Recommendations for Interaction Design in Spatial Computing from the Perspective of Future Technology

by

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Abstract

The design industry is experiencing tremendous changes along with the upcoming arrivals of frontier technologies. This thesis takes a forward-looking perspective and conducts extensive recommendations for interaction design in spatial computing. The recommendations aim to assist designers and developers in improving the user experience of products that involve spatial computing technology. It also explores the essentials of theories, principles, experiments, and industry practices in domains including interaction design, user interface design, user experience design, cognitive psychology, extended reality, and spatial computing. The influential knowledge of different domains divides the recommendations for interaction design into three aspects: visual representation, embodiment, and engagement. The body content will start with a conclusive thesis proposal as an instruction. Second, it will collect a comprehensive literature review. Third, based on the literature, this thesis will build a thorough analysis of a case product by utilizing heuristics evaluation. Fourth, it will refine the remarks from the case study to conduct more extensive recommendations step-by-step. Finally, this thesis will demonstrate some practical applications to explain and visualize the recommendations. The consistent goal throughout is achieving an exceptional user experience in the spatial computing environment.

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Chapter One

Introduction

1.1 Problem Statement

Throughout the history of industrial design, interaction design has never been attached to significance until the 2000s. The marvel of technology and business creation pushed designers so intensively that the design thinking process was refined, aesthetic trends were diversified, the impact of domains bloomed, and consumer acceptance of innovation was changed. Driven by demand growth, design innovators are consistently undergoing criticism and self-criticism for the sake of achieving a perfect user experience. The industrial design industry is far from perfect, but designers still need to prepare. The various design concepts, new design tools, and dissimilar design languages are updating faster than ever due to the influence from different domains, advanced technologies, creative business ideas, and the existential value of designers. Drawing from conceptual design collaborations, design teams technologically research and predictably suggest the future of user experience, significantly distinct from the present. Thus, it is necessary to research to assist user experience designers to shift their perspective from current to future. Furthermore, some of the present popular theories for interaction design are doubtfully suitable. Thus, to refine the future user experience, this thesis will analyze those existing theories.

1.2 Need for Study

Technological innovation and diffusion are being rapidly implemented in the design industry in the twenty-first century. Is a screen-based product an emerging technology? The answer could be different in the following situation. Historically, the digital screen has developed over one hundred years as an old-school technology. However, the recent commercialized screen-based product is utterly different from retro products. Current in-screen interaction maintains various problems awaiting to be solved. For decades, designers kept building and upgrading concepts, tools, and theories for those issues, revealing problems in the facets of interdisciplinary influences and the design industry.

More widely speaking, as a reflection of screen-based products, the development of both physical and virtual interaction design will face a shift when the newest conceptual technologies are commercialized. The concepts, tools, and theories will need review, reflexivity, modification, and upgrades. This research is committed to examining the existing design theories from the perspective of future interaction design.

1.3 Objectives of Study

The overall objectives of this study are:

- To state the perception of interaction design shifts when future technologies (roughly after 2030 (Stone et al., 2016, p. 52) are commercialized.
- To analyze the interaction design and UX design of case studies via reference literature.
- To reflect the valuable remarks from the case studies in general interaction design.
- To conduct recommendations for future interaction design.
- To apply the recommendations to a conceptual design.

1.4 Definition of Terms

Analog: "something having the property of being analogous to something else" (Fellbaum, 1998).

Artificial intelligence: "artificial intelligence is the application of rapid data processing, machine learning, predictive analysis, and automation to simulate intelligent behavior and problem-solving capabilities with machines and software" (DeepAI, 2019).

Augmented reality: “augmented reality (AR) is an experience where designers enhance parts of users’ physical world with computer-generated input. Designers create inputs—ranging from sound to video, to graphics to GPS overlays and more—in digital content which responds in real-time to changes in the user’s environment, typically movement” (IxDF, 2019a).

Counterpart: “a counterpart is a person or thing having the same function or characteristics as another” (Fellbaum, 1998).

Design thinking: “design thinking is a non-linear, iterative process that teams use to understand users, challenge assumptions, redefine problems and create innovative solutions to prototype and test. Involving five phases—Empathize, Define, Ideate, Prototype, and Test—it is most useful to tackle problems that are ill-defined or unknown” (IxDF, 2017a).

Extended reality: “extended reality (XR) is a term referring to all real-and-virtual combined environments and human-machine interactions generated by computer technology and wearables, where the 'X' represents a variable for any current or future spatial computing technologies” (“Extended Reality,” 2021).

Frontier technology: “frontier technologies are technological advancements that have passed through the research and development (R&D) phase but have not yet been mass-marketed nor adopted by the mainstream” (Kambria, 2019); “Frontier technology is the next phase in the evolution of modern technology. It is the intersection where radical forward-thinking and real-world implementation meet” (Strait, 2018).

Gesture interaction: “gesture is a posture or movement of the user's upper limbs. Through gestures, people can express their interaction intentions and send out corresponding interactive information” (Li et al., 2019, p. 86).

Industrial design: “industrial design (ID) is the professional practice of designing products, devices, objects, and services used by millions of people around the world every day” (IDSA, 2019).

Interaction design: “the design of interactive products and services in which a designer's focus goes beyond the item in development to include the way users will interact with it” (IxDF, 2017b).

Spatial computing: “spatial computing is human interaction with a machine in which the machine retains and manipulates referents to real objects and spaces” (Greenwold & Paradiso, 2003).

User experience design: “user experience (UX) design is the process design teams use to create products that provide meaningful and relevant experiences to users” (IxDF, 2017c).

User interface design: “user interface (UI) design is the process designers use to build interfaces in software or computerized devices, focusing on looks or style” (IxDF, 2017d).

Virtual reality: “virtual reality is a simulated experience that can be similar to or completely different from the real world” (“Virtual Reality,” 2021).

Visual hierarchy: “the visual hierarchy is the principle of arranging elements to show their order of importance” (IxDF, 2015);

Visual metaphor: “a visual metaphor is the representation of a person, place, thing, or idea by means of a visual image that suggests a particular association or point of similarity” (Nordquist, 2018).

Visual spatial attention: “visual spatial attention is a form of visual attention that involves directing attention to a location in space” (“Visual Spatial Attention,” 2021).

1.5 Assumptions

The prediction of future technology and user experience design trends would not be ideal regarding the complexity of the design and technology industry. This research is as far as possible to conduct a prediction based on different scholars' contributions. This study assumes that: artificial intelligence technology and computer hardware are advanced enough to collect and handle real-world data and reproduce ideal visual elements in real-time seamlessly; the user experience design in the future is culturally and commercially trending towards a converged direction; consumers are willing to contribute their personal data for machines to learn; people's aesthetics are not extraordinarily different but converged in the future.

1.6 Scope and Limits

Scope: this study focuses on user experience applied to the interaction design category physically and virtually in a predictable future. The study will mainly involve information from literature, journals, and lectures. These recommendations aim to be universal to apply to present conceptual interaction design or in the future.

Limits: the design theory selection of this study does not cover every existing design theory; aesthetically, visual elements could be positive or negative, and this thesis mainly focuses on acknowledged positive visual elements; the future prediction of this research is not guaranteed and is limited to about the year 2030; the research object of case study for this research is representative but not comprehensive.

1.7 Procedures and Methodology

To conduct the study:

Step One Literature Review

- Conduct a technological preview and prediction.
- State practical design theories for user experience design.

- Research existing information about future interaction design.

Step Two Case Study

- Case study of the interaction design of conceptual designs.
- Reflect on the case study in terms of interaction design and user experience design.
- Conclude initial recommendations for future interaction design.

Step Three Recommendations Creation

- Improve the initial recommendations.
- Generalize the recommendations to a broader range of products.
- Create recommendations for future interaction design.

Step Four Recommendations Application

Step Five Conclusion and Reflection

1.8 Anticipated Outcome

Throughout this research, designers should better understand why and how to picture the interaction process when the technology changes in the future. The significant change of the statement would be a transition from the interaction for screen-based two-dimensional to the interaction for a higher dimensional system. The recommendations would help designers and developers to make the transition properly.

Chapter Two

Literature Review

2.1 Technological Reserve

The wheel of technology pushes designers to look out for potential design trends. By understanding the frontier technology, which could be the next phase in the evolution of modern technology, this research attempts to make a reliable prediction of interaction design over the next decade or two.

By 2020, scientists, engineers, and dreamers from worldwide presented numerous frontier technologies. Besides, they are committed to commercializing those technologies. This section will introduce different kinds of frontier technologies that could potentially impact current interaction design. An interaction designer's job is going beyond the interactive products and services in development to include the way users will interact with those products and services (IxDF, 2017b).

2.1.1 Turning Reality into Data & Reproducing Reality

In 2002, engineers developed a system based on a consumer video projector to generate sequences of structured light patterns (Rusinkiewicz et al., 2002, p. 439). Through different kinds of program processing, it could generate a real-time, machine-produced 3D model. Also, it is designed to be inexpensive, fast, and easy to use and demonstrates results from prototype implementation patterns (Rusinkiewicz et al., 2002, p. 445). In 2018, Microsoft's Project Zanzibar developed a Tangible User Interfaces (TUI) in a rollable rug equipped with NFC tags, touch sensor, and hover gestures detector. It enabled users to interact with digital content by directly manipulating the physical environment and objects (Villar et al., 2018, p. 1). In 2019, a university collaborative team demonstrated the robustness of their method for resolving collisions between volumetric objects (Han et al., 2019, p. 20), which is based on the computer physical simulation tool MPM (The Material Point Method) that was developed in 1994. In 2020, L3 autonomous vehicles hit the road (IEEE, 2020). Autonomous drive integrates cameras, radar, and other sensors (Olsen, 2018) to create real-time, low-fidelity 3D modeling data for programs to utilize. In 2021, Nvidia cooperated with US universities, optimized SDFs (signed distance functions) (Park et al., 2019, p. 165) technology, and, for the first time, enabled real-time rendering of high-fidelity neural SDFs (Takikawa et al., 2021, p. 1). It is worthy of mentioning that Neural SDFs took advantage of artificial intelligence deep training technologies.

Real-time 3D modeling, a tangible user interface, a physical simulation tool, and neural SDFs real-time rendering along with current hot property technologies – artificial intelligence – are potentially delivering future practical methods for industrial designers to understand and implement.

2.1.2 Artificial Intelligence

"Artificial Intelligence (AI) is a science and a set of computational technologies that are inspired by—but typically operate quite differently from—the ways people use their nervous systems and bodies to sense, learn, reason, and take action" (Stone et al., 2016, p. 55). The CEO of Intel, Pat Gelsinger, claimed that about sixty percent of the global population has connected to the Internet. The percentage will increase to 90 percent by the time of 2030 (Gelsinger, 2021). "Substantial increases in the future uses of AI applications, including more self-driving cars, healthcare diagnostics, and targeted treatment, and physical assistance for elder care can be expected by the year 2030" (Stone et al., 2016, p. 55).

2.1.3 Motion Capture

With the growing augmented reality and virtual reality market, hand gesture tracking technology could cast off gloves with a wired interface (Premaratne, 2014, p. 5). The technology could implement widespread and low-cost vision approaches, primarily based on depth cameras (Kiselev et al., 2019, p. 163). Gestures are the new clicks, and gestures are very effective as they are very natural (Batchu, 2019). A recent hand gesture recognition solution detects both front and back sides of five fingers' horizontal, vertical, and depth information (Dinh et al., 2014, p. 579). However, there is a lack of gesture types in the interactive process of users (Xiao et al., 2020, p. 303). Also, culture plays an integral part in motion comprehensive tasks. In non-verbal communication, the frequency, rhythm, viewpoint, and description of motion events are culture-related (Brown, 2010, pp. 258-259). Research offers a technique called gesture elicitation studies (Morris et al., 2010) which is collecting requirements and expectations from end-users to prove that gestures authored by end-users are easier to memorize and discover than those created by researchers or designers (Wu et al., 2020, p. 2). Motion capture also achieved eye-tracking, and it can generate real-time thermodynamic diagrams of a user's vision (Steinicke et al., 2014, pp. 95-98).

At present, motion capture technology is resolving to capture the scope and resolve culturally distinctive challenges. In time, research and the growth of related fields would bring breakthroughs to implement high-fidelity motion capture.

2.1.4 Technological Prediction

The reproducibility of reality, the physical system, and motion capture will significantly improve efficiency, accuracy, and validity in a predictable future. In addition, developers would consistently build dedicated hardware and software. These improvements are in preparation for the Extended Reality (XR) platform. When frontier technologies break into civilian uses, it is possible to revolutionize people's interactive behaviors. On this occasion, people are going to have a more integrated digital reality. The fragmentation between physical objects and flattened infographics will be meaningfully reduced.

2.2 Interaction Design Today

The concept of user experience (UX) instead of user-centered design (UCD) (Lyonnais, 2017) was proposed by Donald Norman in 1988 (Norman, 2013). UX brought UCD to a broader audience (Kujala et al., 2011). Designers worked on developing experiences for target users for decades. Academic researchers have introduced and widely spread numerous concepts and methodologies. This section recalls the design trends in this area in the past twelve years and the following essential design concepts: design thinking, visual representation, visual hierarchy, and affordance.

2.2.1 Interaction Design Concepts

Design Thinking. The path of design thinking is full of various idea-fragments. One of the core challenges design thinking teams to face is navigating through this sea of fragments (Plattner et al., 2012). Design thinking is essentially about: "**being human-centered** to be empathetic to your audience; **ideating**, the process of thinking through multiple options and solutions for a given problem; **using prototypes** as a way to help you work through design problems; **being process-sensitive** and understanding that a client's products and services comprise many parts that form a whole" (Moule, 2013, p. 8).

In addition, data-based design thinking methodology is practical in various circumstances. Making information out of data, a seemingly easy task, is quickly confounded when the designer attempts to integrate elements of aesthetics of emotion (Kolko, 2010).

Design thinking eventually pushes the design process to a directional idea generation. Divergent thinking, as well as convergent thinking, are frequently used methods. Divergent thinking is a thought process or method used to generate creative ideas by exploring many possible solutions (“Divergent Thinking,” 2021). In terms of convergent thinking, it generally means giving the “correct” answer to standard questions that do not require significant creativity. Joy Paul Guilford coined this term as the opposite of divergent thinking (“Convergent Thinking,” 2020). Specifically for industrial designers, divergent and convergent thinking requires a mixture of analytical skills (logic, engineering, and the development of "appropriate solutions") and creative skills (drawing, mapping, "blue sky thinking") (Kolko, 2010).

