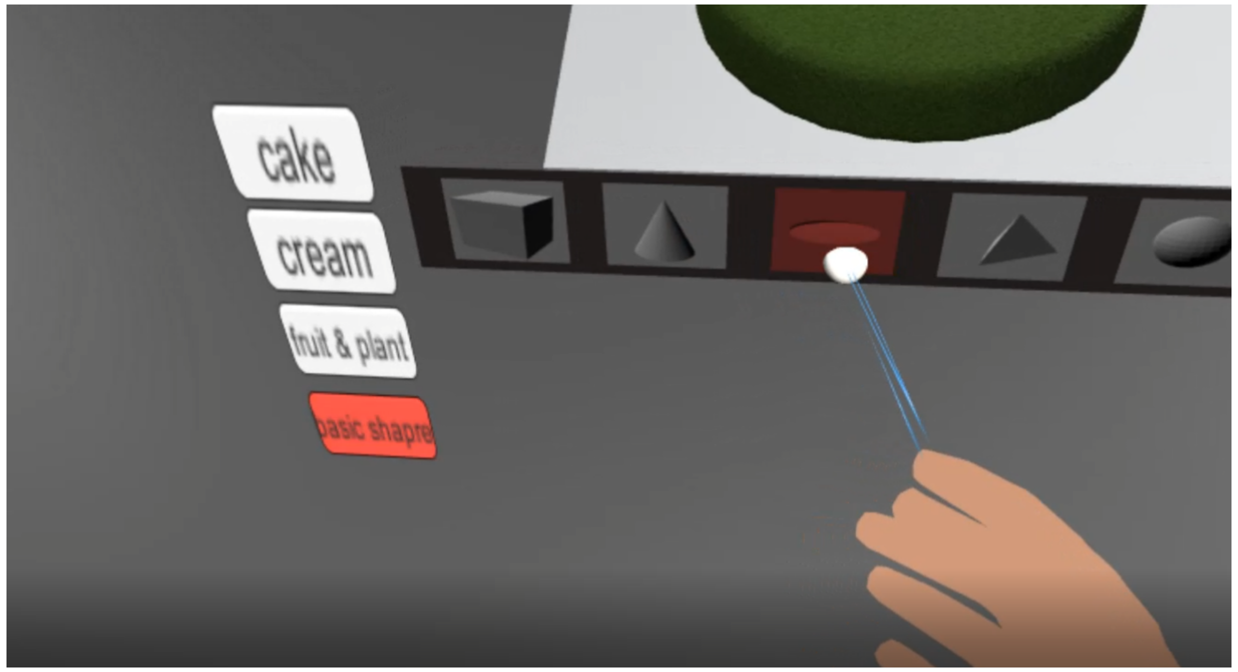


Figure 47. Cake in the virtual environment)

Visual cues of food presentation (R8). When playing with the virtual cake models, users can perceive the gustatory quality and detailed “feel” of the cake because vivid visual cues of cake are given. These visual cues with regards to cake textures are generated in Blender3d, in aid of the texture drawing and shading functions. The color density and identity are simulated by editing the basic color component, to visualize the food flavor. In addition, the illuminance distribution is simulated by editing the roughness component, to display “the feel of freshness” of the cake. Finally, the visual texture is simulated by editing the displacement component, to visually present the mouthfeel.

After that, the texture is rendered as a png image in Blender3D, and then imported into the Unity3D as a material component, and attached to the virtual cake models.

Figure 47. Cake in the virtual environment)

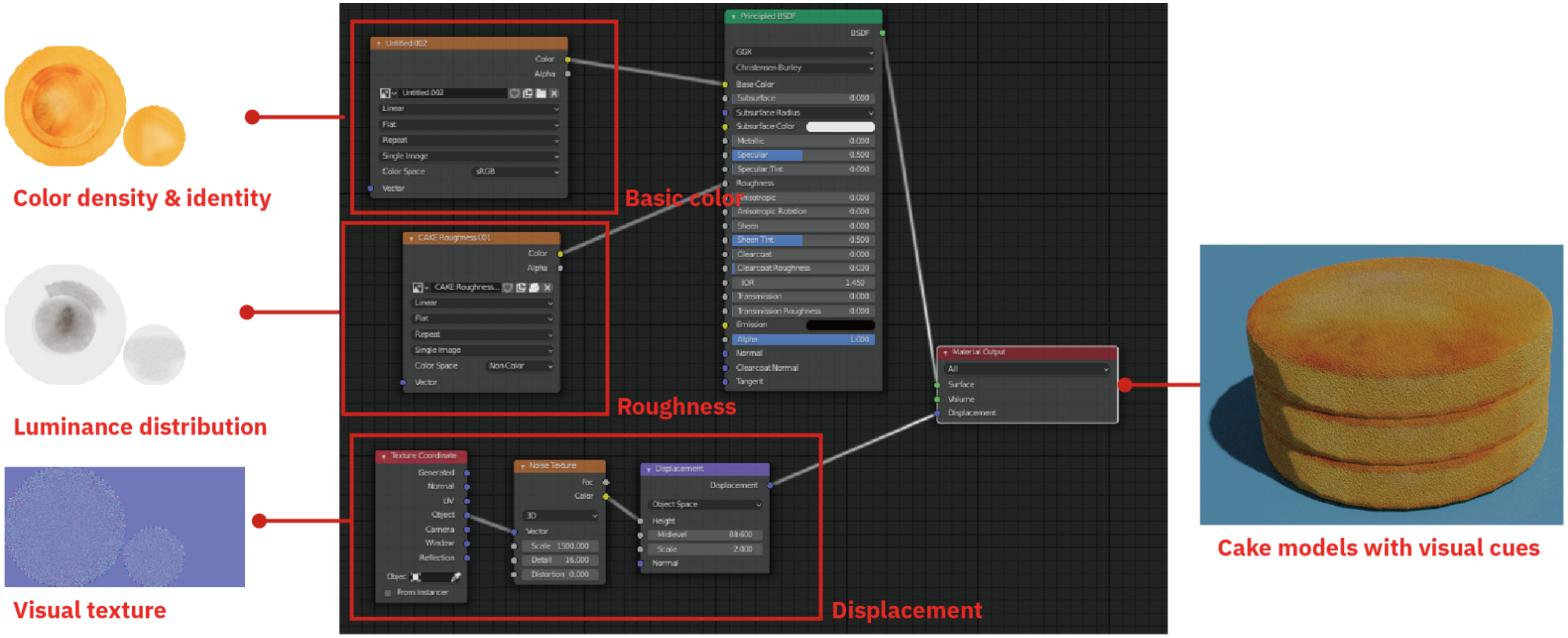


Figure 46. texture editing in Blender3D

Gesture-based 3d manipulation in one-to-one scale (R4, R6). Users can play with the virtual cake models with their hands in a natural and easy way. In this sense, intuitive gestural commands for 3d interaction are employed, for the basic 3d manipulation: translation, rotation and scaling.

Firstly, users can freely move the 3d objects with the single-handed interaction. By pressing the trigger button of the Oculus Touch, users can virtually grab a certain 3d artifact, and change its location by moving the hand.

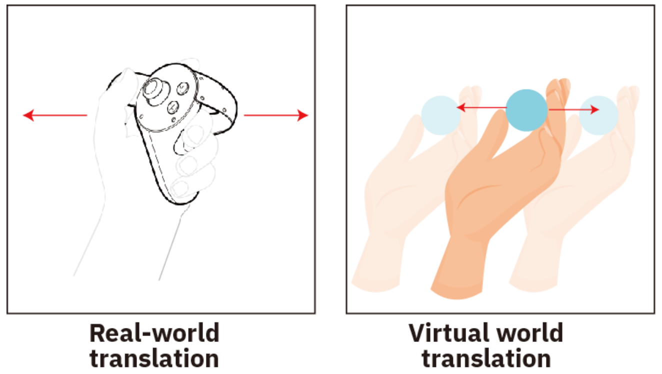


Figure 48. 3d manipulation, translation

Secondly, all the 3d models can be freely rotated when it is grabbed by the virtual hand with intuitive single-handed interaction. Users can easily change orientation of the grabbed 3d object by twisting the wrist.

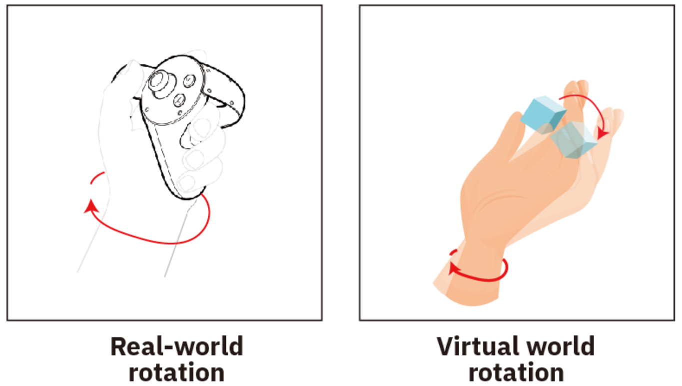


Figure 49. 3d manipulation, rotation

Additionally, users can resize a 3d geometry with both the single-handed and bimanual interaction. In this prototype, two scaling interactions are realized: vertical scaling (z-axis) and horizontal scaling (x-y plane). with intuitive guestural command. When an object will be scaled, three control points will appear: upper, left and right (Figure 52). For the vertical scaling (Figure 51), users need to use one hand to grab the upper point, and drag it along the z-axis. When the upper point is dragged upwards, the height of the object increases; if the upper point moves downwards, the object is shortened vertically. For the horizontal scaling (Figure 50), users need to use two hands to grab the left point as well as the right point, and drag them along the x-axis in the opposite direction. When the two points are dragged closer to each other, the horizontal cross-section of the 3d object is shrinked, and vice versa.

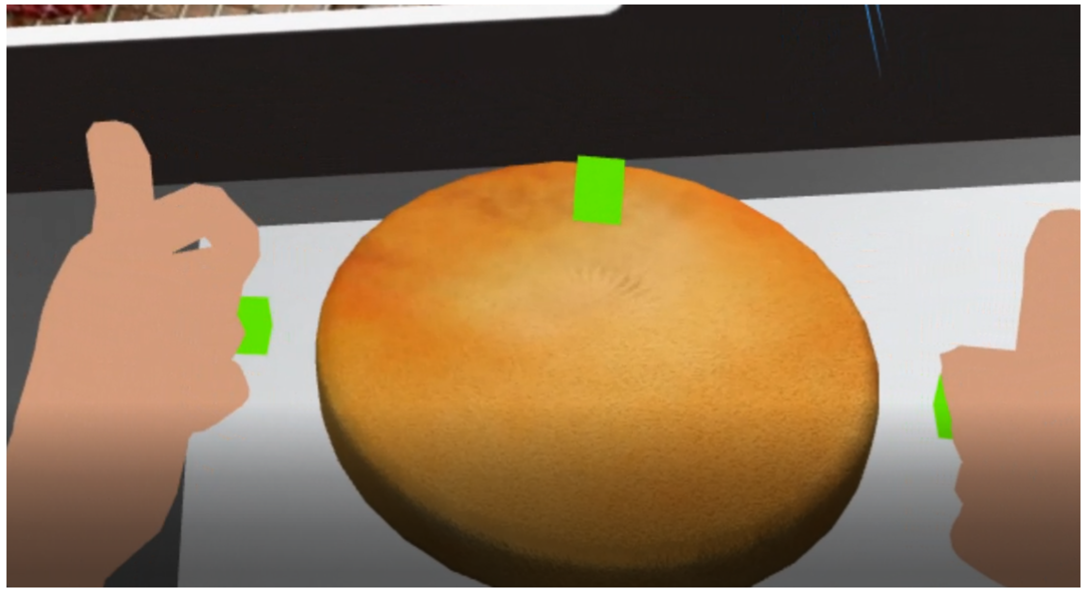


Figure 52. resize the models in the virtual environment

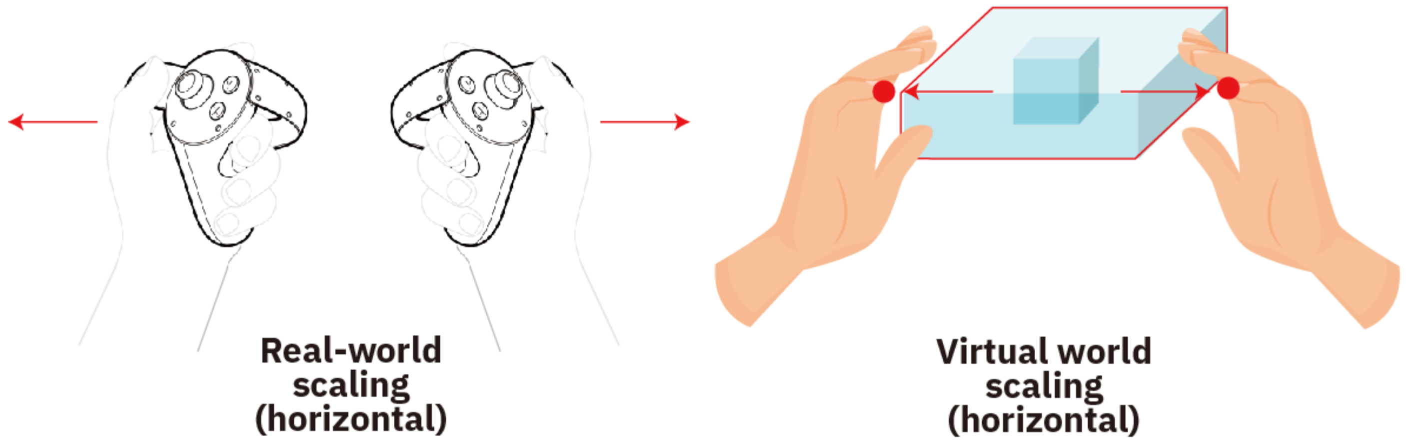


Figure 50. 3d manipulation, horizontal scaling

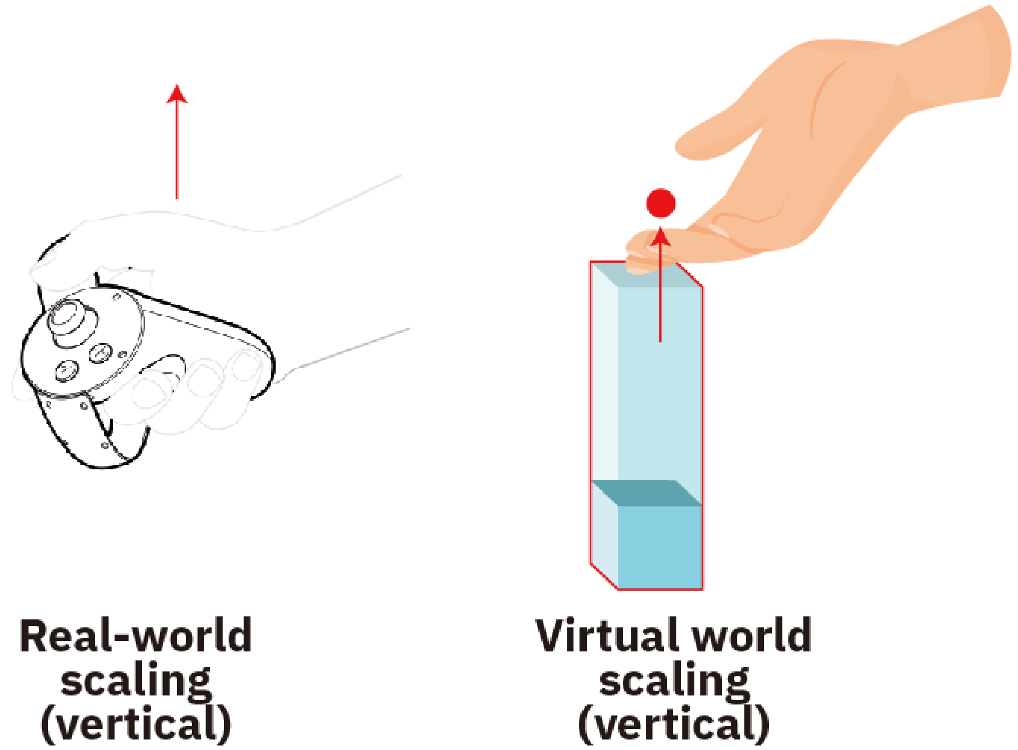


Figure 51. 3d manipulation, vertical scaling

Agreement

Image capture in the virtual environment (R9). After the cake idea is formed, the two users need to reach an agreement on their design decisions. So they need to gather all the information with regards to how the final design decision is made. In this prototype, users can capture images of their design process. They can freely set the location and orientation of the camera, and switch between the front and rear lens by clicking the switch button. Then they can capture the image by clicking the “shoot” button. After that, the captured images are represented as virtual “physical photos” floating in the 3d space, and users can freely resize, move and rotate them. To realize this function, Unity inspector and C# scripts are used, to control the direction, active status, rendered texture and width of view field of the Unity camera.