Visual Representation. As the second dimension of interaction design, visual representation refers to the elements that are not words within a product, such as typography, diagrams, icons, and other graphics (IxDF, 2018a). Aesthetic attachment moves us closer to visceral responses, but testing and optimizing things like delay, response, and state are equally important (Brown & Longanecker, 2013). As Donald Norman explains, millions of years of evolution have created in humans (and most of the animal kingdom) split-second decision-making instincts formed largely from immediate emotional responses (Norman, 2002). For graphic design, every choice of color, font, icon symbol, layout location – every pixel on the screen – is a subconscious mental interaction (Cao, 2015). Visual representation and feedback after representation are vital in interaction design.

Visual Hierarchy. Visual hierarchy is the principle of arranging elements to show their order of importance (IxDF, 2018b). An Interface is more than pretty visuals: it is a medium for users to accomplish their goals (Bank, 2015). Visual presentation of a web interface is essential for: **informing users:** like an invisible hand, the interface should guide users from one action to the next without feeling overbearing; **communicating content relationships:** the interface should present content in a way that matches how users prioritize information; **creating emotional impact:** people may be more prone to forgive a site's shortcomings if it produces a positive emotional response (Wroblewski, 2008, p. 7). Fundamentally, manipulating these characteristics: size, color, contrast, alignment, repetition, proximity, whitespace, texture, and style (IxDF, 2018b) prioritizes the interface based on how people scan for information then displays a further accentuation (Bank, 2015). Aesthetically, designers should create an attractive influence of visuals into first impressions, create trust, create identity, encourage user forgiveness, and improve usability through relaxation (Cao, 2015).

Visual hierarchy's application could break down into more detailed fields such as navigation design, animations design, guided actions design, and MAYA (Most Advanced Yet Acceptable) principle's application (Bank, 2015). Visual hierarchy development ties with users' comprehension. The wisdom of the MAYA principle, coined by Raymond Loewy (Dam, 2021), applies to user interface design. MAYA principle includes: **familiar visual metaphors** — the actions on site should have roots in actual tasks the users have experience with; **traditional fallback options** — different users will have different comfort levels; **sensible scope** — in other words, do not reinvent the wheel (Bank, 2015).

Affordance. Affordance is a property or feature of an object which presents a prompt on what can be done with this object (Tubik Studio, 2018). The term affordance refers to the perceived and actual properties of the thing, primarily those fundamental properties that determine just how the thing could possibly be used (Norman, 2013). Affordance is made with particular semiotic resources (Forceville, 2011, pp. 3624). It provides strong clues to the operations of things. Knobs are for turning. Slots are for inserting things into. Balls are for throwing or bouncing (Norman, 2013). When users look at a UI, a positive affordance should be self-evident, obvious, or at least self-explanatory (Krug, 2014, p. 32) without question marks, mental chatter, and error (Krug, 2014, p. 37). According to the MAYA principle (Dam, 2021), affordance is consistently changing with people's comprehension of everyday things. As for graphical affordance, it presents visuals – including photos, branding signs, icons, buttons, fields, notifications, copy (language), and animation, applied to an interface and helping users to scan its functionality (Tubik Studio, 2018). The strong connection between epochal character and affordance statement drove graphic design into explicit and implicit upgrading trends.

Hick's Law and Fitts's Law. Hick's Law is "time it takes to make a decision that increases with the number and complexity of choices available" (Yablonski, 2020, p. 23), with the equation of $RT = a + b\ \log_2(n)$ (Soegaard, 2020) ("RT" is the Reaction Time, "n" is the number of stimuli, "a" and "b" are constants); Fitts's Law is "the time to acquire a target is a function of the distance to and size of the target" (Tognazzini, 2014). The equation of Fitts's Law (IxDF, 2019b) ("MT" is Movement Time, "D" is the distance between the origin and the target, "W" is the width of the target, but for the designer, it could count as the size of the target, "a" and "b" are constants): $MT = a + b\ \log_2(2\frac{D}{W})$. The two equations are similar types, and both point out the value that designers should adjust when designing graphics for a better user experience.

2.2.2 Design Trend

The virtual button design reflects the stylish trend of user interface design. Historically, the visual button's development starts in the '80s. Virtual buttons, for the very first time, appeared inside computer interfaces (Bowers, 2019). Before virtual buttons formally functionalized, physical button design (from the 1930s to 2000s) ran through: the styles of Streamlining ("Streamline Moderne," 2019), Functionalism (Henderson, 2015), Bauhaus architectural style

(Phaidon Design, 2006, p. 752), Back-to-Nature, Minimalism (Henderson, 2015), and the combination of post-modernism and computer technology (Fiell & Fiell, 2012, p. 20). Physical interaction includes but is not limited to interactions with buttons, switches, or toggles. The evolution of physical interaction could reflect on the evolution of product semantics. The semantics' original definition is artificially constructed languages (Hempel, 2019). Product semantics was coined in approximately 1984. Product semantics is the study of the symbolic qualities of synthetic forms in the context of their use and the application of this knowledge to industrial design (Krippendorff & Butter, 1984, p. 5). With the dot-com boom of the '90s, there is a new form of a button — the buttonless button. Into the 2000s, touchscreen technology became more and more advanced (Bowers, 2019). Meanwhile, Krippendorff underlines that product semantics is not an extension of traditional semiotics. Instead, objects are seen in a new paradigm in a context (Krippendorff, 2006) (of other things, situations, and users, including the observing self). Product semantics study appended an extra layer to both physical and virtual button design principles, especially when touch interfaces were rapidly becoming mainstream (Ullrich, 2019, p. 19). In the 2000s, surface buttons merged virtual and physical buttons into a single, tactile experience (Bowers, 2019). This discussion uses web design's click-box button (from 2009 to the present) to illustrate the design trend.

In 2009, greyscale dominated the design of buttons (Figure 1). Delicate gradients, rounded corners, and shadows appear in almost every button design. This aesthetic refers to native system buttons (Dobry, 2017).

Figure 1

The Typical Button Design in 2009 (Dobry, 2017)

In 2010, the design was very similar to 2009's button design (Figure 2) but with more details (such as inner shadows) and much more decorative typography (Dobry, 2017).

Figure 2

The Typical Button Design in 2010 (Dobry, 2017)

In 2011, the design (Figure 3) elements did not follow any rules for applying shadows or lighting (Dobry, 2017). This year, designers discarded the rules of light and shadows. Also, the physical features of buttons are disappearing.

Figure 3

The Typical Button Design in 2011 (Dobry, 2017)

In 2012, buttons experienced the decline and the final form of skeuomorphism, and the beginning of Flat Design (Dobry, 2017). The final skeuomorphism button design (Figure 4) canceled the depth of text simulation but reserved the gradient of color to hold the minimum depth feature from the physical button. Afterward, the virtual button design has generated a gap.

Figure 4

The Typical Button Design in 2012 (Dobry, 2017)

In 2013, the button design (Figure 5) abandoned any attempt to give their app or web buttons the third dimension and decided to go flat.

Figure 5

The Typical Button Design in 2013 (Dobry, 2017)

By 2014, the button design (Figure 6) started to use the ghost button style or flat buttons, two-pixel borders with vibrant colors (Dobry, 2017). Virtual buttons had discarded all the features of physical buttons and gotten into the simplest form.

Figure 6

The Typical Button Design in 2014 (Dobry, 2017)

In 2015, designers took advantage of the Material Design guideline (Google LLC, 2020), which gave flat button design (Figure 7) a more hierarchical relation. The flat surface of the button with a delicate shadow underneath signals the significant impact of Material Design on current trends (Dobry, 2017).

Figure 7

The Typical Button Design in 2015 (Dobry, 2017)

In 2016, designers came up with new elements to mix with Material and Flat Design. Gradients appear on the surface of buttons, not to emphasize the third dimension but to emphasize the button (Figure 8) material itself (Dobry, 2017).

Figure 8

The Typical Button Design in 2016 (Dobry, 2017)

The year 2017 is a year of Minimalism and Flat Design (Dobry, 2017). Meanwhile, the variation of designs became more diverse and numerous.

Figure 9

The Typical Button Design in 2017 (Dobry, 2017)

In 2018, designers started to add micro-interactions into button design by applying animated feedback or humor. Micro-interactions are subtle moments centered around accomplishing a single task (Babich, 2016).

In 2019, Neumorphism (Figure 10) became a welcome design style for designers as a variation of Skeuomorphism (Malewicz, 2020). The Skeuomorphism style was not regressive but represented part of the elements. In addition, Neumorphism integrated micro-interactions into its stylish guideline.

Figure 10

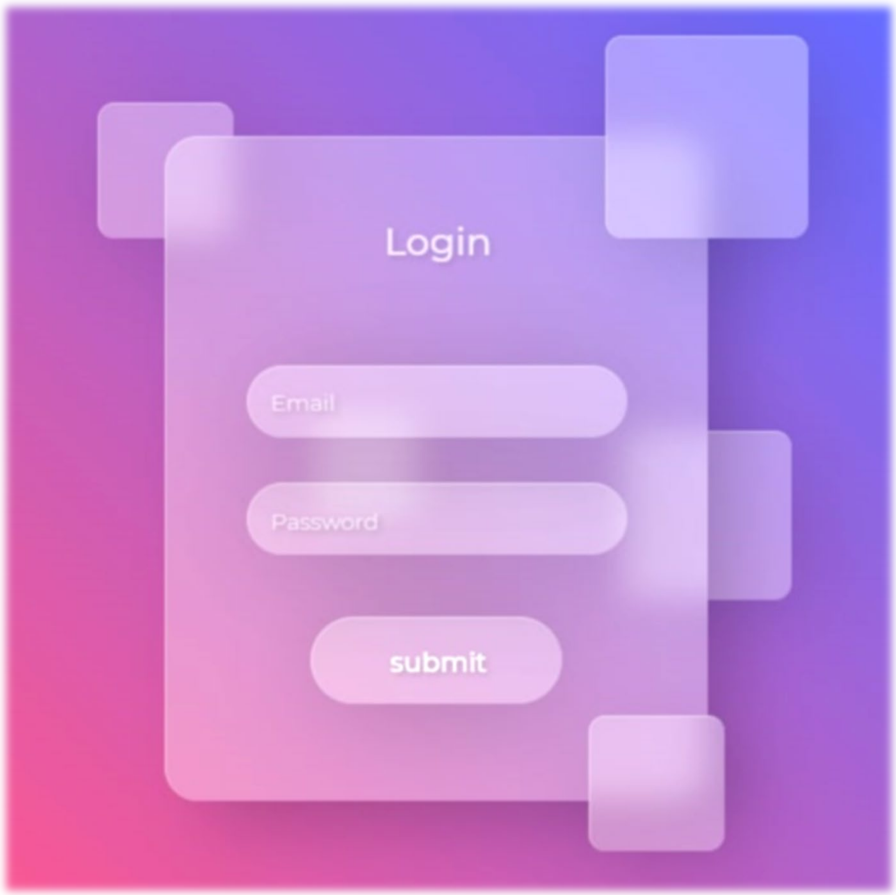
The Typical Button Design in 2019 (Daniels, 2020)

In 2020, while Neumorphism was imitating an extruded, plastic surface (but still looking like one layer), Glassmorphism is a bit more vertical. Its most defining characteristics are transparency (frosted-glass effect using a Background Blur) (Malewicz, 2020). Glassmorphism

(Figure 11) was beyond a single button design but an entirely stylish guideline. It was a variation of Material Design but emphasized its layer of visual hierarchy as well as accessibility.

Figure 11

The Typical Interface & Button Design in 2020 (Fallon, 2020)



The virtual button design had been isolated from any relation to physical button design from 2014 (Dobry, 2017). The user experience between virtual and physical has separated so that in this design gap, designers should build connections between them. Since we are using a touch surface for this type of control interface, it enables a dynamic, responsive user interface. However, it also places responsibility on the designer to create a meaningful and confusion-free user interaction (Ullrich, 2019, p. 19). The interface of macOS, iOS, Windows 11 have already applied Glassmorphism in 2021.

In summary, from Skeuomorphism to Flat or Material Design to Neumorphism or Glassmorphism, designer's perspective varies from isolated innovation to mutual enrichment. The reinforcement integration of micro-interaction, typography, accessibility leans the design trend more to usability and engagement. Gradually, the design trend fits more with the user experience design principles.

2.3 User Experience in Interaction Design

User experience cannot be designed since we cannot design the user and the situation, but designers can design for the user experience (Boyle, 2013, p. 18). This quote suggests that the user experience is externally changeable but internally consistent. Generally, user experience is a multidimensional and interdisciplinary concept (Kujala et al., 2011, p. 473), but from the perspective of designing a product, usefulness, usability, learnability, aesthetics, and emotions conduct an experience (Moule, 2013, p. 4). To more broadly apply to interdisciplinary concerns, a great user experience design meets the facets of useful, usable, desirable, findable, accessible, credible, and valuable (Morville, 2016). This section addresses the factors that strongly connect to user experience design and crucially impact this research's directionality.

2.3.1 Technology, Business, and Design Industry

Advancing technology extends human behaviors and enhances the human experience and should not cause frustration or angst at every touchpoint (Moule, 2013, p. 15). Meanwhile, the evolution of technology creates new challenges, which require new solutions (Boyle, 2013, p. 36). Thus, design and technology promote each other mutually. Now, to design an interactive product, we need to take care of several channels. Cross-channel defines our current environment, where technology has faded into the background and information has become shapeless and ubiquitous (Domingo, 2015).