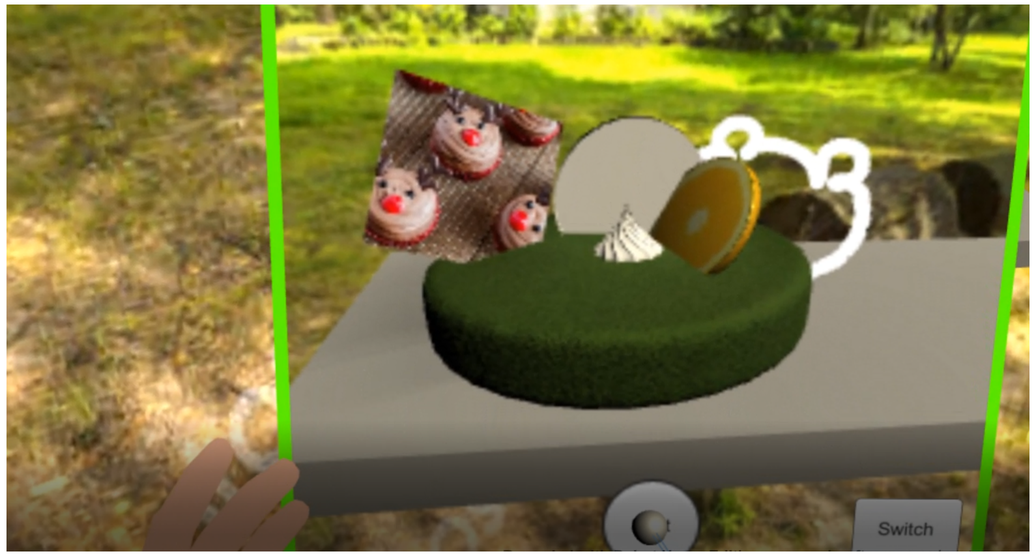


Figure 53. capture image in the 3d space


Figure 54. physical photos produced by the camera

When everything is settled, users can see the final cake contract on the screen, by clicking the “final” button on the screen. The contract shows all the textual information (e.g., 3d data, delivery time, delivery method) of the cake in aid of automatic archive function of the computer system (realized by Wizard of OZ). Users can also combine the photos they take with the contract, then further elaborate some special design details.

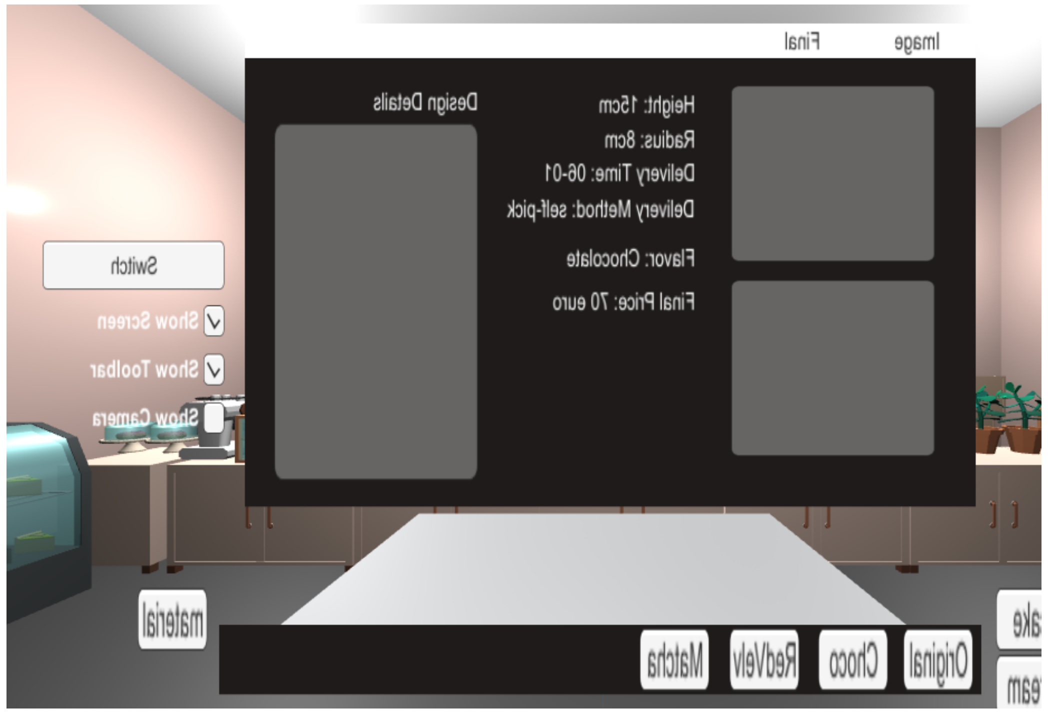


Figure 55. the contract

Figure 56. attach photo to the contract

5. User evaluation

The previous chapter describes the implementation of the socialVR prototype. In this chapter, we will utilize this prototype to investigate the user experience of the customized cake co-design activities in socialVR. This research started from two research questions: investigating virtual social behavior and validating the functionalities of this tool. To answer these questions, we invited six participants to evaluate the socialVR tool by experiencing the VR prototype, and asked them to share their opinions. The results show that users' behavior is highly influenced by the emotional connection with the interlocutors in VR as well as their internal interests in this task, and 80% of design requirements positively support VR co-design work.

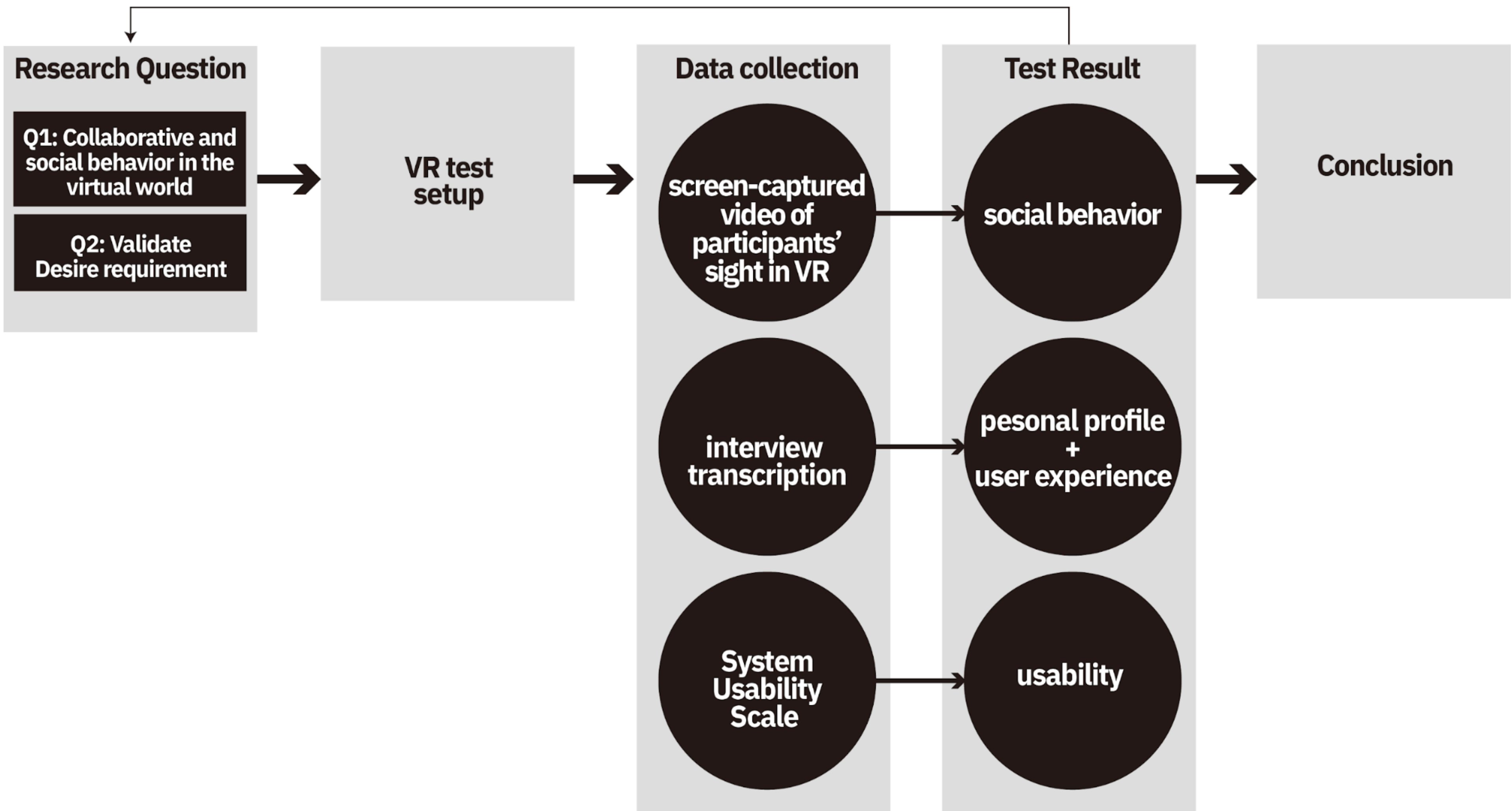


Figure 57. Structure of this chapter

5.1 Research question

The goal of the test is to understand the impacts of socialVR on social interaction in the context of collaborative creative tasks, as well as to validate the design requirements (chapter 3) which are concluded from the initial user research (chapter 2).

1. *How does this socialVR tool affect users' collaborative and social behavior in co-designing customized cakes, compared with face-to-face communication?*

2. *Do the design requirements fix users' latent needs in the cake co-design activities?*

5.2 Test Setup

Method

The participants were invited to experience the socialVR prototype in the researcher's studio. Each participant was asked to utilize the socialVR tool to customize a virtual cake together with a researcher, in a dual-user VR setting. The test started from contextualization: participants were inspired to imagine a context in which they would like to prepare a unique cake for someone or a special occasion. Based on this context, the participant collaborated with the researcher to customize a context-fitting cake in the socialVR world by wearing HMDs. During this process, the participant played the role of the client, while the researcher played the role of a professional cake maker. After the VR co-design session was finished, the participant would be invited to tell about his or her experience, and evaluate the usability and functionality of this socialVR tool.

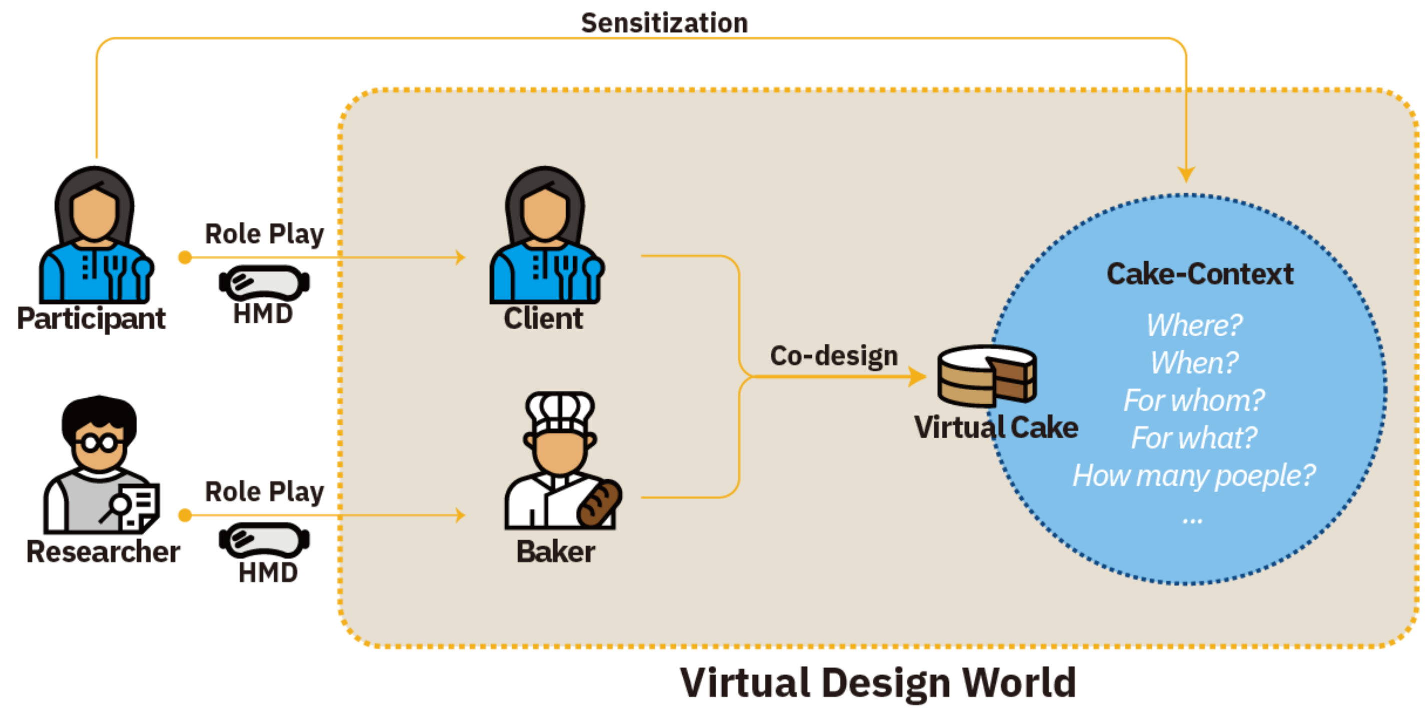


Figure 58. Method of user test

Participant

Six participants, who were TUDelft students (3 male & 3 female), were invited to experience and evaluate the socialVR prototype. They had different experiences in using VR applications before this test. And they generated different contexts in which their cakes would be consumed. Each participant was rewarded with a ten-euro voucher after finishing the test.