Commercially speaking, design and technology are the catalysts of change in the "experience economy" (Boyle, 2013, p. 74). Companies should improve customer satisfaction and loyalty through the utility, ease of use, and pleasure provided in the interaction with a product (Kujala et al., 2011, p. 473). It is about understanding and prioritizing those needs before, during, and after any user interaction with a company. This move switches the traditional IT approach where technology drives decisions (Moule, 2013, p. 4). There are three stages of technology use. They are the enthusiast stage, professional stage, and consumer stage. Users are enclosed in the consumer stage (Moggridge, 2007). The stages have provided a means for problem-solving issues in one's daily life while increasing users' level of engagement with technology (Moule, 2013, p. 26). Technology as an agent can shift or manipulate human behavior, so there are golden opportunities to be had. However, part of the challenge designers and developers face is understanding what influences users to change their behavior in the first place (Fogg, 2003). Ultimately, making technology and design coordinating still are about the users having a seamless user experience (Domingo, 2015).

2.3.2 Emotionality, Sociability, and Personality

Emotional user experience affects how people make decisions, become motivated (or unmotivated), behave, and perceive personality (Gorp & Adams, 2012). A big reason for designers to concentrate on the emotionality of the product is that emotion dominates decision making, commands attention, and enhances some memories while minimizing others (Reeves & Nass, 1998). People are irritable, demanding, and often distracted (Moggridge, 2007). The research found that users' perceived usefulness loses its dominant predictive power when applied to hedonic systems (Heijden, 2004, p. 696). Hence, if designers take advantage of people's irritability, those people will forgive shortcomings, follow the touchpoints, and appreciate if designers reward them with positive emotion (Walter & Spool, 2011, p. 15). "Omit the unimportant in order to emphasize the important," declared Dieter Roman (Kolko, 2010). Designers could utilize emotionality to affect users' essential cognitive functions in conscious and unconscious minds (Gorp & Adams, 2012, p. 26).

A fifth imperative exists besides designing for usability, utility, satisfaction, and communicative qualities: designing for sociability is important because technologically driven social changes can be creative (Moggridge, 2007). When technology has created a habit in people, a person's use of a product is automatic, without thought. Technologies with a social aspect are winners in the habit-formation stakes (Moule, 2013, p. 231).

Modern living is highly interactive and highly personal (Domingo, 2015). Emotional design's primary goal is to facilitate human-to-human communication. The computer will recede into the background, and personalities rise to the surface. The personalities in design should shift with the context (Walter & Spool, 2011, p. 30). Microdetails are what users remember long after their interaction with the product is finished, as they tend to communicate personality and shape individual appeal for one product over another (Moule, 2013, p. 132). Personality builds rapport. Humor is one of the personality's most potent pheromones. If done right, humor evokes laughter (Boyle, 2013, p. 109), and laughter is a bonding function within individuals, a strong social glue (Provine, 2000).

Designing for both sociability and personality enhances the emotionality of design. In a way, emotional design narrows down the design process to individuals. The emotional design does more than entice and keep the audience engaged; it helps ensure designers communicate to the right people. Showing emotion in design, as in life, is risky but an emotional response to the design is far better than indifference (Walter & Spool, 2011, p. 84) due to the disconnect between the designer and audience enhanced by the noise of artificial stimuli (Kolko, 2010).

2.4 Cognitive Science

Cognitive science is the interdisciplinary study of mind and intelligence, embracing philosophy, psychology, artificial intelligence, neuroscience, linguistics, and anthropology (Thagard, 2020). The goal of cognitive science is to study the mind and to understand its structure.

2.4.1 Cognitive Psychology

Cognitive psychology is a branch of cognitive science (Batoufflet, 2019) that strongly relates to interaction design. "Cognitive psychology is about how your brain works and how all of your senses interact to give you your perception of what the world is" (Hall, 2020). The objects are processed by the users' brains and stored in either short-time memory (SMT) or long-time memory (LMT) (Sharma, 2020). The branches of cognitive psychology's theories contributed practical guides to user experience design. Studies such as color preferences between males and females can be beneficial for UX designers to choose the right color of the interface and create user-friendly navigation. The Left-to-Right Theory indicates how to place content to receive the necessary reaction. The Chameleon Effect addresses that all people tend to mimic the emotions and feelings of others, and it is popular in content marketing. The Serial Position Effect suggests that people can memorize the first and the last items best while having trouble recalling items placed in the middle (Cue, 2020).

2.4.2 Information Overload and Cognitive Overload

Information overload occurs when the amount of input to a system exceeds its processing capacity. Decision-makers have relatively limited cognitive processing capacity. Consequently, when information overload occurs, a reduction in decision quality will likely occur (Toffler, 1971).

The future interfaces will require less learning curve and avoid information overload (Kuznetsov, 2019). The existing and arriving technologies collect a massive amount of information without filtering. Also, over time as technology advances, the information will increase exponentially. Miller's Law states that the average person can keep only 7 (± 2) items in their working memory (Yablonski, 2020, p. 35). To avoid information overload in designs, designers should follow these principles: keep content simple, relevant, and clear; provide supporting and balanced content; make the content clear what is to be done with the information; make content accessible for the user to take action (IxDF, 2017e).

The effort required to process information is known as cognitive load, and it is critical to the success of digital product design. The human brain is not optimized for the abstract thinking and data memorization that websites often demand. Many usability guidelines are derived from cognitive limitations (Krug, 2014). When users feel overwhelmed in their thinking process, this excessive thinking is called cognitive overload. As a designer, the job is to give a straight path to the goal by clearing out the obstacles beforehand (Halarewich, 2016). Splitting information into different sections, using enough white space, and reducing unnecessary information give the user the chance to process all the information (Tim, 2021).

2.5 Future Interaction Design

As addressed by Guanzhong Liu (2020), professor at Tsinghua University, in his speech:

> Business and technology are tremendously advanced today. Technologies could infatuate our minds, and business is blindly making profits. This circumstance would cause polarization. Designers must be level-headed because the design is human-centered, and design is the kind closest to the human race's core needs. Technology and business are not human-centered, but the design is. However, design is weakly standing in between the two

big trees of technology and business. The design was born in the Industrial Revolution. What design was going to achieve at that period was not petty tricks, was not a flash of inspiration, but was developing interventions in advance for the Industrial Revolution. In the future, the design must go exploring uncharted territory instead of chasing profits in familiar territory. (paras. 31, 34, 58, 76)

Along with the thorough definition of user experience design, suggesting innovation and opportunities improve the human condition by dancing and intertwining four forces of interaction: domains of impact, tech marvels, business creation, existential value (Gajendar, 2016). In terms of interaction design, respectively: **the domains of impact:** “the specialization of interaction design will be more defined in the future where UX Design will touch different industries and business areas,” addressed by Alessandro Floridi, who is a UX manager at Deloitte, Sydney, Australia (Ligertwood, 2018); **tech marvels:** “technology will blend more seamlessly into the environment. As our world grows more comfortable with AI, AR, voice, and connected devices, we will design less for pixels or form factors and more for information — where, when, and how to present it,” said Ben Huggins, senior interaction designer for YouTube, San Francisco, USA (Ligertwood, 2018). In addition, “as a result, the future of UX design will not just be about design, but expanded into “design plus a domain”, whether it be AR, VR, speech interface, AI, machine learning, blockchain, content strategy, finance, transportation, healthcare, etc.” claimed by Kaiting Huang, interaction designer at Google, in Seattle, USA (Ligertwood, 2018); **business creation:** “If you have the time and the energy for a strategic pivot, heading in the direction of some careers like these: avatar designer — suggested by Glen Murphy (Android/ Chrome); cybernetic director — suggested by Matias Duarte (Google); digital conductor — suggested by Bill Buxton (Microsoft); nanotech designer — suggested by Carl Bass (Autodesk); fusionist — suggested by Asta Roseway

(Microsoft); organ designer — suggested by Gadi Amit (New deal design); interventionist — suggested by Ashlea Powell (IDEO); ethnographic designer — suggested by me; emotion designer — suggested by me," quoted from Andrew Doherty, the CEO of Another.ai at Berlin, Germany (Ligertwood, 2018); **existential value:** "I'm worried that UX design is getting a bit bloated and fluffy and hope that we can start working on removing unnecessary techniques from our UX process to become more lean, efficient, cost-effective problem solvers," addressed by Adham Dannaway, senior UI/UX designer from Sydney, Australia (Ligertwood, 2018). The question of "Why Design?" lies at the core of the existence of designing, "Visualizing and awakening the hidden possibility of an industry," said Kenya Hara, designer of MUJI in Japan (Gajendar, 2016).

To look at the future of interaction design, designers must consider conversations, engagements, and embodiments, not just slick gestures, mechanics, or tools that sensationalize or romanticize a fantasy notion of interaction (Gajendar, 2016). **Conversations** are central to what we do: staging necessary and significant dialogues with stakeholders and teammates as well as with users via the "It" being created (Gajendar, 2016). In the future, designers will bring more non-verbal cues into the interaction (Kuznetsov, 2019). **Engagements** are the product encounters themselves, the actual using of "It" to act in some way or achieve a goal or perform a task (Gajendar, 2016). At present, there are common strategies to design for emotional engagement, e.g., surprise, delight, anticipation, elevating perceived status, and limiting access to elicit a feeling of exclusivity (Walter & Spool, 2011, p. 65). The design of the future will be more intentional and focused (Sparklin, 2019). "New interaction paradigms are starting to take root, allowing us to create unprecedented connections," said Audrey Liu, the director of product design at Lyft, San Francisco, USA (Ligertwood, 2018). **Embodiments** are the manifestations of a designer's ideas into some perceptible form that can be engaged with on various levels, thus enabling the rich, storied conversation to happen. Hopefully, they enable a shift in that person's attitudes and behaviors for the better. We will eventually move away from interfaces full of menus, panels, buttons and move towards more 'natural interfaces,' i.e., interfaces that extend our bodies. The future interfaces will not be locked in a physical screen, but instead, they will use the power of all five senses (Kuznetsov, 2019).

We are experiencing the Fourth Industrial Revolution, and UX Design plays a crucial role (Ligertwood, 2018). In summary, looking towards the future, technology and business are demanding, innovating meanwhile increasing sophistication of their products; the user experience design is converging various domains while subdividing; the exponentially increasing amount of information is demanding while burdening. The future of interaction design will dramatically change: whether the machine will make user experience design menial or automated (Ligertwood, 2018); whether the methodology will hold up its longevity (Morville, 2016); whether the designers themselves will need to adapt their way of working to contribute rapidly and efficiently (Ligertwood, 2018).

2.6 Summary

The literature review provides information for the essential composing parts of what designers should consider in the future state.

Technological Reserve assists the designer in foreseeing and preparing for the application and development direction of technology.

Interaction Design Today gathers the historical design trend and influential design theories that would be referred to and utilized for analysis in the following chapters.

User Experience in Interaction Design brings a more extensive scope of theories and focused the designer's vision on the users.

Cognitive Science discusses more profoundly the human factor in interaction design and screened the influential parts.

Future Interaction Design collects various professional opinions to target the scope of this thesis to the future of interaction design.

Essentials from this chapter will be quoted or readdressed in the following chapter. The entire thesis will consistently apply the prediction of the technology state and then be built upon this state. The visual design part in the literature review will be specified and examined on actual products as a vital section. The visual design primarily includes design thinking, visual hierarchy, visual representation, Hick's Law, and Fitts's Law. The following sections will connect those works of literature to practice in a broader scope — user experience domain, including emotionality, sociability, personality, and cognitive science. The literature review touches on extensive domains for the following chapters, but some pieces of literature will not be included. For example, this thesis would directly implement the detailed typography guidelines within the visual representation instead of examining them because the title is more related to the interaction design domain.

This thesis will break down and reorganize the essentials within the literature to assist designers and developers have a better understanding of how to utilize the knowledge in literature. The proximal example of future interaction design is in conceptual products claimed as futuristic products. The following chapter will pursue a case study of conceptual products and conclude valuable remarks for conducting recommendations.

Chapter Three

Case Study

Drawn from conceptual design teams, the future of interaction design has revolutionary potential. The team technologically researched and predictably suggested the future of user experience, which is significantly distinct from the present. The distinctions reflect the business, technology, design, and relevant practitioners. The uniqueness of the future interaction that implements technology and user experience design is a commercial promotion for companies. In this section, the discussion of the case study mainly focuses on the facets of the design industry that involve some generic business and technology concepts.

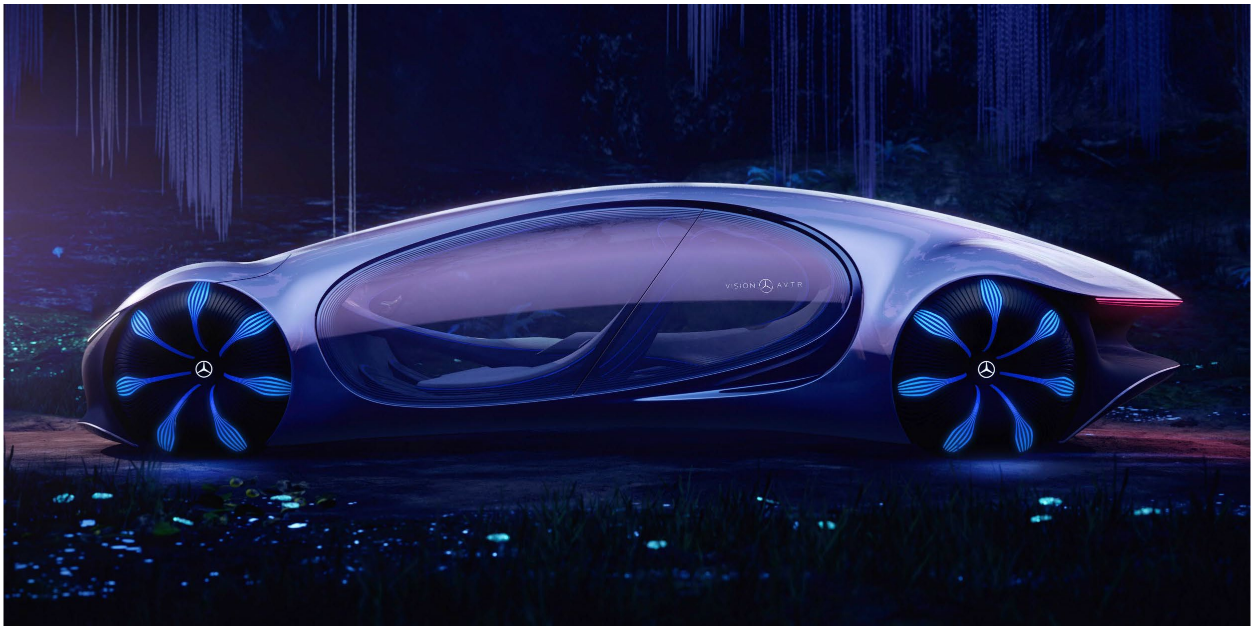
This section will mainly study and evaluate the case in the following aspects. **Heuristics Evaluation**: In heuristic evaluation, researchers, guided by a set of usability principles known as heuristics, evaluate whether user-interface elements, such as dialog boxes, menus, navigation structure, online help, and so on, conform to tried-and-tested principles (Sharp et al., 2019, p. 550). The following analysis will refer to the *First Principles of Interaction Design* (Tognazzini, 2014). Also, it will illustrate the details of the case; **Insight of UX**: evaluate the interaction design up to user experience design; **Valuable Remarks**: conclude the essences from evaluation and insight sections, and then compose initial recommendations for future interaction design.