No.	Gender	Age	VR experience (before this test)	Cake-consuming context
P1	F	25	>3	Mother's birthday
P2	F	24	>3	A seminar about hospice care
P3	M	25	1 or 2	A friend's birthday party
P4	M	24	2	Confess love
P5	F	27	0	Father's birthday
P6	M	25	0	A friend's birthday party

Tale 4

Test Setup

The VR test was conducted in the researcher's studio, which was about 25 square meters. In order to simulate the context in which the two users were physically separated, a physical separation, which was made from furniture, was set in between the two users. Additionally, the two users communicated with each other on skype wearing noise-cancelling earphones, so that they heard each other from the earphones instead of the real world. This also helped to mimic a remote communication context.

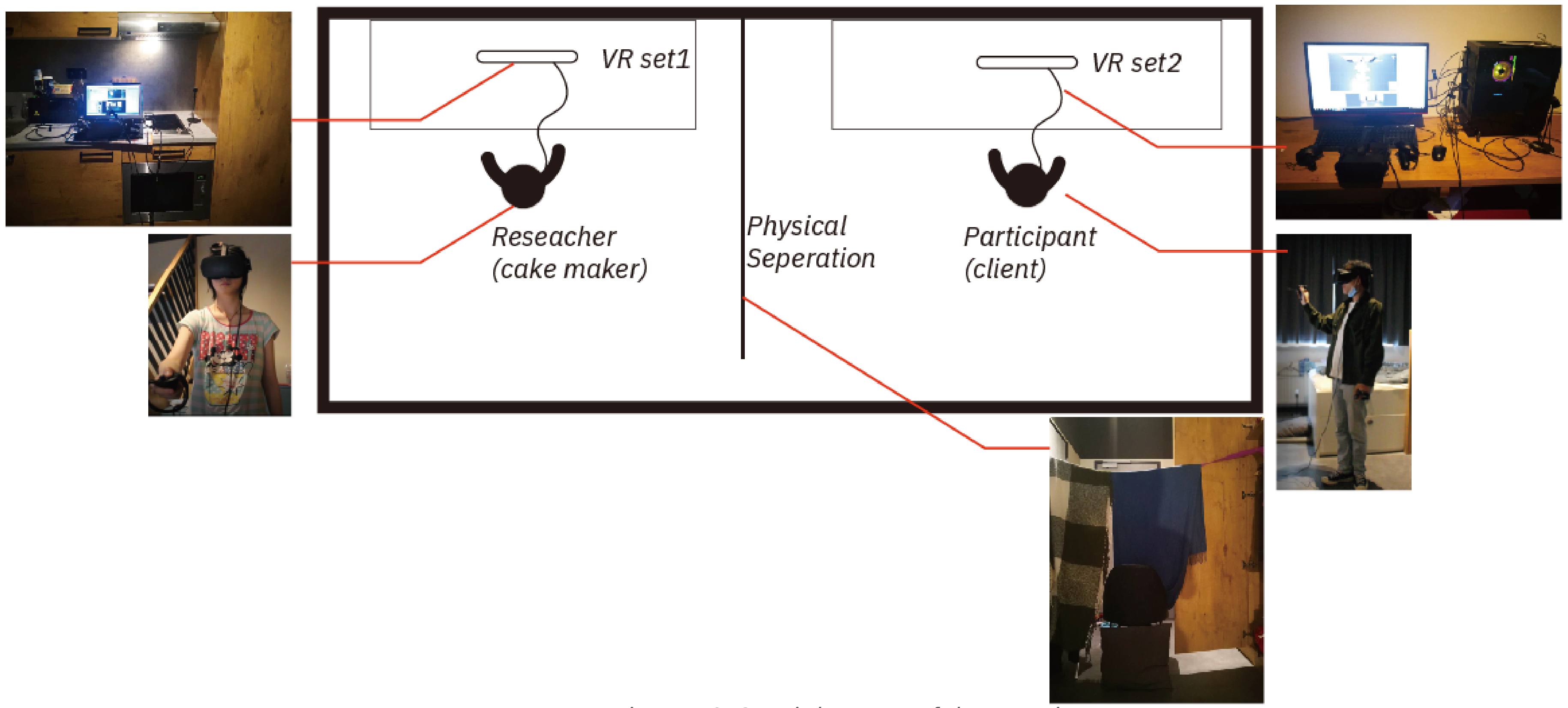


Figure 59. Spatial Layout of the test site

Material

Hardware. Two Oculus Rift devices (one headset, two VR handles, two location sensors), one VR-enabled laptop, and one VR-enabled desktop computer were used to run the test.

Prototype. The VR prototype was developed and ran in Unity3d. In order to connect the two users in VR, two identical Unity3d files were respectively loaded into the two VR-enabled computers. While the two computers were running the VR application at the same time, all the data (e.g., size of 3d objects, body movement) in the virtual world was synchronized via the internet in aid of PhotonPun, a plugin for networked multiplayer games in Unity.

Procedure

The test was divided into three phases: pre-test interview, VR co-design test, post-test interview & questionnaire (Figure 60).

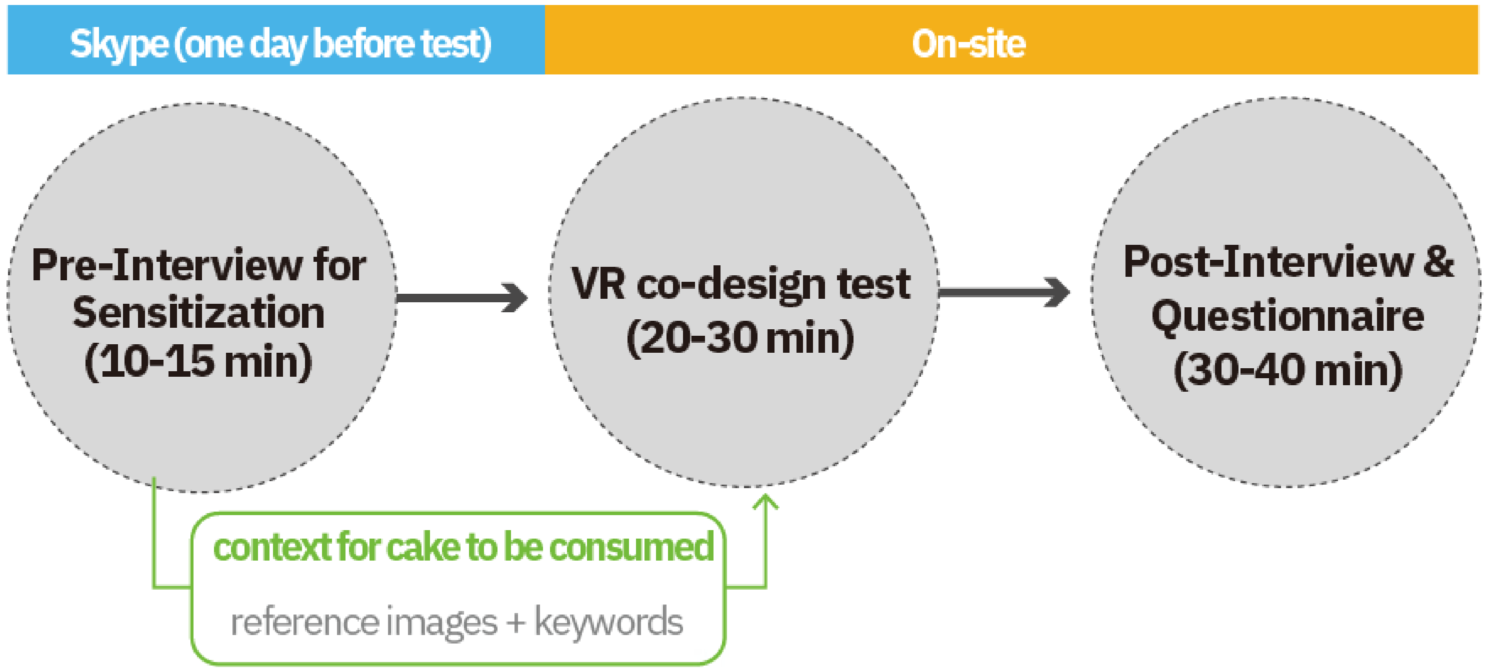


Figure 60. procedure of the test

No.	Context	Keyword	Reference Image
P2	A seminar about ideating better hospice care for Chinese migrant in the Netherlands, with the social worker, staff in nursery, Chinese migrant elderly.,	• Discussion-provoking • Bright • Rich flavor • Combination of Chinese and Ducth culture • Healthy for the elderly • Share	

Figure 61. P2's keywords and reference images about the desired cake

PRE-TEST INTERVIEW (10-15 min)

The pre-test interview was a semi-structured interview which had been performed on Skype one day before the formal VR test. The aim was to personalize the co-design task for each participant and immerse the participant into the role of a client. During the interview, the participants were asked to reflect on their previous experience of customizing or sharing cakes, and then talked about a specific person or an occasion for which they wanted to personalize a cake. After that, they were inspired to describe the context in a more detailed way (i.e., time, location, number of cake-shares). Additionally, the participants were encouraged to ideate and describe the features (i.e., flavor, color, 3d shape) of their dream cakes based on a collection of reference images offered by the researcher. They can also freely search for the images on the internet to inspire themselves. Finally, a series of reference images and keywords which could represent the participant's ideas was collected. These data would be used in the following VR test, so as to personalize the VR co-design experience for each user (Figure 61).

VR CO-DESIGN TEST (20-30min)

In this formal VR co-design test, two VR users (one participant, one researcher) wore the HMDs to collaboratively personalize a cake using the socialVR tool.

Preparation for personalization. In order to better engage the participant into the creative tasks, each session was personalized, based on the "cake-context" which the participants came up with in the pre-test interview. Firstly, the reference selected images in the pre-interview were manually imported into the socialVR tool in advance and displayed on the screen in the virtual environment (Figure 62). Secondly, the cake maker prepared a list of questions and professional advice based on the keywords which are relevant to the participants' dream cake.

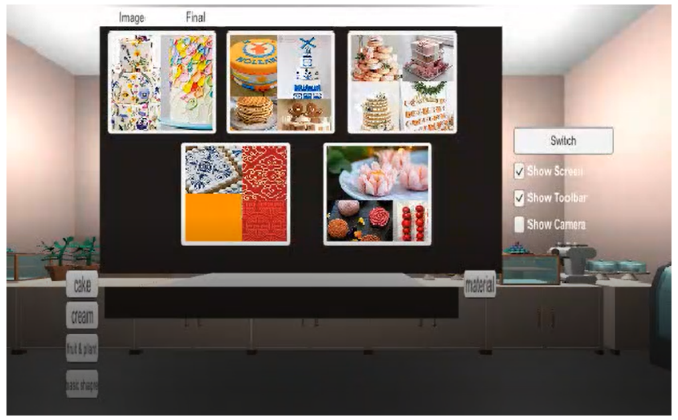


Figure 62. screen loaded in P2's reference images

Instruction of VR operation (5-10min). Before the co-design task started, the participants were instructed to get familiar with the basic VR handle operation, user interface and functionalities. During the instruction, participants wore the HMD and were audio guided (e.g., "Press A button and move your hand, then you can sketch freely") by the researcher. The VR handles and finger movement were visible in the virtual world, in order to lower their memory burden of the layout of buttons on the VR handles, and enable them to figure out which button was actually pressed by themselves. After all the interaction techniques were introduced, participants were given 5 minutes to freely self-explore the VR tool.

Collaborative co-design task (15-20min). After the introduction, the formal virtual co-design session began. The participant was asked to play the role of a client and utilize the socialVR tool to personalize a cake together with the researcher who played the role of a baker. The whole session took about 15 to 20 minutes, and generally included three phases: exchanging ideas, co-building cakes, confirming the decision.

POST-INTERVIEW & Questionnaire (30min - 40min)

After the VR test, a semi-structured interview was performed. Participants were asked to share their experience of the virtual co-design activities, as well as the opinions on the socialVR tool in terms of functionality and interaction techniques. A question list was made (Appendix A). After that, participants were asked to fill in a System Usability Scale (SUS) form (Appendix B) to evaluate the usability of this tool. They were encouraged to think aloud when filling in this form.

Data collection

Qualitative and quantitative data were collected during and after the test .

During-test. Qualitative data was gained during the VR test. All the co-design sessions were audio recorded. Additionally, the screen video record was made to archive the participants' view in the virtual world.

After-test. Both of the qualitative and quantitative data was collected during the VR test. The qualitative data was gained from the audio record of the post-interview, while the quantitative data was obtained from the SUS questionnaires.

5.3 Results

The study results aim to answer the two research questions which are proposed in chapter 5.1: investigate the impacts of socialVR on the social behavior in co-design, as well as validate the design requirements (chapter 3) of the socialVR tool. In addition, the usability of this tool will be investigated based on the SUS questionnaire results.

5.3.1 Investigate collaborative and social behavior

RQ1: *How does this socialVR tool affect users' collaborative and social behavior in co-designing customized cakes, compared with their previous experience (face-to-face meeting)?*

In order to investigate the social behavior in the virtual world, three analyses were made. Firstly, the participants' social behavior was figured out by observation study. Then, the following task was to find out what factors lead to such behavior. Thus, we made the second analysis, making a user profile to specify each participant with regards to personal interest in cake, VR acceptance, and requirements on emotional connection in cooperation. This analysis was mostly based on the information self-reported by participants in the pre-test and post-test interview. After that, we performed a thematic analysis on the transcription of the post-test interview, to investigate the participants' experience and thoughts in the virtual co-design activities.