3.1 Case: Mercedes-Benz's Concept Car: The VISION AVTR

Car design requires a broad scope of skills to cooperate. Exterior stylists, sculptors, interior designers, product designers, fashion designers, specialists for operational elements, steering wheels and buttons, product designers, coders, and digital designers create the user experience, the systems we see on and beyond the screens. It works a bit like an orchestra with all these elements coming together (Banks, 2020). Therefore, concept car design appropriately reflects the prospect of future technology and design. This section will delve into the interaction design of the Mercedes-Benz VISION AVTR (Figure 12), launched in 2020.

Figure 12

The Mercedes-Benz VISION AVTR (Mercedes-Benz AG, 2020)



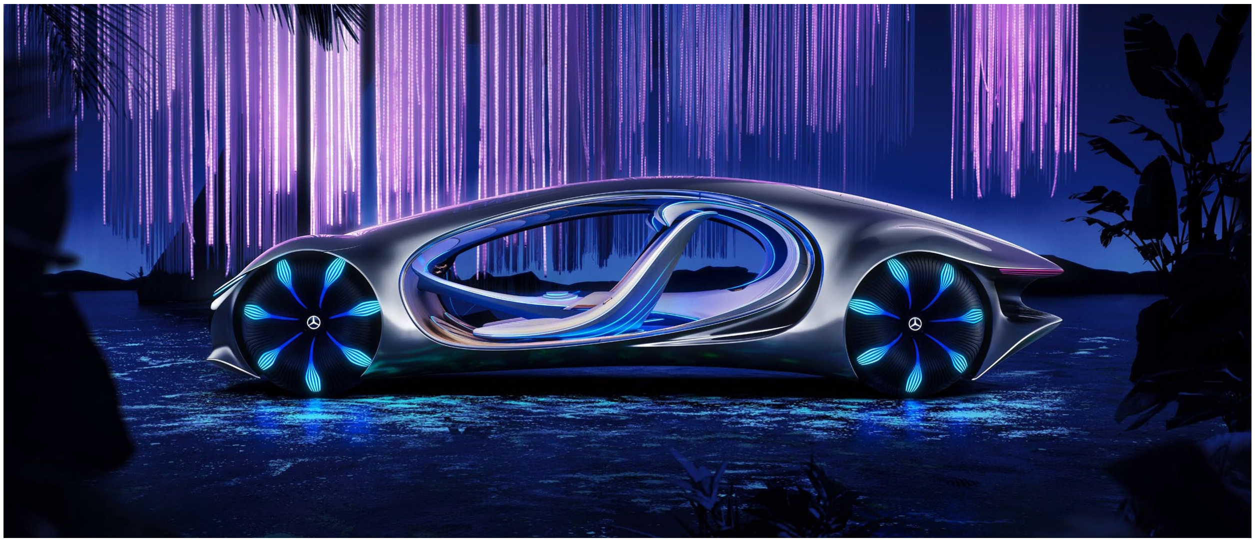
3.1.1 Overview

Mercedes-Benz presented the Vision AVTR at the CES in Las Vegas, a concept car with shapes and content from the future. In designing it, Gorden Wagener, head of Daimler design, was inspired by the film *Avatar* (A&D, 2020). The distinctive inside-out design structure connects inside and outside to an emotional entity, inspired by several creatures from the movie *Avatar* (Davidson, 2020).

An organic, stretched one-bow design and unique, spherical-shaped wheels (Designboom, 2020) are the iconic impression of this futuristic car (Figure 13).

Figure 13

Organic, Stretched One-bow Design (Mercedes-Benz AG, 2020)



3.1.2 Heuristics Evaluation

The VISION AVTR shows an entirely new interaction between human, machine, and nature (IoT Automotive News, 2020). The following evaluation content would reference Bruce Tognazzini's (2014) *First Principles of Interaction Design* to discover valuable remarks.

Aesthetics. *Principle: the visual design should be as thorough as the behavioral design.*

Learnability: The VISION AVTR elevates the intuition of being a passenger but decreases the intuition of being a driver. The interior and exterior are connected via large oval openings and outer lines that spiral through the cabin (Designboom, 2020). In addition, there is no steering wheel or central control panel in this car, which reinforces the purpose of character shifting while driving this car.

Satisfaction: Design language inspired by nature characterizes the appearance of the concept vehicle. The appearance was illustrated by the stretched, sporty "one-bow" design (Figure 13), which merges with spherically pronounced wheelhouses (Hoang, 2020). For example, the roofline above the passenger compartment is as taut as a bow ("one bow") (Stuttgart, 2021). The

VISION AVTR's visual design (Figure 14) contains organic elements and fluid lines. Especially the tire design (Figure 15) inspired by the flying jellyfish from the movie *Avatar* World creature (Darvall, 2020) equips the vehicle with the themed flowing light effect.

Figure 14

The VISION AVTR's Sketches (Mercedes-Benz AG, 2020)

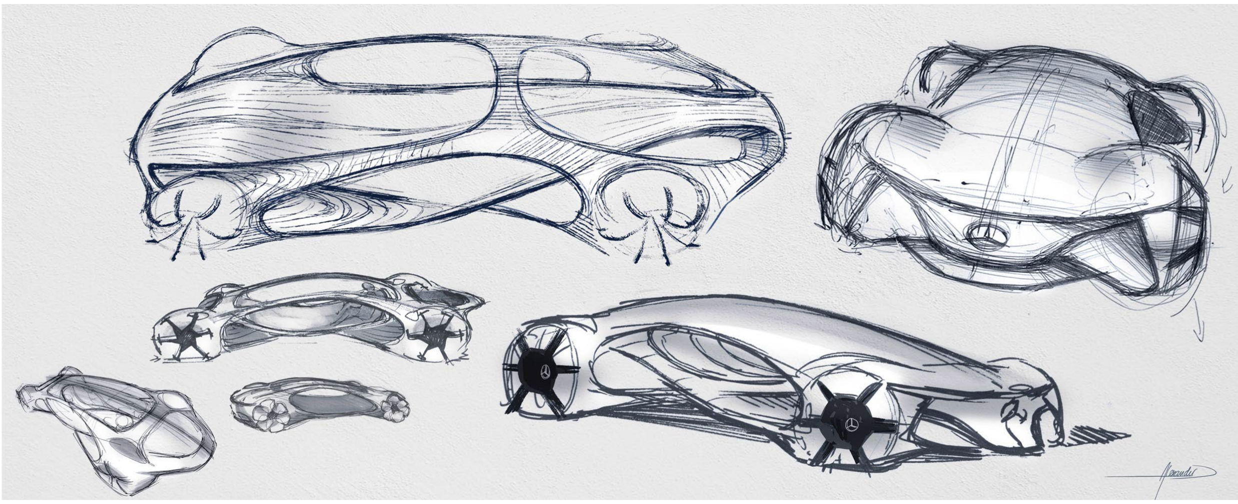
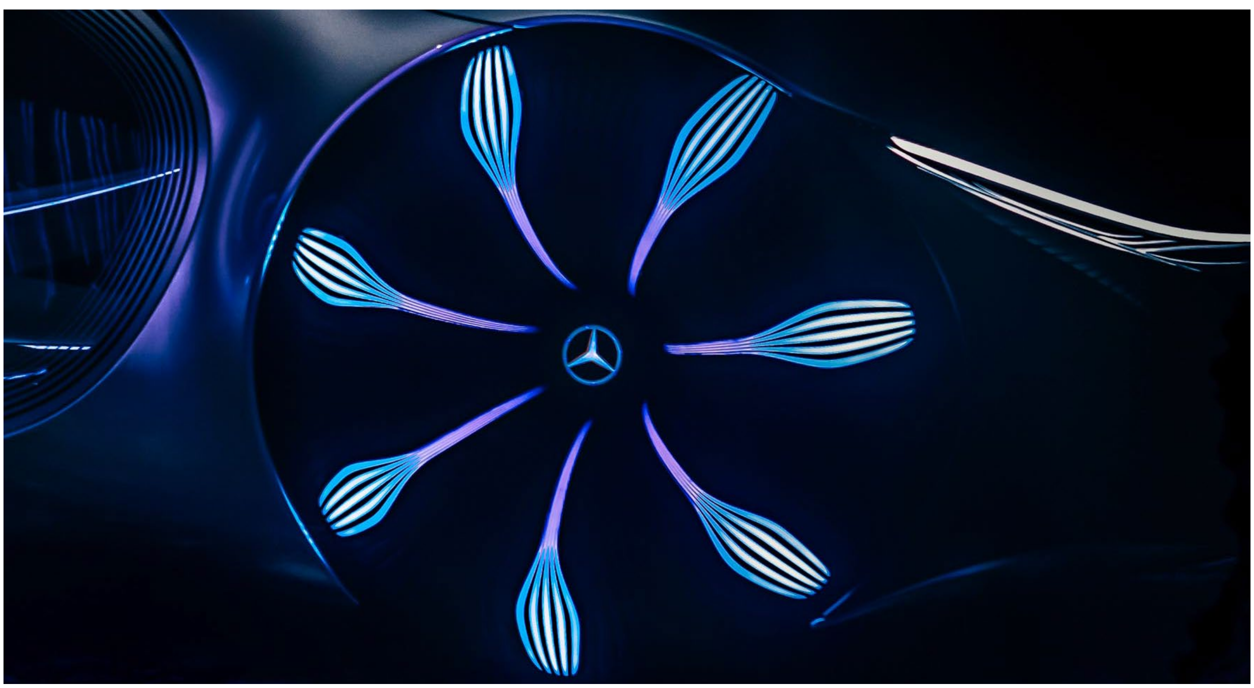


Figure 15

The VISION AVTR's Tire Design (Mercedes-Benz AG, 2020)



Productivity: The VISION AVTR equipped an organic battery made of recyclable materials and seats made of vegan leather microfiber that guarantees environmental sustainability throughout the entire production cycle (Davidson, 2020). The “one-bow” design is underlined by the frameless doors and a high, curved beltline (Stuttgart, 2021) as efficient product innovation. How much this visual design would impact productivity is imponderable in the context of future industry chain involvements in material techniques, electric systems, autopilot, etc.

Anticipation. *Principle: bring to the user all the information and tools needed for each step of the process.*

Hardware: Recent luxury car design tends to hide the door handle and deploys a key-less system for entering the car. The AVTR continues the concept of the hidden door handle and turns it into an automatic wing door (Figure 16). The automatic wing door simplifies the unlocking and opening process and accomplishes the entrance function for user anticipation. The ergonomics is up to a point improved because the door is no longer blocking half the space for entering like current vehicles. However, the enclosed ceiling is still blocking partial entering space in terms of having a natural and comfortable sitting motion. BMW’s concept car (Figure 17), released in the same year, addressed another design of wing doors to entirely free up the space for the user to enter the car.

Figure 16

Automatic Wing Door Design (Mercedes-Benz, 2020)

Figure 17

BMW Vision Next 100 (MacKenzie, 2016)

About the interior design, the AVTR's design concept is to enhance the immersing aesthetic and subtract or substitute traditional driving appliances.

The central panel, steering wheel, gas pedal, and foot brake have seemingly disappeared. However, they are replaced and combined into a hand UI projection (Figure 18), a ribbon screen (Figure 19), and a driving console (Figure 20) (the design team named it the "merge control" (Smith, 2020)). One aspect of AVTR's philosophy of future car design targets the driver's natural sitting posture and effortless operation.

Figure 18

Hand UI Projection (Mercedes-Benz AG, 2020)

Figure 19

Real-time 3D Graphics on Ribbon Screen (Mercedes-Benz AG, 2020)

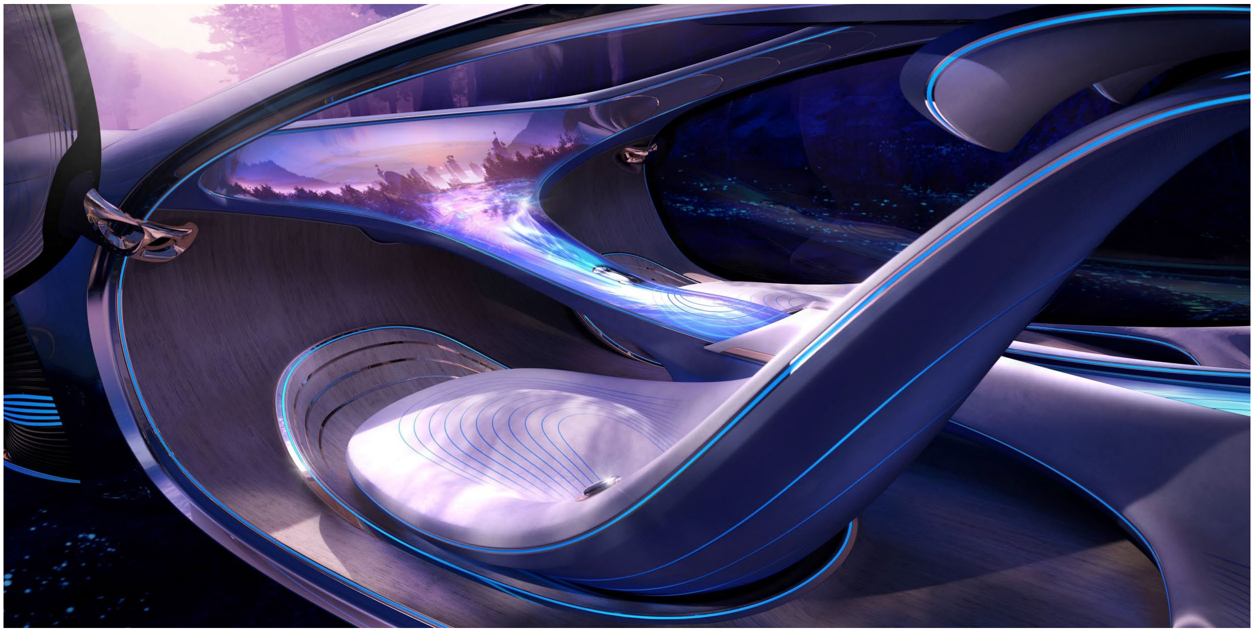
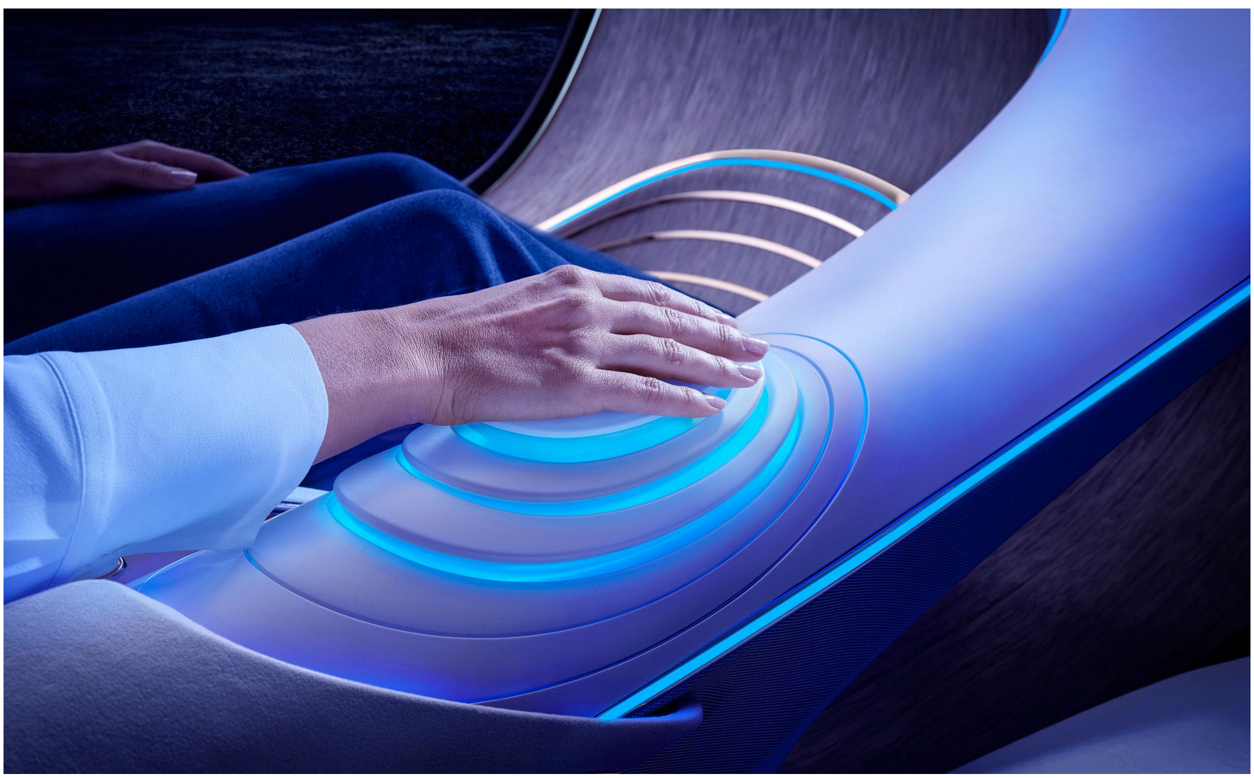


Figure 20

Driving Console (Merge Control) (Mercedes-Benz AG, 2020)

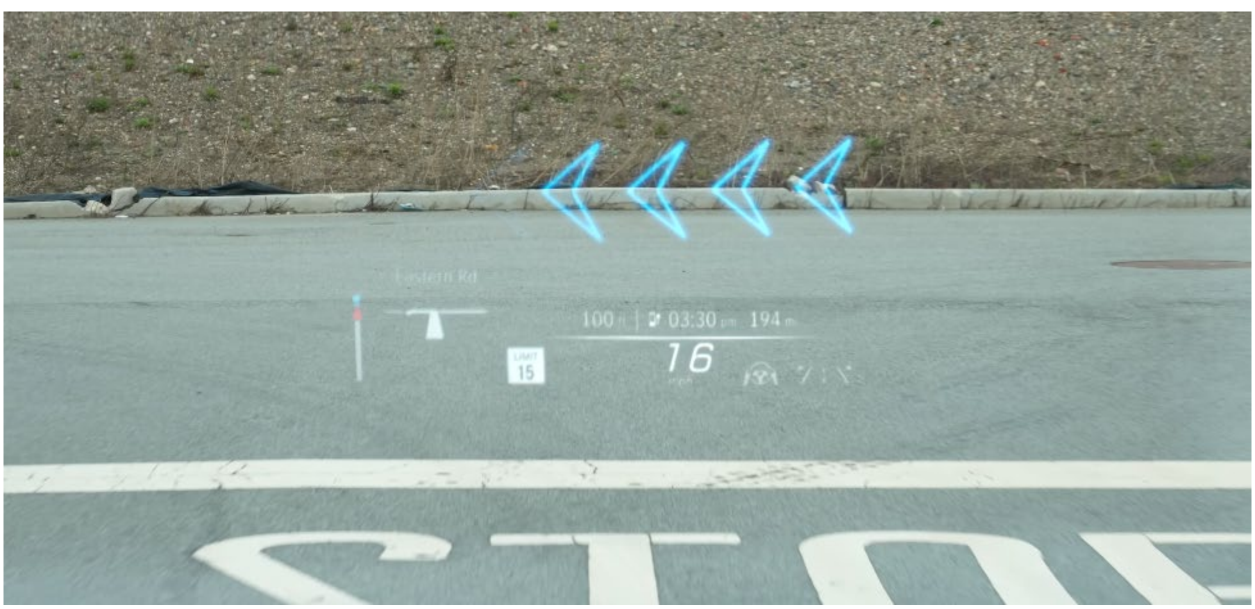


The AVTR design team intentionally merged the driving components but kept the essential anticipation of the user in terms of the driving experience.

Software: The primary function of this interaction is to select real-time 3D graphics to display on the ribbon screen (Figure 19) to tie to the *Avatar* movie theme. Aside from the hand UI projection interaction design, the ribbon screen merely functions as an immersive display. The landscape replaces the traditional driving status, A/C temperature, media knob, etc. This design decision lacks information and tools to provide anticipation for the user. The user would lose track of nearly any data which the present vehicles provide. Even if the AI technology could take over settings for the user, this particular design lacks user autonomy because of the lack of notification, agreement, and forgiveness. More broadly, Mercedes Benz's commercialized luxury car has already equipped a head-up display on the front windshield (Figure 21) to implement AR navigation.

Figure 21

Head-up Display on Mercedes Benz EQS (Marques Brownlee, 2021)



In terms of user experience design, it is debatable whether the user (as a **driver**) will necessarily require the vehicle to offer driving data compared to the present because the FSD (fully self-driving) and AI (artificial intelligence) are likely capable of taking control of the data in the future. The design decision should let the driver or passenger choose what to display to ensure user anticipation. However, as a **passenger**, citing the concept from Amazon subsidiary Zoox's autonomous cab (Figure 22), it was designed like a moving comfortable private room to let passengers sit face to face. Different from the early 20th century, more recent cars are treated more as utilitarian appliances instead of an extension of personality (Mauriello, 2021). Based on this macrotrend, autonomous vehicles are preferentially designed visually and functionally to showcase their safety. Reflecting on AVTR, the future vehicle with driver and passenger, the anticipation for driver or passenger should have been substantially distinct. However, the AVTR's design indicates that these two kinds of anticipation should converge because the symmetrical design allows the passenger to seamlessly take over the driving console. Matching the UX design principle, the AVTR's design target's intention to shift the passenger to a co-driver is obvious. When assuming the design team intended to have a driver and co-driver, the anticipation remained a minor difference: The driver side has the electrical park brake control. Other than that, the co-driver could implement the same anticipation as the driver, for instance, driving (one at a time) and hand UI projection control.

Figure 22

Zoox Autonomous Cab (O'Kane, 2020)

Autonomy. *Principle: exercise responsible control; use status mechanisms to keep users aware and informed.*

The VISION AVTR is inclined to be aware and inform users in a non-text, emotional and organic way.

As a driver: The driving console, previously mentioned, featured a dynamic engine starting procedure (Figure 23): when the driver rests one hand above the glimmering flattened console, the console will synchronize the driver's heartbeat rate with the up and down breathing rhythm of the console, then it will raise itself; meanwhile, the entire car's ambient light will increase the brightness, as the indication of waking up (starting the engine). Since the AVTR's design strongly connects to the movie *Avatar*, the design philosophy is to bring an immersive and vivid driving experience that makes the car organic and lively, like the lively plants in the *Avatar* world.

The VISION AVTR introduced the concept of driving the car with this all-in-one console instead of spinning the steering wheel and proceeding footwork about this unique driving control interaction. The console works by tilting to turn, pressing forward to accelerate, pressing backward to brake, and spinning to drive sideways, providing the driver's natural setting and resting position. The symmetrical design opens the access for both driver and passenger. The console could differentiate the user by their heartbeat rate.

Figure 23

Driving Console (Merge Control) Starting Motion (Mercedes-Benz, 2020)

The VISION AVTR presents a hand UI projection (Figure 18) interaction instead of a traditional button or screen control. The interface adapts to the user – and not the other way around. By simply lifting the hand, an interface is projected onto the palm, allowing passengers to interact intuitively with the interior of the VISION AVTR (Mercedes-Benz AG, 2020).

In terms of the in-depth interaction detail of hand UI projection, the innovative interaction design’s overall process is: first, open up palm in order to wake up projection and centralize the icon onto the palm (the round icon eased in); second, offset the palm to left or right to locate different options (shows up as different icons for different categories with animated bubble transition); third, fold palm to jump into sub-menu (indicator: the icon expands and eases out) then fold again to select and activate (indicator: the icon turns red and the seat has a different pattern of vibrations with the different selected scene) (Figure 24).

Figure 24

Hand UI Projection Interaction Map (Smith, 2020)

The projection system desires to reduce the idea of issuing commands by turning the interface into a digital membrane (Smith, 2020). Claimed by Advanced Experience Design Vera Schmidt, the digital membrane solution is a different perspective which is machine approaching humans instead of humans actively touching the display. This concept of machine-approaching humans is indisputably innovative, but the prototype persists in critical design issues when matching the *First Principles of Interaction Design*.

The palm is doubtfully an ideal surface to project graphics. The natural deformation of everyone’s palm would distort the icons which were designed for flat display. It results in opposing the Learnability, Readability, Discoverability, and Metaphor principles.

Projection induces an uncertain interaction boundary. The uncertainty of interface typography would possibly cause a gap in the learning curve. When Fitts’s Law is implemented in interface design (using the pinning actions of the sides, bottom, top, and corners of the display), the user's response time would erratically increase.

With certain technical limitations, the prototype's user autonomy of hand UI is a decent design with its simplicity. The tab switching animation, color shifting, seat vibration, and responsiveness addresses a simple and effective “start and select” function.

As an audience: Modern cars must inevitably equip turn lights and brake lights, and AVTR seamlessly integrates them into the light system. The turn indicator light (yellow color) is glowing on the tire light (Figure 15). The accelerated and brake indicators are integrated into the bionic flaps (Figure 25). The bionic flaps function as an extended-expression of passengers because they will tilt while the car is turning, they will turn red against the wind direction while the car is braking, and they will turn blue along with the wind direction while the car is accelerating (based on the speed). AVTR successfully matches the user autonomy for the audience and elevates it by offering an organic, lively, and emotional design.

Figure 25

Bionic Flaps (Mercedes-Benz AG, 2020)

Consistency. *Principle: “The most important consistency is consistency with user expectations” — William Buxton.*

Mercedes Benz is a company that has existed for over one hundred and forty years. The VISION AVTR, designed to foresee the future, maintains several design languages from the current commercialized model to sustain consistency.

The one bow design (Figure 13) is Mercedes Benz's recent design guideline for connecting the front and back of the car to provide a nest shape, which protects and comforts passengers physically and, more importantly, emotionally.

In recent years, ambient light (Figure 26) has landed on luxury cars made by Mercedes Benz, Lexus, Audi, Lincoln, and BMW, and eventually, ambient light will become standard. The AVTR's concept is utilizing light technology to flush the whole car instead of the interior only. The lighting design of AVTR participates in branding, appearance, embarkation, and the driving experience (refer to Aesthetic evaluation and Autonomy evaluation section.)

Figure 26

Ambient Light (Mercedes-Benz AG, 2020)

The union of separated parts and progressive lighting system opportunely apply the emotional design theory so that AVTR holds the principle of consistency.

Discoverability. *Principle: communicate the gestural vocabulary with visual diagrams.*

The hand UI projection (Figure 24) is gesture-based on augmented reality interaction. As mentioned in the Autonomy evaluation section, there are significant issues with the prototype. However, in terms of discoverability, the surprise it delivers is pleasant. “All your senses are triggered, not only the visual but also the haptic and acoustic ones,” said Vara Schmidt, the advanced experience design of the VISION AVTR (Smith, 2020). The design team implemented this interaction design due to the guideline created by the head car designer Gorden Wagener, named **Sensual Purity**.