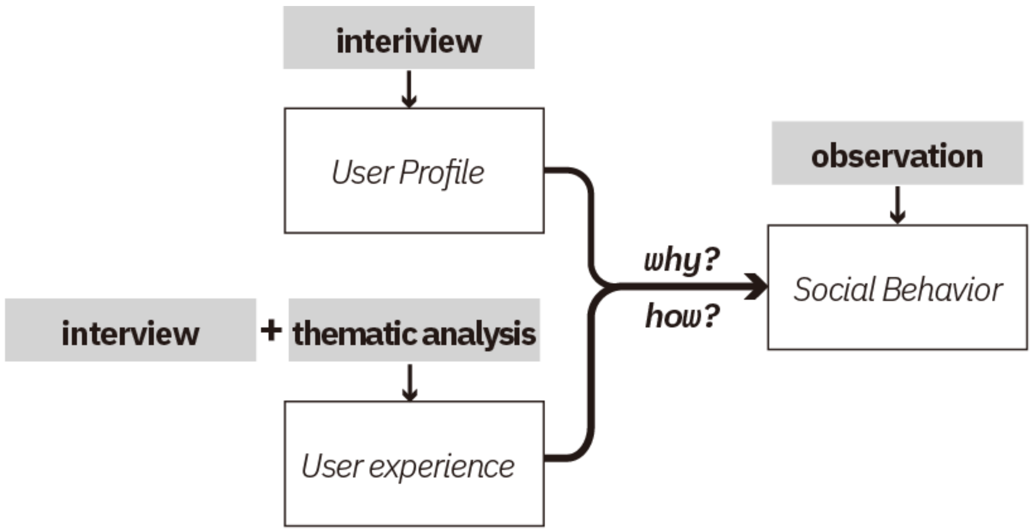


Figure 63. Structure of analysis for RQ1

Analysis 1: Observation

The screen-captured videos of the participants' VR view were watched by the researcher, in order to observe the **collaborative and social behavior of participants in socialVR co-design tasks.** From observation, we find that there were two typical collaboration modes among the six tests: client-oriented and baker-oriented.

In the client-oriented mode (Figure 64), the customers built the virtual cake based on their ideas throughout the whole design process. During this process, cake-makers might give some profesional ideas via verbal description (i.e., cake maker to P5:"I don't think this cream fits the rice cake, but you can try that, it depends on you."). Additionally, the cake maker sometimes participates in 3d modelling in order to assist the clients or present some alternative options (i.e., cake-maker helped P2 to arrange the spatial layout of the decoration flower). In general, the client is the primary actor who interacts with the 3d cake models, and has higher engagement in co-design.

In the baker-oriented collaboration mode (Figure 65), the customer usually conveyed their requirements and ideas to bakers via verbal communication (i.e., P4: " I want a combination of several small cake cubes of different flavors.") before the 3d building. After that, the cake maker built up the cake based on the clients' thoughts. During this process, the client gives some comments on the cake by talking to the bakers (i.e., P1: "Can we decorate the cake with strawberries in this way?" (pointing to a reference image)), or, do some small refinement by directly manipulating the 3d shapes (i.e., P3 changed the size of the cake body). Generally speaking, in the baker-oriented mode, the cake-maker contributes more to cake-making, and the client has relatively lower engagement in the design process.

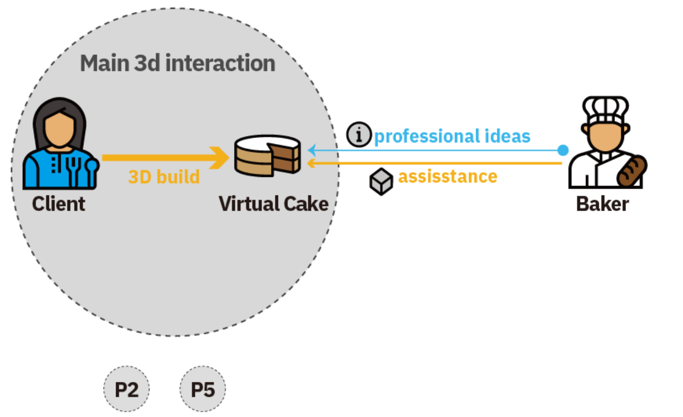


Figure 64. Client-oriented mode

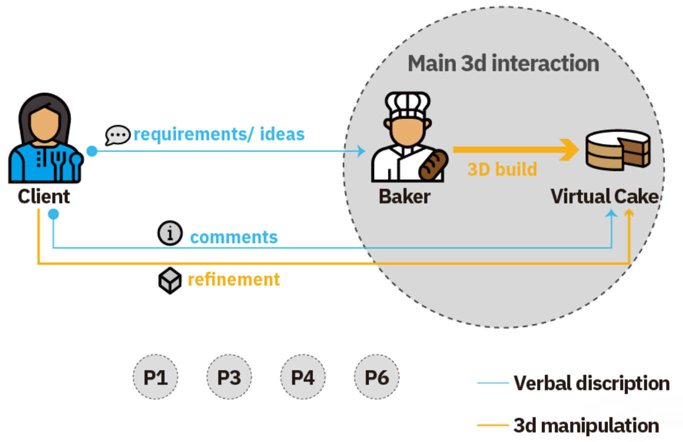


Figure 65. Baker-oriented mode

From observation, we found that P2 and P5 chose the client-oriented mode, while P1, P3, P4 and P6 chose the other mode. Thus, more analyses were needed to find out what factors influenced their choices. So we made a user profile and thematic analysis of participants' quotations.

Analysis 2: User Profile

From pre-test interview, observation in VR test and post-test interview, we found that each participant was different from three perspectives: **creative motivation in customized cakes, capability of adapting to VR, and need for emotional connection in collaboration.** We assume that these three factors might have some impacts on user's social behaviour in virtual cake co-design. Thus, we specify each participant based on these three factors (Figure 66).

	Gender	Creative motivation in customized cake	Capability of adapting to VR	Need for emotional connection in collaboration
P1	F	**high** "This cake has enriched emotional meaning, so I want to design it by myselft, instead of asking a baker to make it. These two methods are different. " aesthetic + flavor + Social Meaning + Novel material	**high** "I have used VR for several times, so I didn't spend too much time to adapt to the virtual environement"	**high** "I am outgoing in collaboration, and I always unconsciously have body contact with the other one."
P2	F	**high** P2 used to customized cake with cake maker, and is a amateur of cake making configuration + aesthetic + flavor + social Meaning + Novel material	**high** "I have tried socialVR before, and I think I have already get used to interact with virtual avatar.	**low** h
P3	M	**low** "It (designing cakes) is troblesome, and a littble bit girlish. " configuration + aesthetic	-	**low** "I won't consider emotional connection in this context (collabotation)."
P4	M	**low** "I prefer to order a cake online and make a choice from predefined options" configuration + aesthetic + social meaning	**low** "I need some time to get used to the VR interaction."	**high** "I like doing all the collaborative work tog"
P5	F	**high** P5 used to buy specially designed cakes for her friends configuration + aesthetic + social meaning + novel material	**low** "I felt hectic because I need to deal with so much things at the same time. And I had, I had to learn VR interaction, to see something, and communicate with you. Too much information.	- When talking about collaborative design work, P5 mentioned more about 3d interaction , design fidelity, 3d tool function.
P6	M	**low** "I have no idea about cake-making" aesthetic	**low** "I felt uncomfortable when wearing the VR headset." "I am unfamiliar with VR."	**high** "collboration is not only about work, it requires extra communication, gossip, have a coffee, have a lunch together." " If I cannot feel other's emotion, such as satisfaction, I will quickly lose interest in the work"

client-oriented mode (P2, P5) · baker-oriented mode (P1, P3, P4, P6)

Figure 66. User profile

creative motivation in customized cakes. This item refers to participants' personal interest and motivation in creating unique cakes. We evaluate this factor from two dimensions. The first dimension is about how the participants describe the issue of cake-making with regards to personal experience, interest and creative confidence. For example, P2 had several experiences of customizing special cakes together with bakers. This showed that she had a higher creative motivation in personalizing cakes. However, P3 thought that cake-making was a girlish task and he didn't have too much interest and knowledge in this activity. Thus, P3 has a lower creative motivation in designing customized cakes. The second dimension is defined as the creativity scope of participants' cake ideas, which were described by them in the pre-test interview. For example, P1,P2 and P5 give a wider range of creative description of the desired cakes, with regards to configuration, aesthetics, social meaning (i.e., P2 aimed to create a meaning of culture combination for the cake), flavor and novel food material (i.e., P5 wanted to use traditional Korean steamed rice cake for the material of the cake body), while the other three participants, P3, P4 and P6, merely talked about the configuration, aesthetic and flavor. **An interesting finding is that female participants (P1, P2, P5) had a higher creative motivation in personalized cakes than male participants (P3, P4, P6).**

capability of adapting to VR. This dimension is defined as the user's personal ability of acclimating physiologically and behaviourally to a shift from the real world to the virtual environment, as well as learning new VR interaction. This capability varies from person to person. For example, P1 and P2 said that they had little difficulty in adapting to the virtual avatar and mastering VR. However, P5 claimed that she was overwhelmed in learning to interact with the virtual world and communicating with the cake maker at the same time, and P6 told that he was uncomfortable wearing the HMD and felt alienated when situated in the virtual environment. Generally, the capability of adapting to VR is relevant to previous experience of using VR devices. Participants(P1,P2) who had more VR experiences before seemed to have higher capability of acclimate to VR in the test.

need for emotional connection in collaboration. From a post-test interview, we discovered that some participants (P1, P4, P6) place more value on emotional connection in collaboration (i.e.,P6: "If I cannot feel others' emotion, such as satisfaction, I will quickly lose interest in the work."). They focus on body contact (P1) and facial expression(P4, P6) in the face-to-face collaboration. However, the other participants (P2, P3, P5) focus less on this issue (i.e.,P2: "I am result-oriented, and time efficiency is most important to me, I don't think emotion is an important issue in this case."). They claimed that emotional connection was not that necessary in the context of collaboration (P2, P3), the time efficiency (P3) and functionality (P5) of the tool was more significant to them.

Analysis 3: Thematic analysis

The post-test interview was transcripted, and relevant quotations were picked out. These quotations were clustered for two rounds. In the first round, they are categorized into two groups: virtual social behavior and 3D creative task. Then, in the second round, the quotations were further grouped inside the two categories. In the category "virtual social behavior", the quotations were categorized based on the three dimensions of socialVR user experience proposed by J.Li, et al. (2019): **Quality of Interaction, Social Meaning, Immersiveness and Presence.** Each item was compared with the face-to-face interaction, to figure out the differences and similarities. We discovered that some of these differences and similarities, as well as the participants' personal features (user profile),collectively affected their socialVR behavior. Then, we will elaborate each category in the following writing.

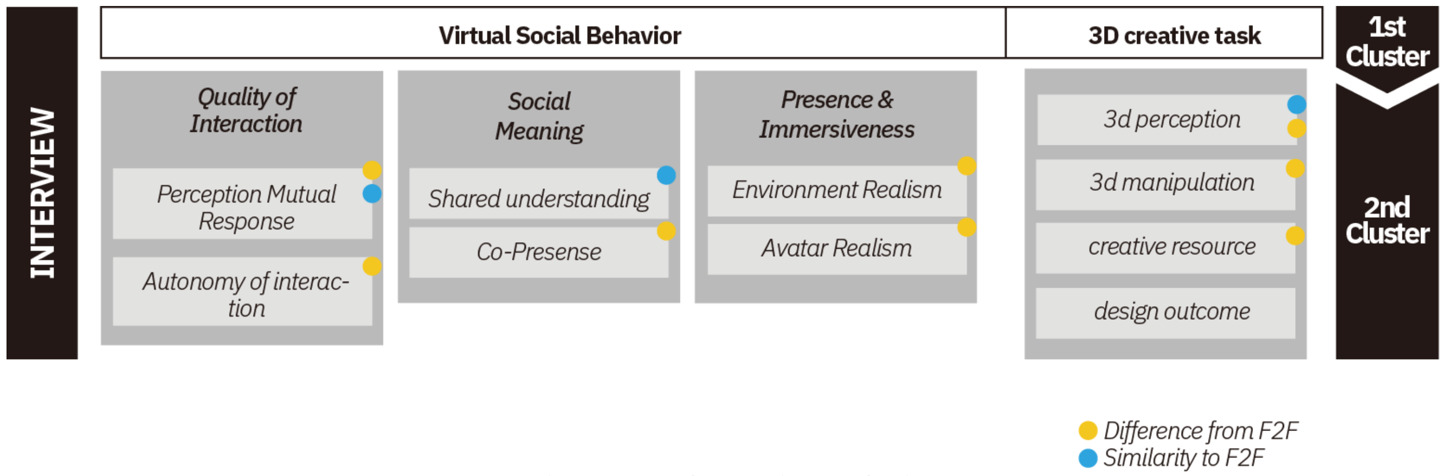


Figure 67. Thematic analysis

Quality of interaction

Quality of interaction is defined as the quality of interaction with the system and with other users via the system [26]. We figure out two categories inside this dimension: **perception of mutual response** and **autonomy of interaction** (Figure 68).

Perception of mutual response. Perception of mutual response refers to the participants' capability of perceiving the reaction from other interlocutors in terms of information, action and emotion. In this case, we discover three insights. Firstly, information reception in socialVR mainly depends on verbal communication and 3d visualization. For the verbal interaction, P1, P2, P3, P6 has claimed that the primary interpersonal interaction is talking. P2 and P3 claimed the verbal communication in socialVR was fluent and similar to that in the face-to-face meeting (i.e., P2: "the information exchange (is socialVR) is fluent, and is the same with the face-to-face communication."). As for the 3d visualization, all participants thought that it is the added value of this socialVR tool, it helps interculaters to convey and understand tacit information (i.e., size, shape) easily. For instance, P5 has said: "Whenever you say something, you always show an example (of a 3d shape)." P2 and P4 claimed that synchronized 3d information helps to improve the accuracy of exchanging 3d information (P2: "(if we were just talking), we might have a different (visual) imagination of what we are talking about."; P4:" if someone doesn't

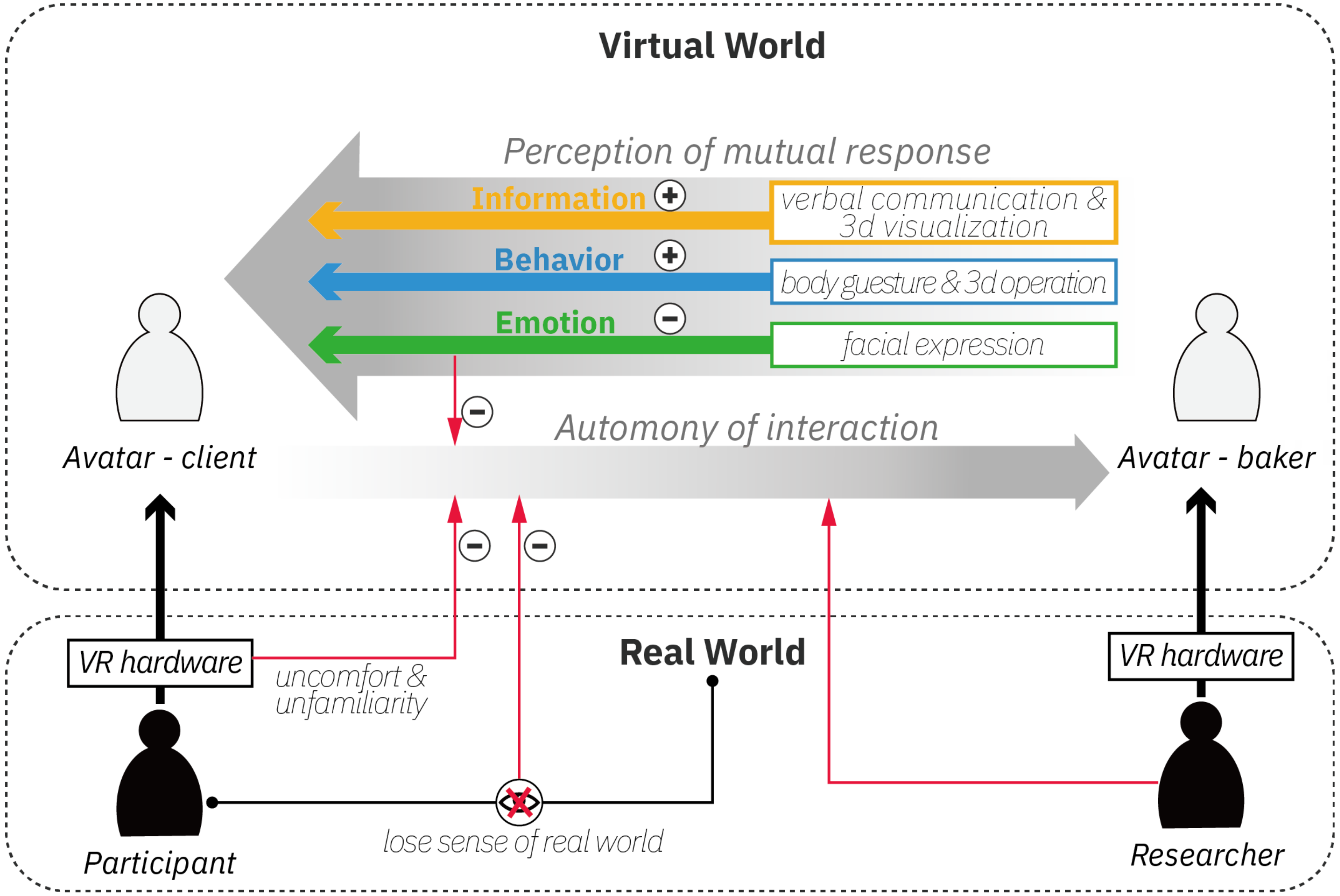


Figure 68

know how to visualize his ideas, then he cannot describe it clearly by words, so there might be inconsistency between his thoughts and his words."). In general, all participants thought they could understand their interlocutor's ideas throughout the co-design session, due to fluent verbal communication and 3d visualization. Secondly, participants perceived the response of behavior via body gesture and 3d manipulation. For the body gesture, participants have different perceptions of it. P1 thought that she can interpret social meaning from very simple body movements. She said:" When you move your body, I can feel that you are going to say something." However, P6 said that he could not perceive any mutual response from the other one's body language. For other participants, they didn't have too much impression on body gesture in the co-design process. We noticed that the action of producing or manipulating 3d shapes was perceived to be the primary reaction of behavior. For example, P2 has said:" When I said that I wanted a flower, you immediately generated one and carried it to me." P1 has said that: " When I say something, for instance ,' a large cake body', you quickly act based on my words." P3 has said:"For the behavioral interaction, I think there were a lot of (3d) operations.” P6 has also said: “I can feel that you react to my ideas based on the results of your action (3d operation).” To summarize, 3d manipulation in accordance with the interlocutor’s request, was perceived to be an active behavioral response. Thirdly, five of the six participants (P1, P2, P3, P4, P6) mentioned that emotion could not be perceived because there was no facial expression on the face of the virtual avatars. However, the lack of experienced emotion had different impacts on each participants’ social behavior. P2 said that she felt more relieved because in the virtual world she didn’t need to focus on and respond to the other’s emotion. It seemed that the lack of emotional connection in VR freed her from the social norm and manner in real world communication. As she described, “It decreased social pressure, and it might be a good choice to shy people. I felt free and the feeling is like turning off my front camera in a skype meeting.” Also, P2 has said that emotional connection was not an important issue in collaboration from her view, “I am a result-oriented person.” On the contrary, P4 and P6 claimed that they were less engaged because of the lack of experienced emotion. P4 thought that the VR communication lacked reciprocity because there was no facial expression and movement of the mouth. He has said: “I didn’t know whether you were hearing me and focusing on me when I was talking.” He didn’t know whether he should take further action in the co-design work because he had know idea whether his words were heard and understood by the baker. Likewise, P6 felt that he was not talking with a person because there was no facial expression on the virtual avatar, and lack of experienced emotion made him less engaged. He said that he usually perceived the collaborator’s emotion (i.e., satisfaction on the work) from the facial expression, and emotional connection made the collaboration more pleasant. “For me, pleasure is important to work, if I just focus on finishing a task, I will lose interest.” He thought that he was not involved in the co-design and contributed less to the cake idea,“You (researcher) asked me to give you more suggestions (when designing the cake), but my interest was not provoked, so I could not offer some creative ideas.” But for P1, P3 and P5, we didn’t find big impacts on behavior caused by the lack of facial expression. For P1, she thought that even if there was a lack of facial expression, she could partially perceive the other’s emotion from body gestures. P3 thought that the lack of experienced emotion and facial expression was not an essential problem in the context of collaboration. P5 didn’t mention this issue during the interview, she focused more on the functionalities of the tool.

Autonomy of interaction. In this case, autonomy of interaction is defined as participants’ capability and motivation to initiate an interaction with others. We discovered that four factors undermined the autonomy of socialVR interaction. Firstly, uncomfort of wearing HMDs made participants less proactive in VR communication. This only happened on P6, who had never worn VR headsets before and wore a pair of glasses inside the headset. “Wearing a VR headset is uncomfortable and hot, and impaired my experience.” This made him less engaged in the creative tasks, as he had described: ”I lost interest when wearing the HMD, I will be more engaged in talking about design face to face.” Secondly, participants who were unfamiliar with VR devices and VR interaction had less autonomy. P3 had said that: ”I needed to operate the VR interface so that I could do the design work, however, I need some time to acclimate to the virtual environment and VR interaction because I am new to VR.” Likewise, P5 has said that she felt hectic because she needed to learn the VR interaction and communicate with the cake maker at the same time. “Too much information for me”, as she said. In addition, P6 has said: ”I felt uneasy because I am not familiar with VR, it is my first time using it.” Thirdly, losing sense of the real world made interaction less active in interpersonal interaction. P1 has said that she had lots of unconscious bodily interaction (i.e., pat the shoulder) with others in face-to-face collaboration, however, in the virtual world, she seldom touched the other virtual avatar because she was afraid of hitting the furniture if she had some body gestures, “because I could not see the real world”, as she said. Additioanlly, P5 has said that:”I had no idea where the real world object was, and lost the sense of distance, I had a feeling of fear.” Finally, an interesting insight is that four of the six participants (P1, P3, P4, P6) said that one of the reasons they had less engagement was that they lacked a call-to-action to join the design work because the cake maker was too proactive in cake-making. P3 has said that:” When you were manipulating the objects, I thought I shouldn’t interrupt you so that you could express your ideas completely.” P4 has said:” You were always making the cake and introducing what you made to me, at that time I didn’t know whether I should take some actions.” P1 has said that:” I hoped that you could give me more chances to manipulate the cake by myself. You could take a short break and invite me to join the cake-making.” P6 has said that:” You kept asking me questions, so I thought that you just wanted me to give some comments verbally, and let you make the cake on your own.” P1, P3 and P4 said that they were willing to engage more in cake-making actually, but they felt that they were not given the chance to join in or the cake maker seemed to be authoritative. “You were a guide in this design process.” as P4 has said. Generally speaking, participants could not perceive a prompt for joining in the co-design work when communicating with the bakers. However, from the cake maker’s (the researcher) view, she could not perceive the motivation of the clients in the cake-making. Thus, she tried to be more enthusiastic in communication, by keeping asking questions and playing with the 3d models, so as to inspire the clients.

However, this action, which was taken by the cake maker as a sort of encouragement, was inaccurately perceived as an dominant attitude by the participants, and hence, decreased their engagement. In general, it seemed that there was a misunderstanding between the two interlocutors conveying and perceiving emotion in the socialVR. We noticed that three of these four participants (P1,P4,P6) had a higher requirement for emotional connection in collaboration. However we could not figure out a reasoning line between this element and their perception of the baker's attitude.

In conclusion, we will generalize the impacts of socialVR interaction on social behavior from two aspects: perspective of response and autonomy of interaction (FIXME). On one hand, we found out that socialVR generally enabled participants to perceive the other's reaction with regard to information and behavior, similar to the face-to-face interaction, and it added extra value to understanding tacit information (i.e., size, aesthetic, 3d shape) and perceiving behavioral responses due to the real-time 3d visualization and manipulation. However, unlike face-to-face communication, there is a lack of facial expression in socialVR and people cannot perceive the emotion of the other interlocutors. On the other hand, we discovered three factors which might impair participants' autonomy to interact with other users and the system: uncomfort caused by wearing HMDS, unfamiliarity with VR, the lack of visual sense of the real world, emotional perception as well as the baker's attitude.

Social meaning

Shared understanding. All participants thought that they had a shared understanding on the design process and final decision with the cake maker during the virtual design process. Firstly, shared visual references and joint attention helped interculaters to build up a clear consensus. On one hand, interlocutors can develop their communication on a common visual evidence (i.e., image, object), which enhances the comprehension of the conversation context and the accuracy of information exchange. As P5 has said: "I could understand you because we were discussing based on the same image." Also, P2 has mentioned about one of her experiences that she used to personalize a cake with a baker by merely talking, so she could only mentally visualize the cake according to the baker's verbal description. However what she got was different from what she expected, because there was a gap between the baker's words and her imagination. On the other hand, intuitive deictic gestures in VR help the interlocutor direct the other one's attention to the correct target easily. From observation, we noticed that all the participants naturally used hands or laser pointers to refer to a specific picture, a 3d object or a position when expressing their ideas (Figure 69). For example, when P3 was describing the desired height of the cake, she used her hand to refer to a cake photo, and said:" I want three fifths of this cake's height.", then she used her finger to roughly point out the corresponding position on the picture. Secondly, real-time manipulation and embodiment keep interlocutors on the same page when developing their ideas. Real-time 3d operation "translates" all the design interventions from abstract words to visible action. As P1 has described, "Whenever I said something, you could immediately edit the cake model based on my words, so we could quickly reach a consensus." Additionally, the effects of design intervention can be visually perceived by all the co-designers due to real-time embodiment. For instance, P2 claimed that: "(If we don't have the tool), we might have different imaginations of how the cake would be. But now, (with this tool), we could clearly see all the changes we made on the cake." P3 has also said that it was easier to understand 3d shapes in the virtual world because the object could be real-time edited.

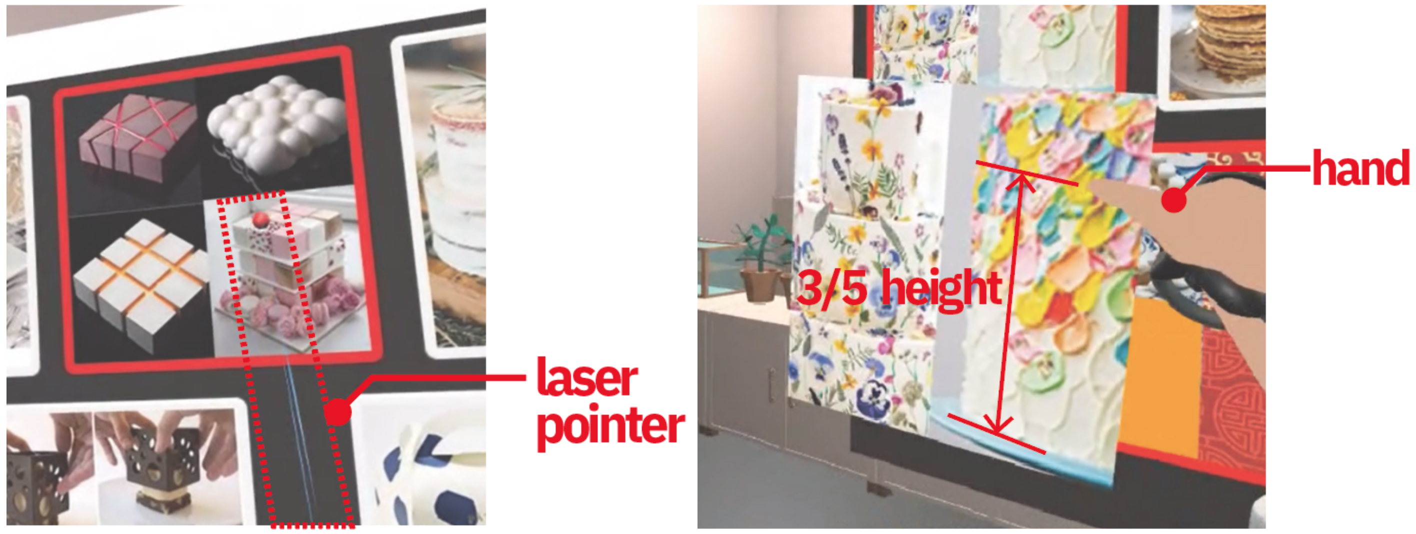


Figure 69. Deictic gesture

Co-presence and Shoulder-by-shoulder setting. Five of the six participants (P1,P2,P4,P5,P6) thought that they were co-located with the cake maker in a shared virtual environment, imagining that they were physically separated with the researcher. But P3 said he could not evaluate the virtual co-presence, because he was conscious of the fact that he stayed in the same studio with the researcher. P5 thought that the feeling of co-presence stemmed from the visible virtual avatar of the other user. However, she pointed out that the co-presence feeling was undermined because the two interlocutors were always talking to each other shoulder by shoulder. As she said:"I didn't have too many chances to look at your avatar, because I needed to focus on the screen. So sometimes I felt that we were just having a telephone call." Besides, P2, P3, P4 mentioned about the shoulder-by-shoulder setting. P2 thought that talking shoulder-by-shoulder made her focus less on the interlocutor, but she didn't think this factor had any impacts on her experience in co-design. P3 and P4 thought that shoulder-by-shoulder communication was unnatural and different from the real-world collaboration in which people are prone to talking face-to-face.