Human Interface Objects. *Principle: human-interface objects can be seen, heard, felt, or otherwise perceived; human-interface objects should be understandable, self-consistent, and stable.*

Sensual Purity has six guidelines: unexpected moments, stimulating contrast, stunning proportions, freeform and geometry, significant graphics, and natural attraction (The News Wheel, 2016). Apart from the content of marketing exaggeration, the sensual purity guideline is a visual design guideline but emphasizes the viewer's senses instead of car design parameters. The principle underlines the sensibility of the human interface, which is the interior of AVTR in this case. The AVTR’s interior (Figure 26) expresses the visual stimulation in terms of geometric streamlining, the contrast of light and dark, and nearly exaggerated dynamic scenes. The stimulation motivates the user to interact with a unique, lively appliance. In addition, the sustainable material choice and lively components (bionic flips) add the unexpected pleasure of the tactile sense. However, the uniqueness also requires the design to be understandable, self-consistent, and stable. The transparent door design causes the audience’s privacy concern. The wildly curved backseat design is doubtfully comfortable to rest on. Most importantly, the operating system for driver and co-driver – hand UI projection – is a flop in several ways.

Explorable Interfaces. *Principle: give users well-marked roads and landmarks; offer users stable perceptual cues for a sense of "home"; make actions reversible, allow undo; make it easy and attractive to stay in.*

One of the distinct flaws of the VISION AVTR's hand UI projection (Figure 24) interaction design is the poor explorations. As this research described in the user autonomy section, every step lacks reversibility within the user map of hand UI projection. The limitation is primarily caused by interface size and, secondarily, gesture design.

Interface size: Due to the palm being a non-screen, uneven and uncertain surface, nearly all the (scaleable/adaptive) interface dimension guides from Google, Apple, and Microsoft are inapplicable. Even though the concept of digital membrane interface is attractive to explore, the practical interaction area size is beyond the interface size. The excess is hidden, which is against the principle of offering users landmarks and allowing the user to undo. Due to the limitation of interaction area size, the graphics are not supposed to be scalable. Otherwise, the graphics will lose their readability and metaphors.

Gesture design: The gesture design of hand UI projection is purposely different from the gesture design of Augmented Reality or Virtual Reality. The former occurs on a surface, the latter more perceptually designed for the three dimensions. Referring to a user-driven gesture principle (McAweeney et al., 2018, pp. 554-555), listed are five aspects of gesture design analysis: **Time**, **Position**, **Posture**, **Motion,** and **Touch**. Technically, AVTR has implemented the recognition system for the user's hand gesture.

Time illustrates the sequence of motion and hand posture in any given gesture. The few options and levels assist in hand UI projection, optimizing the time of each step. **Position** is specifically fixed position and stop and ending points relative to the rest of the body. Usually using a symbol as an eye, the projection takes advantage of the digital membrane covering the passenger's skin. The point-of-view will be tuned by the user subconsciously within the response area of the recognition system. **Posture** is the shape of the hand necessary to enact a gesture correctly, where **Motion** bend and/or movement was happening helps make the gesture more precise. Hand UI projection obtains three kinds of gestures: raise palm to wake-up, offset palm to browser, enclose palm to select. Reflecting from the fully functional prototype (Figure 24), the wake-up is a well-designed posture for its naturality. The browser posture lacks readability and metaphor: flat graphics are out of shape because of the uneven surface; indication between the graphics is absent since the user will lose track of the total length of tabs. The selecting gesture meets the *Avatar* movie scene for its natural motion of catching/grabbing. **Touch** commonly communicates with touchpoints. However, in terms of hand UI projection, the touchpoints vary. Projection provides visual feedback of browsing (bubble effect), selection (icon expands and eases out), and vibration feedback from the seat. Two visual feedback elements tighten up the theme of the lively appliance and hold up the **Latency Reduction Principle** (Acknowledge all button interactions by visual or aural feedback within 50 milliseconds). The vibration from the seat backrest is an inappropriate way to provide feedback. The design decision went this way because the projection system is not able to implement tactile feedback. However, with a digital membrane over the passenger's skin, tactile feedback is essential.

Fitts's Law. *Principle: the time to acquire a target is a function of the distance to and size of the target; multiple Fitts: the time to acquire multiple targets is the sum of the time to acquire each.*

In theory, interaction design should use larger objects for essential functions and smaller objects for functions that drive users not to perform.

Reflect on the driving console (Figure 23), regardless of the driver training requirement now, and compared with current driving experience, the physical interaction of the driving console substantially optimizes the driving interaction to conform to Fitts's Law. It integrates the steering wheel, gas pedal, and foot brake while eliminating the interoperation issues. Furthermore, integration meets the **Latency Reduction Principle** (Trap multiple clicks of the same button or object). Driver and co-driver have the advantage of driving with a natural resting posture with a responsive and intuitive operation.

Reflecting on the hand UI projection (Figure 24) opposes Fitts's Law by missing the **visual hierarchy** and **affordance**. Visual hierarchy (from navigation design): the lack of default level of hand UI projection results in a minor visual hierarchy. There is no visual distinction between menu, sub-menu, and scene options other than icon change. When every option is designed to parallel in a circle, it is very likely to confuse users. In addition, the interaction area size of the interface opposes the **Visible Navigation Principle** (Make navigation visible) since the noticeable interface does not fit in with overview navigation. Most users cannot and will not build elaborate mental maps and will become lost or tired if expected to do so (Tognazzini, 2014). Besides, the design decision of hand UI projection opposes the **Learnability Principle** (Limit the trade-offs of learnability and usability). The hand UI projection cannot display a sharp icon and the interface boundary. Hence the learning curve would erratically climb up. Though the learnability and usability are not mutually exclusive (Tognazzini, 2014), the hand UI projection prototype achieves the simplex function of selecting 3D graphics for the ribbon screen.

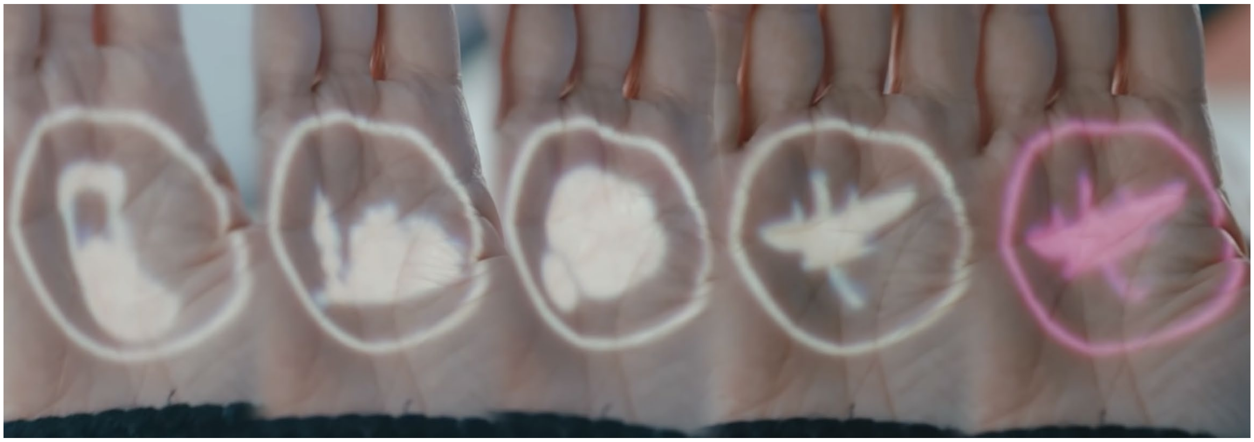
Use of Metaphors. *Principle: choose metaphors that will enable users to instantly grasp the finest details of the conceptual model; expand beyond literal interpretation of real-world counterparts.*

Affordance: A positive affordance of graphics should equip a positive metaphor. The icons of hand UI projection (Figure 27) respectively are three different theme world selections (category menu), 3D scene, and selected 3D scene. Each of the icons does not enable passengers to grasp the meaning of the graphics instantly. Generally, the solution would be adding texts in addition, but the text's readability would be weak due to the deformation of the projection on the hand.

The inverse of skeuomorphism is an abstraction, a prominent feature in so-called flat design, turning once well-understood icons and other elements into meaningless abstractions and even false symbols (Tognazzini, 2014). The hand UI projection design takes over the trending concept from at least the flat design and masks graphics into a round shape. The graphics have their understandable affordance or generic conceptual models such as forest, ocean, and bird. However, the actual function is different from what the metaphor leads to so that the graphics usually need readable labels or designing with a more positive affordance, which is a lack in the current prototype.

Figure 27

Icons in Hand UI Projection System (Smith, 2020)



Furthermore, the other essential interaction, the driving console (Figure 23), generates its character but keeps the metaphor because of its uniqueness. Most metaphors evoke the familiar but usually add a new twist (Tognazzini, 2014). The driving console is located at the very center of the VISION AVTR and performs as a pivotal item. Not to mention the software development behind it, the hardware of prototype that achieves synchronization of the heartbeat rate and operates the car in perceptual intuition builds up the metaphor of central control and eventually evokes the familiar.

Simplicity. *Principle: use Progressive Revelation to flatten the learning curve; do not simplify by eliminating necessary capabilities.*

Progressive Revelation is hiding more advanced pathways and capabilities, revealing them when users come to need them and know how to handle them (Tognazzini, 2014). The simplifying process from the present car to the VISION AVTR is arguable overall. Separately analyzing elements, the driving console (Figure 23) effectively flattens the learning curve by connecting the intuitive operation. Initially, the turning motion of the vehicle requires the foot to press the gas panel and hands to spin the steering wheel. The driving console (named Merge Control) simplifies the required action into one arm only and flattens the learning curve by indicating that if the press forward is driving forward, the press back is braking. The same theory also applies to tilt to turn. The metaphor and Progressive Revelation cooperate to accomplish positive learnability. According to the head car designer Gorden Wagener, sound engineering is also optimized for the driving experience (Banks, 2020). However, as this research listed in the user anticipation and user autonomy section indicates, the simplicity is negative by missing the right to whether driver or co-driver can display the driving data and specific controls, which are necessary capabilities.

3.1.3 Heuristics Evaluation Conclusion

This heuristics evaluation mainly analyzed the aspect of interaction design of the VISION AVTR. As a fully-functioning concept car prototype, AVTR delivers innovative interaction features such as minimum interior, ambient light, wing door, driving console (merge control), and hand UI projection. The features tie with the movie Avatar theme and implement the sensual purity guideline and machine-approaching human concept. In the meantime, referring to *First Principles of Interaction Design*, the interior, driving console, and hand UI projection have some design problems. The following section will be committed to researching the insight of design problems.

3.2 Insight of User Experience

In this following section, this research will analyze the user experience design of the VISION AVTR in detail, mainly from **Visual Representation** – affordance and metaphor, visual hierarchy, information loading; **Embodiment** – sense extension, tangible experience; **Engagement** – conversation, intuitive gesture, individual ergonomics. These facets are the assumable design targets derived from the VISION AVTR design team's perception of future interaction design (virtual and physical). The priority of insight analysis is mapping interaction design to UX design and initiating the creation of the design recommendation.

3.2.1 Insight of Visual Representation

The ribbon screen presented a display for virtual scenes that are different locations from the movie *Avatar*. The design's purpose is to provide immersive surroundings for embarkation. Also, **its operation system – hand UI projection** functioned as a projected interface to the user's palm and operated with the user's gesture. The design's purpose is to trigger the multiple senses of the user to operate an interface. As this research mentioned in the Heuristics Evaluation section, parts of the interaction design are partially against Explorable Interfaces, Fitts's Law, and Metaphor principles. **The merge control (driving console)** presented an all-in-one driving console for driver or co-driver. The design's purpose is to accomplish an intuitive minimalization for the driving experience. In the Heuristics Evaluation section, merge control is positive in most principles. Mercedes Benz advertised The VISION AVTR as a foresight of future car design. Hence the insights from UX analysis will be drawn from the perspective of the future explained in the Literature Review.

Affordance and Metaphor. In the user's view, designers drive the future interface's affordance and metaphor to be more understandable than abstract in the prototype. The design team presented a projection interface that worked like a digital membrane covering skin. In contrast, the projection area (palm) and low resolution (icons) cause a negative affordance and disconnected metaphor. The projection should seamlessly provide a 3D interface over the user's palm/skin to enhance the affordance and metaphor for UX by combining with the elemental convergence trend of the physical object and virtual interface. 3D graphics expand the interspace to display much information and provide more creative potential. In addition, the extension of dimension is beneficial to a relatively small amount of space (a vehicle).

Visual Hierarchy. In a particular part of car UX design, the moveable periphery causes a particular design requirement. The user has limited focus points and processing time, so that it requires the design to be more responsive and more accurate than other appliances. In terms of future vehicle interface design, visual hierarchy is the essential principle. In implementing interactable 3D virtual touchpoints, the extensive meaning of the visual hierarchy principle should be more specified – visual hierarchy for XR (Extended Reality). Because of the elevation of layers, and that user will constantly refocus, the visual hierarchy should keep its appropriate content organization and use appropriate interaction metaphors (Billinghurst et al., 2005, p. 17). Under some design circumstances, the interaction metaphors should be more potent and more conversational.

Information Loading. Due to the approximate physical property of 3D interactive objects, despite the content itself, information overload is likely to occur. The visual representation efficiency would maximize by discovering the appropriate surfaces or coordinates to posit, project, or interact with information. The VISION AVTR prototype provides multiple surfaces, of which the ribbon screen is one. The distinct shape of the ribbon screen itself is not suitable for displaying or developing graphics for any purpose. In terms of UX, the front display area requires positive learnability, readability, and discoverability to let the visual hierarchy and metaphor take effect. Hence, referencing the heads-up display over windshield technology, a flattened or ergonomically curved surface, cooperating with 3D projection, would be a positive information loading area.

3.2.2 Insight of Embodiment

The embodiment is the manifestations of a designer's ideas into some perceptible form that can engage with on various levels of design (Kuznetsov, 2019). Reflecting on the embodiment of the VISION AVTR, the levels of design are traceable.