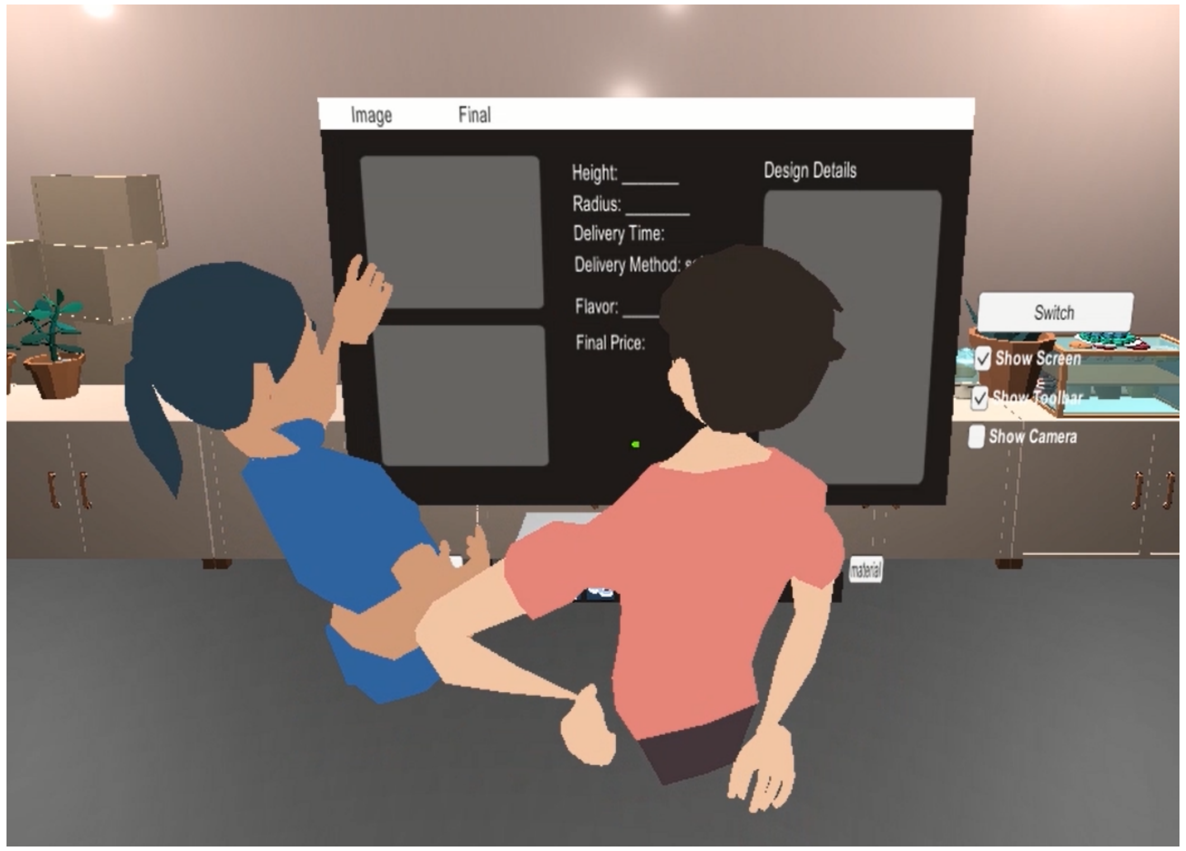


Figure 70. shoulder-by-shoulder setting

Presence & immersion

Presence. According to Witmer and Singer, presence was defined as " the subjective experience of being in one place or environment, even when one is physically situated in another" [82]. From the interview, we discover the realism is most relevant to presence in this prototype. Firstly, four of the six participants (P2, P3, P4, P5) claim that the environment realism should be improved in order to enhance the feeling of being situated in a bakery. P2 said that there should be more baking tools in the virtual bakery. P3 said that some background music could be played in the virtual bakeries, and there should be other guests in the bakery. P4 said that there should be some environmental sounds (i.e., the voice of the store's door opening), also the spatial layout of the virtual space was not similar to the real bakery because there was no kitchen. P6 said that the visual style of the virtual space was too cartoonish, he hoped that it should be photo-realistic for the sense of presence. Secondly, P3 pointed out that the avatar realism undermined the feeling of presence. He said:" I can not see myself in the virtual space because I didn't have legs." Also, he said that the face of the virtual avatar didn't resemble the face of the real user, he suggested that: " It would be better if you attach a real portrait photo to the avatar's face."

Immersion. Immersion is defined as a psychological state of being included in a virtual space. Isolation from the physical world is perceived to be an important factor of immersion [82]. According to the interview, all the participants said that they have no awareness of the real world when performing the virtual co-design tasks, and fully focus on the VR communication.

3D creative task

This category mainly illustrates the interaction between users and 3d objects via the system. It includes four clusters: **3d perception, 3d manipulation, creative resources and design results.**

3d perception. This item refers to the participants' multisensory perception on the virtual 3d objects. Firstly, five (P1, P3, P4, P5, P6) of the six participants claimed that they could perceive the size of the 3d objects. However, P2 said that she needed an extra reference object (i.e., a pizza box) which she already had a clear idea of its size, to recognize the scale of the virtual 3d objects by comparing them with the reference. Thus, during the test, she evaluated the size of the cake by comparing its diameter with the length of the forearm of her virtual avatar. Secondly, two of the six participants (P1, P6) were unsatisfied with the visual aesthetics of the 3d object. P1, who was skilled at 2d sketching, claims that the aesthetic of the 3d models in VR was no better than hand sketching in the real world. P6 stressed that the visual style of the virtual 3d model was non-realistics and the virtual cakes were off color. Thirdly, four of the six participants (P1, P2, P4, P6) claimed that they desired for more multisensory perception of the virtual cakes. P1 and P2 said that they hoped to feel the haptic texture of the food material. P4 claimed that he wanted to smell the cake. P6 said that gustatory quality was an important element for him to perceive the cake, he also stressed that mechanics simulation was lost in the virtual world, and make it difficult for users to evaluate the practicality of the cake ideas (i.e., P6: "If I want to place a lot of fruit on a soft cake body, in the virtual world it is doable, but in the real world it might be impossible because of gravity".).

3d manipulation. This item is defined as users' physical operation on virtual 3d shapes including moving, rotating and scaling. Based on the interview, all the participants said that gesture-based 3d manipulation was quick to learn and easy to use, even if some of them had little experiences in using VR. P4 claimed that easy 3d manipulation helped to lower the threshold of embodying 3d design ideas for the non-experts. Additionally, P2 and P4 said 3d manipulation gave them a feeling of control in the design process. For P2, the action of operation in itself provided her with a feeling of control. As she had said :" Being able to manipulate these 3d models gives me a sense that everything is in control." As for P4, 3d manipulation enhances his autonomy in expressing ideas to others, and hence, gave him a feeling of control (P4:"I have a feeling of control, when I can resize the cake model, showing the cake maker how large the cake should be.")

Creative resources. The creative resources refers to all the elements (i.e., images, preset models) included in the virtual environment, which aims to assist users in creative tasks. Based on the interview, five of the six participants (P1, P2, P3, P4, P5) said that the database of the predesigned models was too small to support personalized creative works. As P3 has said, "I cannot get whatever (3d models) I want, because all the models are loaded into the virtual environment beforehand." P4 said that he hoped to get access to the internet to obtain models and pictures inside the virtual world. Another interesting insight is that two participants (P3, P6) said that the virtual environment was not inspiring enough to support divergent thinking in creative tasks, compared with the real world. P6 said that in the real world he could freely write down his random thoughts on the blackboard to develop creative ideas, however, in the virtual world, he could not do so. P3 claimed that in the real world there were a lot of objects which were irrelevant to the creative tasks, but these objects could somehow offer unexpected inspiration to collaborators. In the virtual world, everything was preloaded and exactly oriented to cake design, some "serendipity" was lost. Additionally, P3 thought that the way to display preset models have some impacts on user's inspiration and creativity. He claimed that the toolbar interface didn't give salient visual cues for users to obtain and interact with 3d shapes. As he said, "In the real baker, all the samples were displayed in a window. But in the virtual space, all the models were confined to a small interface and small icons." Also, he hoped that some 3d sample cakes, constructed by the predesigned cake component models, could be shown, helping him to build up an expectation of his design outcome, "I have no idea what kind of cake I can make based on the current setup of the virtual bakery", as he said.

Design results. In this test, the design results are the finalized 3d cake mode. All the participants claimed that the fidelity of the cake model was low. They had a general idea of how the cake would be (i.e., P2:"I can roughly imagine the (looking of) cake."), but the details are still lost (i.e., P5: "I feel it is hard to perceive the details (in this tool)"). We found that participants have different requirements on the fidelity of the finalized cake. For instance, P2 had a low requirement on the fidelity, she said: "I think this (fidelity) is sufficient, and I hope that cake maker can give me some surprise when I see the real cake, and this is exactly the value of a cake maker." However, P6 had a higher demand on the realism and fidelity, he said "I will feel unsatisfied if the virtual cake model is not the same with the finalized real cake. "

Figure 71. design results of the six participants

5.3.2 Validate design requirements

RQ2: *Do the design requirements fix users' latent needs in the cake co-design activities?*

To answer this research question, we asked the participants to evaluate these design requirements point by point in the post-test interview. One each point, participants were asked to answer two questions:

- *What do you generally think about this function/ interaction technique? Like or dislike?*
- *Does this function/ interaction technique support your design word in a positive way? If so, how does it help you? If not, why?*

R1: Transforming panoramic photos into the immersive virtual environment.

Generally, 5 (P1,P2,P3,P4,P5)of 6 participants felt satisfied with this functionality, indicating that it gave a good visualization and contextualization of the cake (P1: "With this function I can imagine how a cake will look like in my home"). However, P6 claimed that he felt alienated when situated in the virtual environment generated by 360 degree photos, because it was not realistic enough.

R2: Presenting the images in two forms: physical photos floating in the 3d space; digital pictures presented in the virtual screen.

From observation, we found that all the participants frequently referred to certain images shown on the screen when they were describing relevant ideas. P5 said that discussion by referring to a shared image helped to build a shared understanding between the two interlocutors. However, five of the six participants (P1,P3,P4,P5,P6) thought it was unnecessary to turn the screen-displayed images into physical ones. Only P2 thought that this function helped to approximate real world communication, in which people usually grab a physical picture in hand to clarify their design ideas.

R3: Allowing users to draw 3d curves in the 3d space

All the participants thought that this function was useful for personalized 3d work, such as making self-defined shapes or adding texts to the cake. P6 said that the sketching process should be more fluent and smooth. However, P1 thought that making 3d curves are not sufficient to embody a solid 3d shape, for the lack of surfaces. P3 said that 2d sketching on a plane was missed in this prototype.

R4: Allowing users to manipulate 3d shapes in one-to-one scale

Five (P1, P3, P4, P5, P6)of the six participants claimed that they could perceive the size of the 3d object. It helped them to better evaluate the cake ideas with regard to quantity, aesthetic and practicality. (i.e., P1:"I might want to place 80 strawberries on the cake, but actually it is not doable. In this situation, it is important for me to perceive the size of the cake body and strawberries."). However, P2 said that she could only perceive the size of the virtual 3d objects by comparing them with real world reference objects (i.e., a pizza box) which she already clearly knows about the size of. During the test, she perceived the scale of the cake by comparing its diameter with the length of the forearm of her virtual avatar.

R5: allowing users to duplicate and hide the 3d geometries.

This functionality was not realized in this prototype. However, during the tests, all the participants asked whether they can delete a certain 3d object. Thus, it showed that this function was necessary. Additionally, P1 claimed that an advanced duplication and alignment function was preferred ("I wanted a function that the strawberries can be duplicated and placed around the cake in a circle."), for better 3d modelling efficiency.

R6: enabling users to use intuitive and easy gestural inputs to manipulate virtual objects.

All participants indicated that the 3d manipulation is quick to learn and easy to use. All of them mastered how to move, rotate and resize the 3d object within the ten-minute introduction. P1 hoped that the 3d object can be automatically set to some fixed sizes (i.e., 6 inch, 9 inch) when being resized.

R7: offering pre-designed models of the most commonly used cake components.

All participants claimed that the model database was not big enough to meet the needs for designing personalized cakes. Five (P1, P2, P4, P5, P6) of the six participants agreed that the preset model database helped to improve the time efficiency of 3d modelling (i.e., P5:"It helps me a lot when I have to build a 3d model from scratch."). P3 proposed that the user interface of obtaining 3d models didn't give users an overview of all the available options, and salient visual cues to obtain and interact with these models. As he said, "In your prototype, all the models are confined to a small interface. But if I am in a bakery, I can see all the options in a big window, and I might buy something which is beyond my expectation.".

R8: giving vivid visual cues (i.e., glosiness, color identity, color density, visual texture) of the virtual cake.

This functionality was not fully realised in this prototype for tests, because the current computer was not powerful enough to support good rendering quality. P6 pointed that the virtual cakes were non-realistic because they were off color, and he said: "The color differences made me lose appetite".

R9: allowing users to capture images and record videos in VE.

Four (P1, P2, P4, P6) of the six participants liked this functionality for the purpose of social connection (i.e., sharing photos with the one who will receive the cakes, keep the photo for memory). Two participants (P1, P5) thought that this function was useful for comparing different design ideas (i.e., P5:"It might be useful when I need to make a decision from several options."). Three participants (P1, P2, P3) said that this function helped to record the final decision for further negotiation, and hence, improved the user satisfaction. P1 suggested that the image-capture function should be approved by the clients for the sake of portrait privacy.

R10: automatically calculating and archiving the 3d data of the virtual cake

R10: automatically calculating and archiving the 3d data of the virtual cake

5.3.3 Usability

Besides answering the two research questions, we also investigated the system usability. Participants evaluated the usability of this tool by filling in the SUS form, they were encouraged to think aloud while filling in the questionnaires. Although a qualitative analysis was not available because the sample was small (6), we can still get some insights from the SUS data and participants' description.

In general, all participants thought that this tool was easy to learn (Q7), even for participants who have no VR experience before (P5, P6), they gave a score of four. Four of the six participants thought that the tool is easy to use (Q2), except that P3 gave a score of 2 and P6 gave a score of 3. P2 thought that the toolbar user interface didn't offer users salient visual cues to click and obtain preset models(5.3.1). P6 thought that this tool could not perfectly support collaborative work for the lack of physical simulation functionalities. Five of the four participants thought that they could master this system without extra technical support (Q4). Four of the six participants thought that the functionalities were well integrated (Q5). All participants thought that there was little inconsistency in this tool (Q6). Five of the six participants didn't think that this system cost heavy learning (Q10).

When we look into each participant, we find that their grades were partially relevant to their personal VR experience and interpretation on the questions. Firstly, VR experience and acceptance might have some impacts on the score. For instance, P6 generally gave lower scores to the usability and user satisfaction of this tool, because he had no VR experience before, and had lower capability to acclimate to virtual environment and VR interaction. Also, he highlighted that he felt comfortable and hot while wearing the HMD, this influenced the overall experience when using this tool. On the contrary, P2 had rich experience in using VR, and she was quite satisfied with this tool and gave high scores to all items generally. But we could not see a clear correlation between VR experience and the usability scores, because P4(little experience before) and P5 (no experience before) still gave good scores generally. Secondly, different interpretations in the questions affect the scores. P1 had abundant VR experience and learned VR interaction quickly, but she thought that the system was unnecessary complex (Q3), cumbersome to use (Q8) and required extra learning(Q10). Then we found that she had a different understanding on these questions: she interpreted the "system" as "setting up the system with regards to hardwares and softwares" instead of "interacting with the system" like other participants.