Sense Extension. The feedback that comes from vision, touch, and hearing directly impacts the emotion of the audience. “Smell and taste are typically the results of the choice of materials in the product’s construction, but not the decisions of experienced designers” (Garrett, 2010, p. 135). The Sensual Purity guideline that the head designer committed to includes designing the poles of emotion and intelligence (Mercedes-Benz AG, 2016). In the user experience of AVTR, the vision is the entry-level of design. Stimulating contrast, positive elements of surprise, and impressive proportions (Mercedes-Benz AG, 2016) provide visual engagement so that the fantastic image stays in the audience’s head. The touch is the deeper level when the interaction happens. The haptic materials, colors, and sculptural forms generate natural attraction (Mercedes-Benz AG, 2016) implemented in the driving consoles. “The electric car’s sound goes beyond driving,” said head designer Gorden Wagener (Banks, 2020). The hearing experience emphasizes future interaction design since the importance of driving, and the existence of drivers is fading. The level of sound design is beyond the interaction design but so essential that it affects the interactive user experience. Except for the senses in common sense, there are two extra senses when the design of interaction is targeting on the human body: **proprioception** (body position): “the body awareness sense, which tells us where our body parts are relative to each other. It also gives us information about how much force to use, allowing us to do something like crack an egg while not crushing the egg in our hands”; **vestibular** (movement): “the movement and balanced sense, which gives us information about where our head and body are in space” (Pathways.org, 2020). The proprioception and vestibular could impact the driving experience because the vehicle would bring consistent movement to the human body while driving. Considering the different sensory influences in different embarkation states (parking or driving) could promote the user experience.

Tangible Experience. Tangible User Interface (TUI) is a physical object manipulation mapped one-to-one to virtual object operations. Thus, it is incredibly intuitive to use (Billinghurst et al., 2005, p. 17). However, the design philosophy of VISION AVTR for the future does not target imitating or reappearing the human interaction with physical analogs but targets enlarging the tangible experience through digital methods, combined with the sense extension. The sensible scope in MAYA principles (Dam, 2021) reflects that the future design should consistently refresh and innovate. It proves that the existential value of design is growing with history.

3.2.3 Insight of Engagement

The VISION AVTR prototype is uncommonly lacking a virtual voice assistant. Voice command is one of the practical and engaging tools to build up a conversational environment. The design decision indicates a different route of connecting users and then achieving positive engagement.

Conversation. The conversation in design details finds expression in verbal cues, such as dialogue, voice command, etc.; non-verbal cues such as semantics, gesture, etc. The engagement that conversation provides varies in different contexts. The contexts are consistently shifting with the emotionality, sociability, and personality of design. These three properties eventually decide the user's motivation of whether the user wants to engage in the interaction. After gaining the motivation to interact with the vehicle, the physical interaction design starts.

Natural Gesture. The design team was committed to designing an interactive gesture for the hand UI projection. The prototype presented only four gestures for interacting: raise palm, offset palm, enclose palm, and put down the palm. Along with the minimalist projection graphic design, gesture design focuses on the usability of every single command. The hovering two-dimensional graphics limit the diversity and ergonomics of gestures. The design of the gesture is necessary to adapt and optimize when upscaling the hovering graphics from 2D to 3D. The natural gesture represents the effortless operation, non-verbal context, lack of cultural limits, simple performance, intuitive discoverability, and easy memorization (Cantuni, 2019). Most of the gestures designed for the multi-touch digital screen are not natural (Cantuni, 2019). The natural gesture design should be aware of the balance between intuitiveness and consciousness; otherwise, it would be overresponsive or inefficient, which has been experimentally proved (Huh, 2020, p. 62). When it comes to upscaled interaction context, the natural gesture design is commonly sampled from physical products and unconscious motion; meanwhile, it is strongly related to the visual representation.

Individual Ergonomics. The seat design of VISION AVTR aims to secure the driver and co-driver. It indicates the design team intends to bring operation within the minimized motion to make the embarkation experience safe and effortless. The ergonomics in driving UX keep the design human-oriented. Thus, the ergonomics purpose should connect to the individual property and personality. Moderate customizability or adaptivity for physical parts, a virtual interface, and interactions enhance the core of ergonomics rather than applying the generic standard.

3.3 Valuable Remarks

Along with the development of the industrial design discipline, interaction design today focuses on user experience. Concluding from the previous discussion, the future of interaction design would consistently derive from UX and be more subdivided, specialized, user-oriented, and unprecedentedly innovative. This section concludes the essences from the evaluation and insight section. The following remarks would be an initial or potential composition for design recommendations. From the perspective of future technology:

Visual Representation:

- An XR (Extended Reality) interface should incorporate the text, holography, and 2D/3D graphics together and posit them in a sensible and ergonomic space for the user.
- In typography, the visual hierarchy principle remains universal for XR interface.
- Metaphors should originate from the real-world and expand metaphors beyond real-world counterparts.

Embodiment:

- User experience requires the design consideration of triggering multiple senses by adding levels of design.
- Tangible interaction should exceed real-world analogs and innovate features.

Engagement:

- A conversational environment motivates the user to interact.
- Gesture design should be non-verbally congenial and effortless to perform.
- Gestures should balance intuitiveness and consciousness to gain naturality.
- Natural gestures should provide moderate customizability or adaptivity to gain ergonomics.

3.4 Summary

This chapter finishes a complete heuristics evaluation of the VISION AVTR based on Bruce Tognazzini's (2014) *First Principles of Interaction Design* and learns valuable knowledge in the design case's positive and negative aspects. The case study uses the pieces of the literature review such as visual design (affordance, metaphors, visual hierarchy, etc.) and user experience theories (emotional design, cognitive science, etc.) and then explores valuable remarks from the analysis. The insight of the case study deconstructs the outcomes of heuristics evaluation and restructured them into three categories: **Visual Representation**, **Embodiment**, and **Engagement**. In Visual Representation (Affordance, Metaphors, Visual Hierarchy, Information Loading), the literature support is mainly from Literature Review, and the content is a refinement of principles. In Embodiment (Sense Extension, Tangible Experience) and Engagement (Conversation, Natural Gesture, Individual Ergonomics), the content is built on the complete heuristics evaluation of the VISION AVTR. In the following chapter, this thesis will keep the three categories and refine the initial composition to achieve the ubiquity of recommendations.

Chapter Four

Recommendations

According to the in-depth analysis of the case study: Mercedes-Benz's concept car: The VISION AVTR, the initial creation of recommendations has less ubiquity since it is for vehicle design. The initial recommendations outlined the general factors involved in interaction design from the perspective of future technology. Hence, this chapter aims to broaden the feasibility of initial recommendations from future vehicle interaction design to future digital products interaction design. Based on literature and analysis, the positive revisions will apply to the initial recommendations. The design recommendations will be categorized into mainly three parts: **Visual Representation**, **Embodiment**, and **Engagement**.

The recommendations in this research would build up according to the assumptions from in-development technologies, conceptual opinions, simulative demonstrations, and dependable theories. However, the future always has uncertainty, significantly when the design discipline is usually associated with numerous diversiform domains. Thus, the conductions and conclusions of recommendations would tend to be as universal, directional, and constructive as possible, but exceptional circumstances might occur.

4.1 Design Recommendations for Visual Representation

Table 1

Prefatory Guide Chart for 4.1

4.1.1 Elements in Spatial User Interface *(Recommendations at p. 74 and p. 80)*	
Element Taxonomy (p. 70)	**Volumetric Change Decision** (p. 74)

<table>
<tr><td rowspan="2">Five types of virtual objects in spatial UI</td><td colspan="2">For Texts (p. 74)</td><td>For Graphics (p. 75)</td></tr>
<tr><td colspan="2">The comparison of 2D and 3D texts (for reading purposes)</td><td>Icons and presentive contents; a taxonomy for UI components</td></tr>
<tr><td colspan="4">4.1.2 Visual Representation Principles
(Recommendations at p. 81, pp. 82-83, pp. 84-85 and p. 86)</td></tr>
<tr><td>The Use of Metaphors and Visual Hierarchy (p. 80)</td><td>Cognitive Psychology (p. 81)</td><td>Hick’s Law and Fitts’s Law (p. 83)</td><td>Foreshortening Effect (p. 85)</td></tr>
<tr><td>The theoretical effectiveness in Spatial UI</td><td>Using the model of visual perception</td><td>The changes of variate</td><td>The relations with visual spatial attention</td></tr>
</table>

4.1.1 *Elements in Spatial User Interface*

Initial recommendation:

- an XR (Extended Reality) interface should incorporate the text, holography, and 2D/3D graphics together and posit them in a sensible and ergonomic space for the user.

Element Taxonomy. The substantial difference between the XR interface and plane interface is the spaciousness. The holography or 3D element represents and emphasizes spaciousness. The spatial interface certainly will display a more significant amount of information than the present graphics. The spatial interface provides the user with a greater field of view, the potential interactable area, and the extra sensible depth of information such as shadow, material, finish, etc. Based on the technological prediction, the near future is, in all likelihood facing a platform switch. Whether or not people could interact with reality and virtuality in any method, the near future would introduce the spatial interface. Designers certainly will learn to cover the details of the spatial interface.

When the user attaches equipment and activates the spatial interface, the interactable space certainly will go beyond flat screens. Specifically, according to the different design thinking processes (addressed in the following content) towards each type, the taxonomy of elements in spatial UI could be mainly five types of virtual objects. **Volumetric objects:** they are computer-generated and weightless three-dimensional models that can achieve specific needs such as presentation or manipulation, e.g., 3D vehicle hologram (Figure 28); **surface components:** they display wireframed two-dimensional planes that function similarly to the current screen-based device, e.g., virtual theater and floating menu (Figure 29); **interface attachments:** they are a digital interface which attaches on objects, e.g., HUD (heads up display) on the vehicle windshield (Figure 30); **TUI objects:** they are real-world objects registered to computer meanwhile being able to affect virtual elements, e.g., TUI (tangible user interface) (Figure 31); **environment:** immobile virtual or physical elements compose environments which opt-out from the interaction, e.g., digital wallpaper. The taxonomy sets out from the functionality of each category so that the categories have their cross-field, such as surface components that can be presented as interface attachments.

Figure 28

3D Hologram (Euclideon Holographics, 2020)

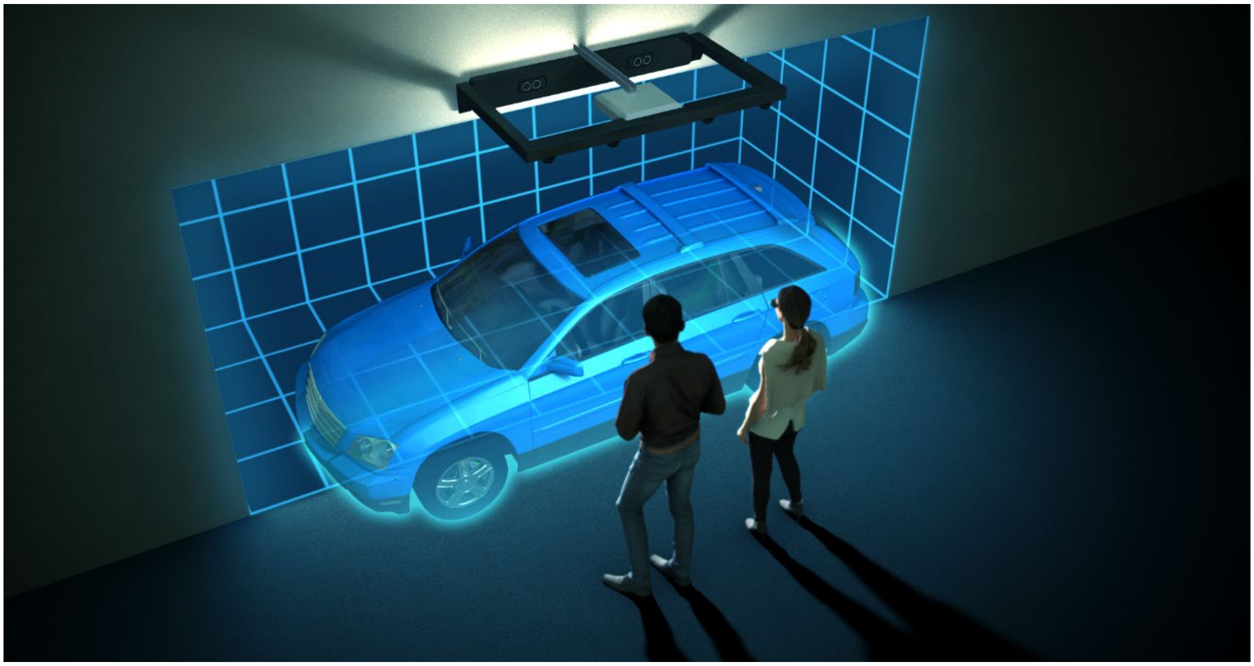


Figure 29

Floating Menu (Alger, 2020)

Figure 30

HUD (Heads Up Display) (Alger, 2020)