1 [strongly disagree] --- 5 [strongly agree]

No.	QUESTION	P2	P5	P4	P3	P1	P6	AVERAGE
6	I don't think there was too much inconsistency in this system.	5	5	5	5	5	4	4.8
7	I would imagine that most people would learn to use this system very quickly.	4	4	5	5	4	4	4.3
5	I found the various functions in this system were well integrated.	5	5	4	3	5	3	4.2
2	I don't think the system was unnecessarily complex.	5	5	4	5	1	3	3.8
3	I thought the system was easy to use.	5	5	4	2	4	3	3.8
4	I don't think that I would need the support of a technical person to be able to use this system.	5	4	4	4	4	2	3.8
10	I don't need to learn a lot of things before I could get going with this system.	5	4	4	4	2	4	3.8
9	I felt very confident using the system.	5	4	3	4	3	2	3.5
1	I think that I would like to use this system frequently.	4	3	4	4	3	2	3.3
8	I don't think the system is very cumbersome to use.	4	3	4	4	1	3	3.2
	AVERAGE (each participant)	4.7	4.2	4.1	4	3.2	3	

Table 6. SUS results

5.4 Conclusion

5.4.1 Effective factors on virtual social behavior

In this part, we are going to elaborate what factors lead to the participants' choices among the two collaboration modes.

Firstly, we collected all the participants' features and user experience (FIXME). We notice that the two groups of participants (client-oriented & baker-oriented) differentiated most on the two dimensions: user profile and quality of Interaction.

Behavior			Client-oriented collaboration		Baker-oriented collaboration			
Participant			P2	P5	P4	P3	P1	P6
User Profile	gender		F	F	M	M	F	M
	creative motivation in cake		high	high	low	low	high	low
	capability of adapting to VR		high	low	low	-	high	low
	need for emotional connection in collaboration		low	low	high	-	high	high
Quality of Interaction	perception of mutual response	info	fluent verbal communication 3d visualization	fluent verbal communication 3d visualization	fluent verbal communication 3d visualization	fluent verbal communication 3d visualization	fluent verbal communication 3d visualization	fluent verbal communication
		behavior	3d manipulation	3d manipulation		3d manipulation	3d manipulation	3d manipulation
		emotion	lack of facial expression	lack of facial expression	lack of facial expression	lack of facial expression	lack of facial expression	lack of facial expression
	Autonomy of interaction			can't see real world	Unfamiliar with VR Proactive attitude of cake maker	Proactive attitude of cake maker	can't see real world Proactive attitude of cake maker	Unfamiliar with VR Uncomfort of HMD Proactive attitude of cake maker
Presence & Immersiveness	shared understanding		✓	✓	✓	✓	✓	✓
	co-presence		✓	✓	✓	✓	○	✓
Social Meaning	environment realism		○	▭	○	○	▭	○
	avatar realism		▭	▭	▭	○	▭	▭
Creative 3D work	3d perception (size)		○	✓	✓	✓	✓	✓
	3d manipulation		easy feeling of control	easy	easy feeling of control	easy	easy	easy
	creative resource		insufficient model database	insufficient model database	insufficient model database	insufficient model database lack of serendipity	insufficient model database	insufficient model database cannot support divergent thinking
	design outcome		low fidelity	low fidelity	low fidelity	low fidelity	low fidelity	low fidelity
Usability	SUS score		4.7	4.2	4.1	4.0	3.2	3.0

positive elements (to VR codesign experience)
negative elements (to VR codesign experience)
marginall elements (to VR codesign experience)
✓ achieved
○ not achieved
▭ not mention

Figure 72. Collection of user experience

Secondly, we further specify the features of the two groups.

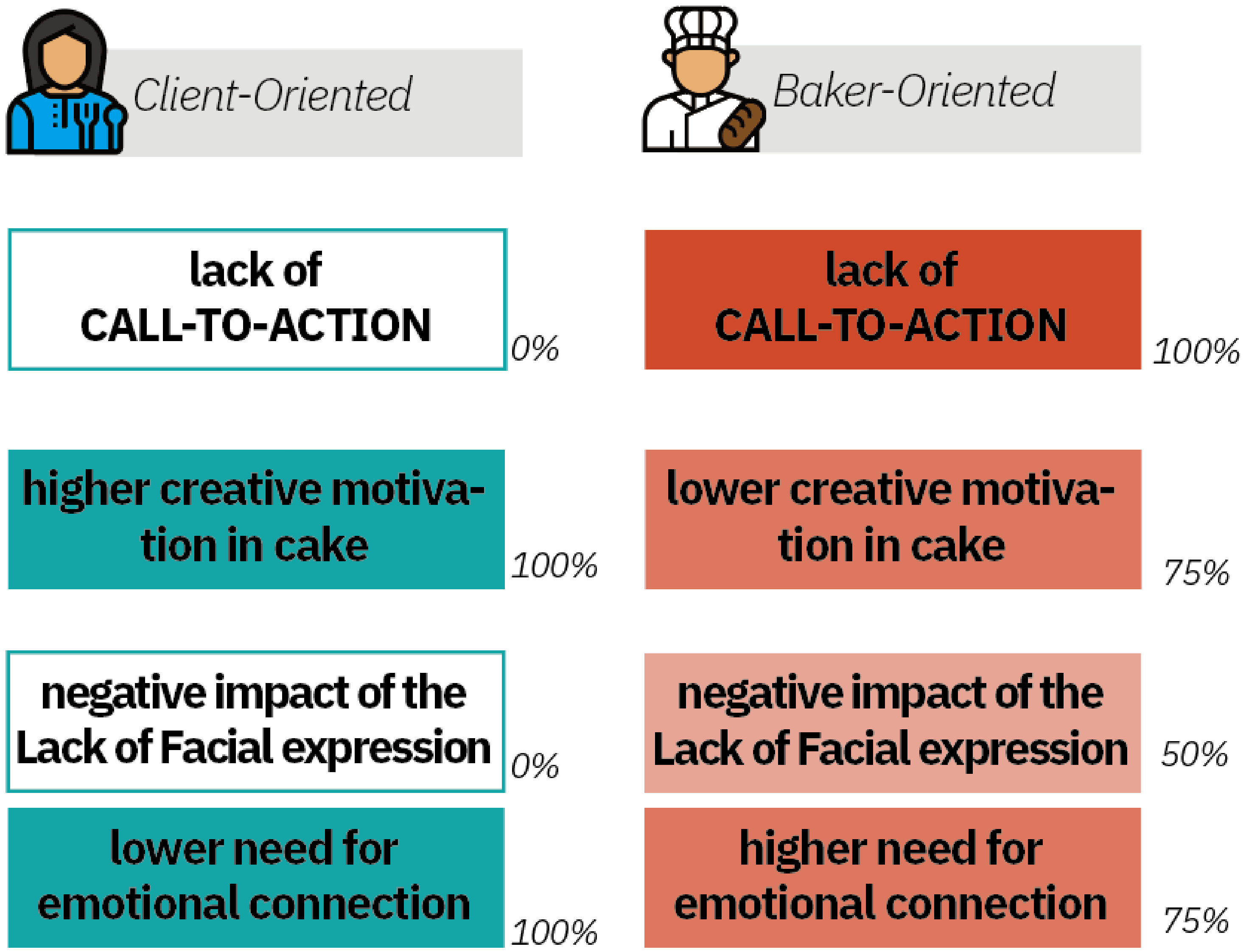


Figure 73. Features of two groups of participants

For the two participants (P2, P5) who chose the client-oriented mode, they both had a higher creative motivation in designing cakes, and such motivation is highly relevant to gender difference (the female has higher interest in cake-making while the male doesn't). Additionally, they didn't have high requirements on the emotional connection in the context of collaboration. The lack of affective interaction had little impact on their behavior, even improved their experience by decreasing social pressure (P3). None of them claimed that they didn't perceive the call-to-action from the baker. For the other four participants (P1, P3, P4, P6) who chose the baker-oriented mode, 75% of them are less motivated and interested in cake design. In addition, 75% of them claimed that they had higher needs for the emotional connection in the context of collaboration. 50% of them claimed that they were negatively influenced by the lack of facial expression and emotional perception, to be more specific, P6 lost enthusiasm in the design work and P4 felt hesitant to take action. In addition, all of them were unable to perceive the call-to-action message from their collaborators (P1, P3, P4, P6). Therefore, they were less engaged in the collaboration, even if 75% of them wished to get more involvement in the design work.

After that, we are gonna discuss the relationship between thesis essential elements mentioned above.

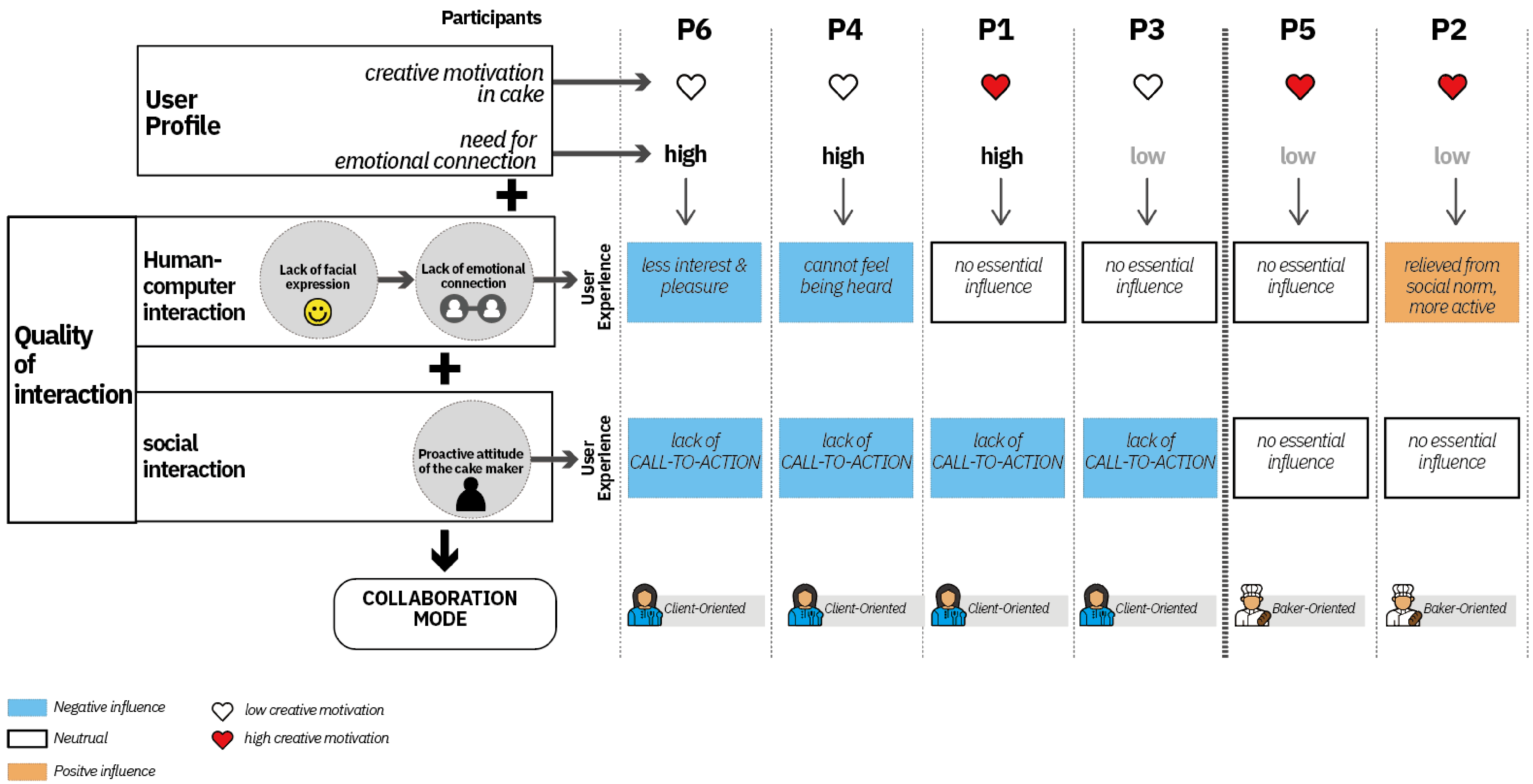


Figure 74. influential factors of socialVR behavior

First of all, we categorize these elements into three categories: user profile (the background of the user), quality of human-computer interaction (how the socialVR system is designed) and quality of social interaction (how the two users interact with each other via the system).
User profile: creative motivation & personal requirements of emotional connection
Quality of human-computer interaction: the lack of facial expression
Quality of social interaction: the proactive attitude of cake make

Across all the six tests, both the quality of human-computer interaction and social interaction almost kept the same, while the user factors differed person by person. They influenced people's experience and behavior collectively and individually.

[user profile (creative motivation)]
It seems that the personal creative motivation in cake design influenced the participants' engagement and behavior. Previous research indicates that interest influenced people' affective engagement in a task and the extent to which they are involved in deeper processing [83]. In addition, based on the test results, all the participants who chose the client-oriented mode had a higher interest in cake-making, while 75% of the four participants who chose the baker-oriented mode had less motivation in creative cake design activities.

[user profile (need for emotional

connection) + quality of human-computer interaction] System factor evoked different user experiences on participants with different user factors. The lack of facial expression made it difficult to perceive the emotion of the other interlocutor, and this issue had different impacts on the participants who have different requirements on affective interaction in cooperation. For participants (P2, P3, P5) who need less emotional connection in collaboration, the impacts were marginal. Especially for P2, the lack of affective interaction even improved her experience by relieving her from the social manner. However, for the P4 and P6, who desired more emotional communication when collaborating with others, the lack of facial expression and poor affective interaction undermined their engagement in the design work (P4: couldn't feel being heard and hesitated to take action; P6: lose interest). For P1 who also highly required emotional connection, the body language partially complemented the lack of facial expression for her to experience the other baker's emotion, so she was not influenced a lot.

[quality of social interaction] The proactive attitude and behavior of the cake-maker affected participants' engagement in the co-design work. All the four participants (P1,P3,P4,P6) who chose the baker-oriented mode claimed that they could perceive a call-to-action, that is, an invitation from the cake-maker to join in the collaborative 3d work. It shows that 75% of the four participants (P1,P4,P6) had high requirements on affective interaction in cooperation, and 75% of them (P3,P4,P6) had less interest in this co-design task. On the contrary, the other two users (P2,P5) who chose the client-oriented mode, didn't say that they were negatively influenced by the proactive attitude of the cake maker, also, all of them had lower needs for emotional connection and had higher interest in the cake. Thus, it seemed that the user factor led to different reactions or interpretations to the proactive attitude of the cake maker. However, this speculation is not solid because the sample is too small (6), in addition, we didn't figure out a clear reasoning line between the user factor and the social interaction factor.

In conclusion, we find that the personal features of participants, requirement on emotional connection and creative motivation, were the most essential factors influencing the participants' engagement as well as their choices of the collaboration mode, because they are the primary differences between these two groups of participants. They can directly influence the participants' engagement (personal interest in personalizing cakes), or might work as a "catalyst" of the human-computer interaction (the lack of facial expression) and social interaction (proactive attitude of the cake maker), provoking different user experiences, and hence, influence their behavior in collaboration.

5.4.2 Validation of design requirements

In general, R1, R3, R4, R5, R6, R7, R8, R9 were proved to be meaningful to the design work, and meet the users' latent needs as expected (chapter 3). Part of R2 was helpful to the design task (show pictures on the screen), while the other part was perceived to be unnecessary (turn slide images into physical photos). R10 remained unknown because it was not realized in the prototype. As for the technical completeness, it showed that R1, R3 and R7 were not realized in a good quality. R5, R8 and R10 were not realized in this prototype.(Figure 75)

	Design requirement	meaningful to design work	technical complete-ness
R4	*Allowing users to manipulate 3d shapes in one-to-one scale*	✅	✓
R6	*Enabling users to use intuitive and easy gestural inputs to manipulate 3d virtual objects.*	✅	✓
R9	*Allowing users to capture images and record videos in VE*	✅	✓
R1	*Transforming panoramic photos into the immersive virtual environment.*	✅	✗
R3	*Allowing users to draw 3d curves in the 3d space.*	✅	✗
R7	*Offering pre-designed models of the most commonly used cake compo-nents*	✅	✗
R5	*Allowing users to duplicate and hide the 3d geometries.*	✅	Ø
R8	*Giving vivid visual cues (i.e., glosiness, color identity, color density, visual texture) of the virtual cake.*	✅	Ø
R2	*Presenting the images in two forms: physical photos floating in the 3d space; digital pictures presented in the virtual screen.*	✅ ⊘	✓
R10	*Automatically calculating and archiving the 3d data of the virtual cake*	?	Ø

✅ *support design work and meet latent need as expected*

⊘ *not support as expected*

? *unkown*

✗ *not achieve a good quality*

Ø *not realized in this prototype*

✓ *achieve a good quality*

Figure 75. validation of design requirements

6. Recommendation

Chapter 5 investigated the impacts of socialVR on social behavior in co-creation. Based on these findings, recommendations for study methods are concluded, for a more comprehensive understanding in the user experience of virtual co-design. Additionally, design recommendations of the VR prototype are illustrated for better user experience.

6.1 Recommendation for study method

More samples

In this study, only six participants were invited for the VR tests. Thus, the test sample was too small to be representative. In addition, the background of all the participants were too similar (⅚ were TUD students; ⅚ were design students; their ages ranged from 24 to 27), and this might influence the holisticity of the test results. In addition, the test results (5.4) showed that social behavior in VR was influenced by personal interest, gender and requirements on emotional connection. Therefore, the test sample should be larger, recruiting participants with diverse backgrounds and personal features, so that we could delve deeper into the relationship between the social behavior and those factors mentioned above. Ideally, the number of the test sample should be over 24.

In addition, we hope to invite participants who truly need to personalize cakes in the real world. From user tests, we discovered that it was difficult to fully contextualize participants because they didn't really need to order a customized cake. Thus, in the tests, participants could not really think and behave in the same way with real clients. For example, in the tests, when the cake maker tried to discuss the price of the cake, clients easily agreed with the cake makers and never bargained since they didn't really pay for that. However, based on the user research (chapter 2), negotiation on cost is an important part of client-baker communication. Thus, some insights about negotiation in the virtual environment were lost.

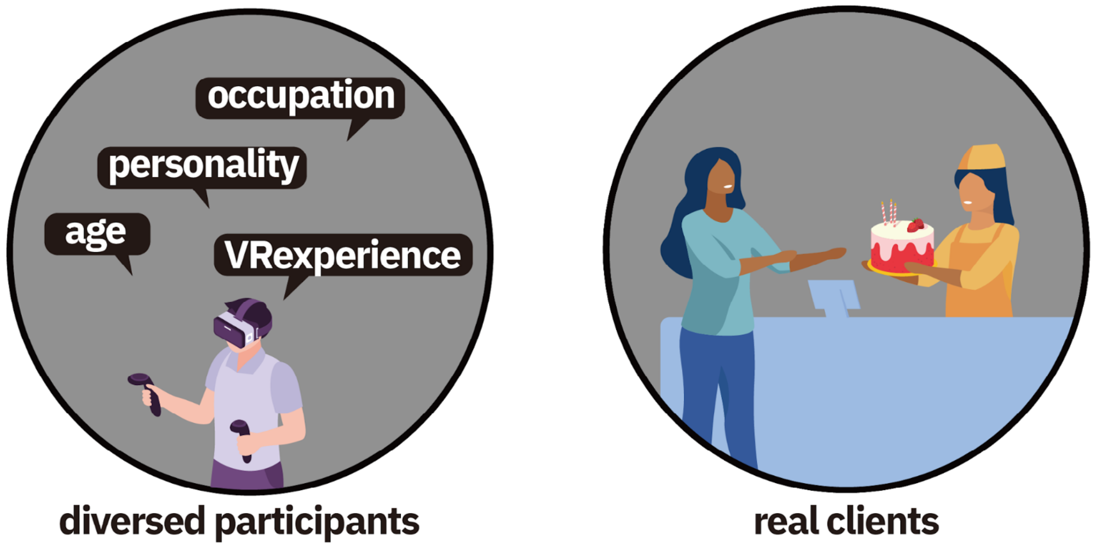


Figure 76

Involve professional cake makers

In this VR co-design test, the role of cake maker was played by the researcher who had little experience in cake making and business negotiation. Even though the researcher had practiced role-play based on the user research results about how cake makers usually communicate with clients (chapter 2), there was still a gap with real bakers with regards to professional knowledge and negotiation skills. In addition, since the opinions of professional cake makers on the socialVR tool were lost, we failed to investigate how this tool affects design experts' behavior in the co-design activities and whether this tool meets their needs. Ideally, three to five professional cake makers should be invited to use the VR tool and share their experiences or opinions on this tool.

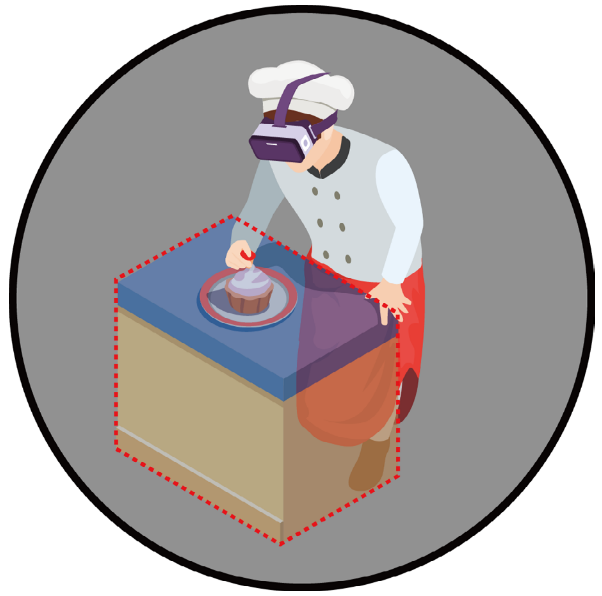


Figure 77

Different assignment

In this test, the six participants respectively generate a context for which they would make a unique cake. Five of the six contexts (P1, P3, P4, P5, P5) are highly personal and emotional (i.e., confess love, friend's birthday). P2 came up with a context which is relevant to her research project (a seminar for envisioning better hospice care), however, this context was also emotion-oriented because of this sensitive topic. In general, all the contexts generated by participants are emotional and personal, and this might have an impact on their experience and behavior in the design process. We assume that such a design process might be different from designing a cake for a result-oriented context (i.e., customize a cake for an anniversary of X company with a budget of 100 euro). Therefore, it is advisable to perform a comparative test and situate the participants in a result-oriented context.

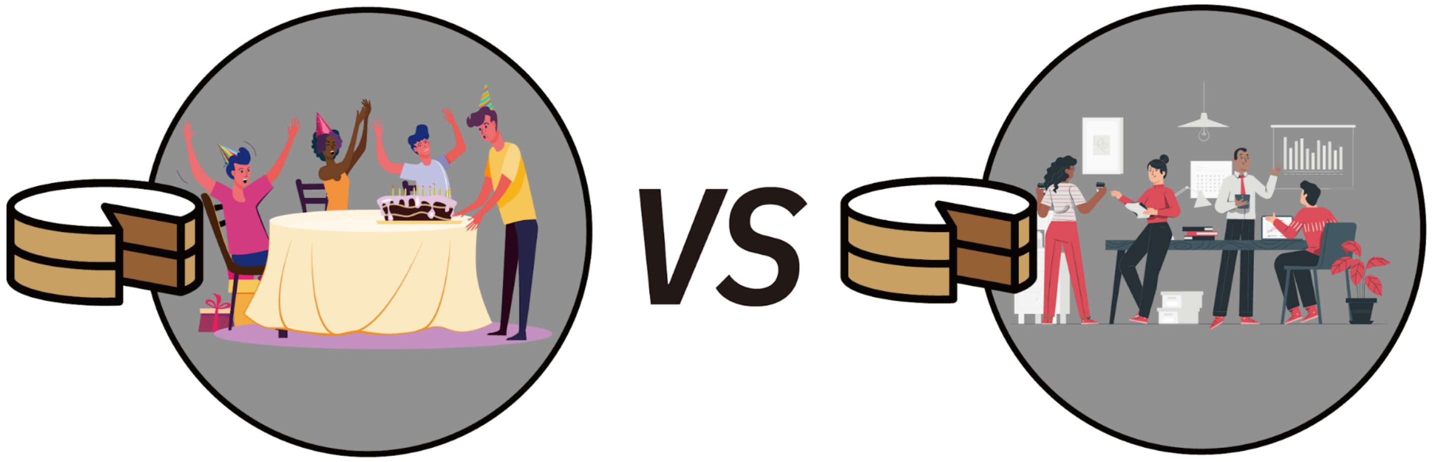


Figure 78

6.2 Recommendation for prototype

Based on the test results and participants' feedback, we came up with a collection of recommendations to improve the socialVR collaboration experience: **design for emotion, design for dialogue, design for realism and design for inspiring environment.**

Design for Emotion

Real-time emotion recognition. Wu et al., has come up with a deep learning system called EMO which can recognize real-time emotions of the user. Unlike the current solution which requires the whole face images, this system is based on the single-eye-area images captured by the eye-tracking camera of the eyewear [81] (Figure 79, 80). Hence, it is promising that such technology will be integrated with VR headsets, identifying real-time emotion of users and visually mapping it to the virtual avatar.

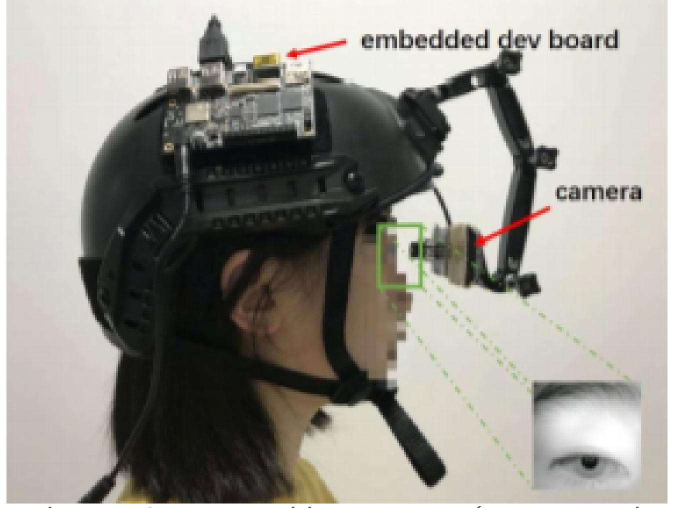


Figure 79. eye-tracking camera (Wu.H., et al. 2020)

Figure 80. facial expression recognition based on eyes' image (Wu.H., et al. 2020)

Emoticon in VR. Emoticon (emotional icon) is widely used in computer mediated communication (CMC), for users to convey emotion and enrich conversation. It is a sort of 2d graphic representation of facial representation. Burgoon et al. argue that, “Visual cue primacy is also stronger when decoding emotions related to positivity... especially when visual cues involve the face” [82]. Thus, emoticons are promising in supporting emotional expression and perception. Currently, emoticon is widely used in screen-based social media applications, and is represented as a 2d icon in a unified size. Users share emoticons by clicking buttons and presenting them in the shared chat window. However, in the virtual world, graphic representations go beyond two-dimension and interaction with the system is no longer limited to the screen. Thus, VR might bring more possibilities to conveying emotion by using emoticons. Firstly, presentation of emotical in VR will be more flexible with regards to scale, dimension and animation effect. Secondly, inside the 3d virtual world, the users can interact with emoticons in a more explorative way, for example, with full body gestures. These benefits might bring better expression power to emoticons.

Figure 81

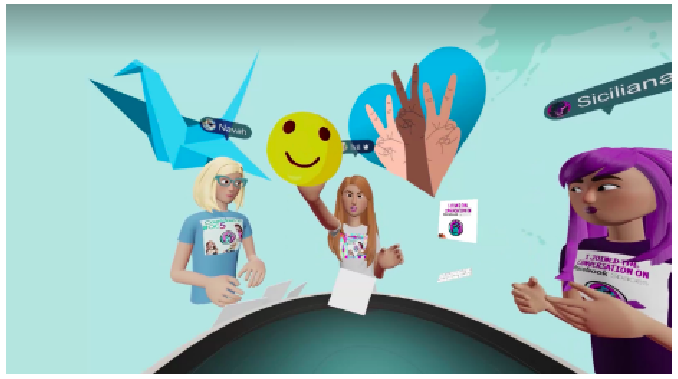


Figure 82. emoticon in VR

Design for dialogue: F2F setting

Based on the test results (5.3.2)Position and orientation of the interlocutors have impacts on the mutual focus of people, co-presence and naturalness of the communication. Three of the six participants claimed that they prefer a face-to-face setting, for a more natural and interaction dialogue. Thus, the spatial layout of the virtual bakery will be changed, so that the two users can naturally talk face-to-face (Figure 83).

Figure 83

Design for Realism

Environment realism. Based on the test results (5.3.1), the environment realism is perceived to be an essential factor of the sense of “being there”. The environmental design of the virtual space can be improved from two perspectives. Firstly, the rendering quality can be enhanced to a photo-realistic level. Second, multi-sensory elements should be included in the virtual space, including visual factors (i.e.,interior decoration, other people), auditory factors (i.e., background music, noise), and even auditory (i.e., smell of food) and haptic (i.e., texture of 3d object) elements.

Figure 84

Avatar realism. Avatar realism has also been mentioned by the participants: the face of the avatar was unlike the real user’s, and there were no legs. This also has a negative impact on the feeling of being situated as well as the naturalness of communication. Thus, the avatar realism needs to be improved. Firstly, the legs should be added to the virtual body so that the whole body figure resembles the real person. Additionally, the face of the avatar should look like the face of the real user. One solution is using face image capture and photo realistic rendering. Another solution is that the user can create and animate a customized character to represent or resemble their appearance (i.e., Memoji of Apple Inc).

Figure 85

Design for inspiring environment

The environments should be more inspiring for non-expert designers to generate creative ideas. Based on the feedback of participants, an inspiring cake studio should offer sufficient 3d creative references for users to build up an expectation of the design outcome, as well as give salient visual cues for users to play with the 3d models (5.3.1). Therefore, the spatial layout is changed, so that users easily get access to the design samples, take them from the fridge and play with them (Figure 86). The way to obtain 3d models is more interactive and playful. This encouraged participants to appropriate the existing design examples to be more explorative.

Figure 86

8. Reference

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