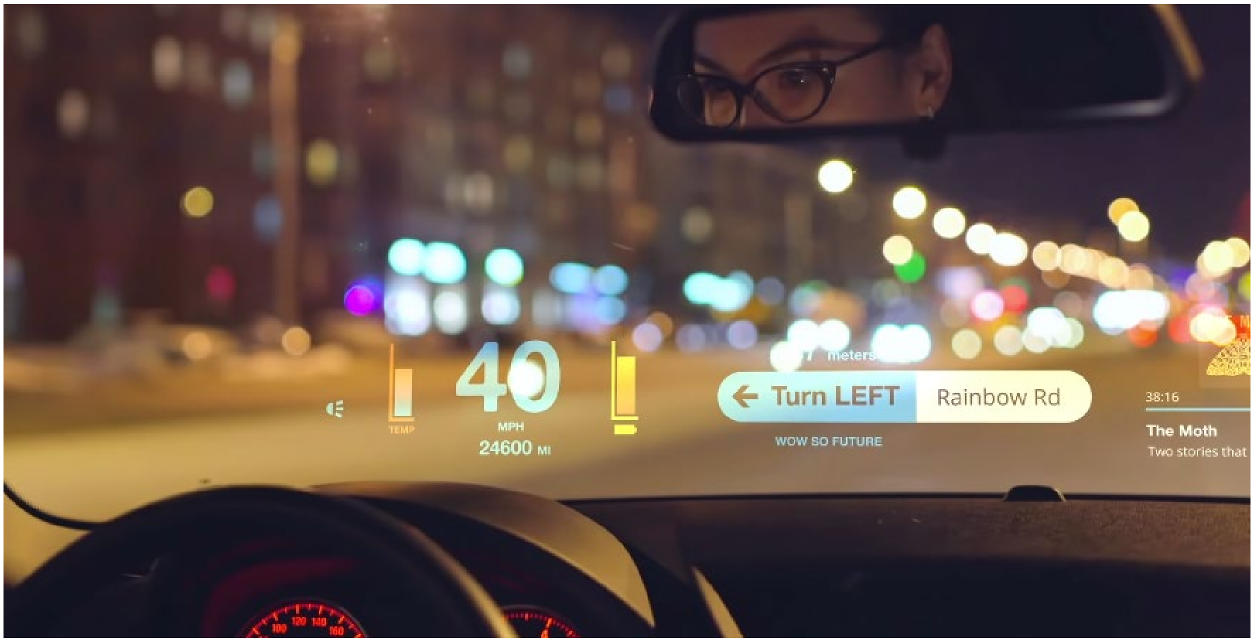
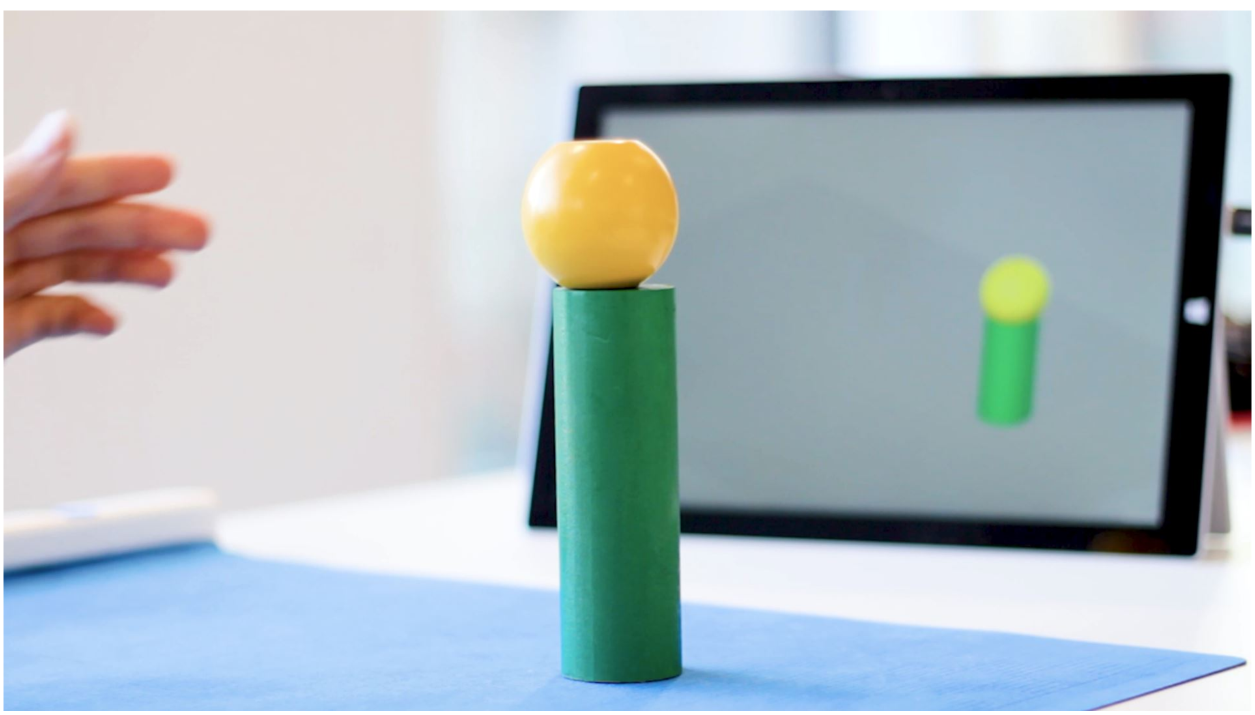


Figure 31

Tangible User Interface (Villar et al., 2018)



To set up a background for the following analysis, these recommendations are displayed:

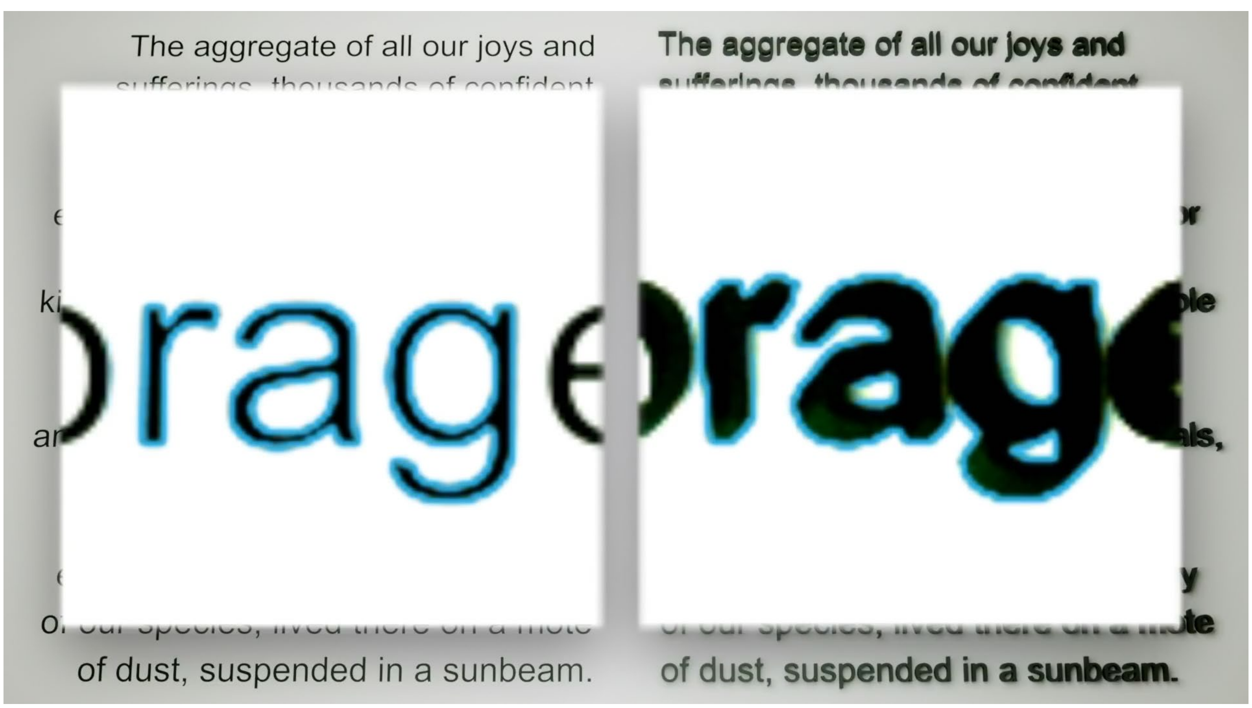
- *In spatial UI design, there are five elements for reference: volumetric objects, surfaces components, interface attachments, TUI objects, and environment.*

Volumetric Change Decision. Organizing and regulating information is one of the existential values of designers. To begin with, the content which user mainly discerns contains texts and graphics. One fundamental design decision for transitioning from graphic design for screen to spatial interface is whether to make the part volumetric.

For **texts:** by outlining the plane text and volumetric text (Figure 32) and comparing the readability, the volumetric form of letters would harm the designed cognitive shape of letters. In addition, the deformation could shift in different view angles. Thus, a readable text design is not recommended to be volumetric. In addition, the text could be presented as graphics when the readability is secondarily essential, e.g., a logo composed with 3D letters.

Figure 32

Plain Text and Volumetric Text Comparison (Alger, 2020)



For **graphics:** the graphics today are chiefly posited within frames (usually rectangle digital screen). The developers and designers figured out methods to enhance the volume of elements such as drop shadow, gradient ramp, transparency, background layer, etc. To advance the concept, they positively recommend graphics with a sense of volume. However, there are two different situations. Firstly, some of the graphics have standardized, e.g., male/female toilet icons. Standardized universal icons for the formal occasion (airport, government, etc.) are frequently located beside the readable texts, and therefore for readability, they are not recommended to be volumetric. Secondly, it depends on the situation whether to make part of UI components volumetric. The screen-based devices are going to persist in being part of the appliance in the near future. In the Literature Review, the design trend part presents the skeuomorphism to flat to Glassmorphism. Various style guides are blooming, but the macro-trend simplifies, reducing the information and cognitive load.

Furthermore, the Law of Prägnanz (or Simplicity) indicates that "people will perceive and interpret ambiguous or complex images as the simplest form possible" (Bradley, 2014). Hence, making the abstract and understandable UI components volumetric is optional because it could eliminate their simplicity. The following section will break down the UI components and analyze the viability of them being volumetric.

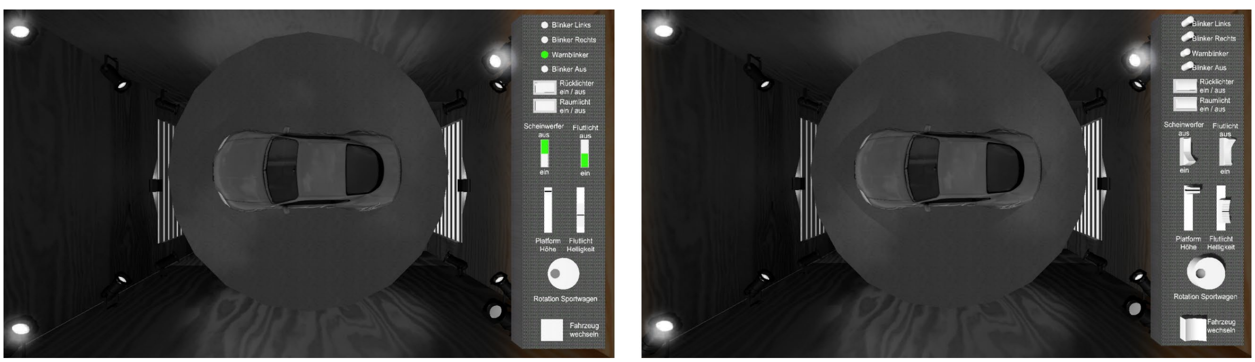
According to the visual representation of the current UI design, UI components are majorly displayed in four categories: input controls, navigational components, informational components, and containers (Usability.gov, 2013). The classification is based on the complexity level of operation. **Input controls** are designed to have the simplest operation (e.g., one-click) that registers a function. Typically, they are toggle, button, date picker, and text field; **navigational components** are designed to have multiple operations or touchpoints (e.g., dropdown menu and selection box). Typically, they are tag, breadcrumb, slider, carousel, and search field; **containers** are designed like a compilation of dropdown lists – accordion, a vertically stacked list of items with interactive areas; **informational components** are designed to display the non-interactive information. Typically, they are a notification, progress bar, and message box. For each of the components in spatial interface design, this research will discuss the design decision of being volumetric. However, the current gist of taxonomy is not related to the property of volume of each element. Referring to one of the *First Principles of Interaction Design* (Tognazzini, 2014): *choose metaphors that will enable users to grasp the finest details of the conceptual model instantly; expand beyond literal interpretation of real-world counterparts,* each UI element has its metaphor within it. A new gist of taxonomy could be the relation between the component itself and the real-world reference. Most of the plane graphics having analogs or counterparts in the real world are the gist. For instance, when the user takes advantage of virtual presentation, the user would prefer a vehicle presentation to be tangible on an accurate scale. Explanation in advance: the word "counterpart" emphasizes "basically the same", and the word "analog" emphasizes "similar or comparable property", but analog and counterpart both have their reference objects.

Toggle and button both have design references – mechanical switch and button from the real world. Combining the trend of minimalism and the Law of Prägnanz, the current toggle, and button in UI is the simplified version of mechanical switch and button because the mechanical structure can achieve multi-stage function (e.g., vehicle's steering lamp switch) without causing the cognitive issue. Oppositely, the toggle and button as 2D graphics are ideally one-time interactive components. In this situation, the toggle and button categorize into components that function below their analog. In short, they are **lower-analogy components**.

“Emphasize biological motion over rigid UI elements that throw away most of what the body does. Avoid button. Use continuous controls” (Lanier, 2017, p. 235). The lower-analogy components are considered as rigid UI elements in this phase. It suggests another way to adapt the spatial technology: replacing the lower-analogy components with continuous controls. However, a rigid UI has its uses, especially when used as an assistive tool (Dauchot, 2018). A study shows the user could easily comprehend the function of both 2D and 3D widgets (Figure 33) when the interface provided enough positive usability. Meanwhile, the user’s intention of operating 3D widgets was usually dominated, and 3D widgets perform better when the preview window is a stereoscopic display (Zilch et al., 2014, p. 7).

Figure 33

Comparison of 2D and 3D Widgets (Zilch et al., 2014, p. 4)



The comparison was experimented on a surface screen, and participants ended up touching every widget, which did not quite match the 3D interaction context. However, the conclusion has a further reference significance. The widgets in the experiment are lower-analogy components (e.g., switch, button, and turntable) that keep the task more uncomplicated. It suggests that the volumetric change serves the cognitive purpose (adding minor dimension) instead of function.

The date picker derives from the paper menu and calendar. To adopt the digital UI, they are simplified visually for a better reading experience. Unlike previous components, the date picker is endowed with extra functions (e.g., calendar integrated with event creator). Hence, the date picker is categorized into **higher-analogy components**.

The text field is the container of readable texts, and a readable text design is not recommended to be volumetric. Hence, the input part should stay in 2D. Reflecting on the reference object of the text field, it is a copy of the physical paper, and they share the same function – adding content. Compared with higher-analogy components, the text field relatively has the same function as its real-world reference. In this case, the text field is categorized into **counterpart components**.

Tags and breadcrumbs serve as a combination of display and selection; they are primarily operable texts or icons. Slider and carousel advance the operation to a sliding or swiping gesture. Sometimes a complex animation will be implemented (e.g., hovering menu and shapeshift). Overall, they have basic reference objects physically, such as the sticky tag and mechanistic slider. Furthermore, micro-interaction, gesture, and hidden information are the properties to identity them into the **higher-analogy components**.

Search field and container are text-heavy components and with the operable area and hidden information. The text should maintain readability, but this does not determine them as counterpart components. Nevertheless, they are built specifically for the digital interface so that they do not have any analog in the real world. Reasonably the search field and container should be categorized into **digital-based components**.

Informational components, including notification, progress bar, and message box, are designed for digital use. In addition, the content inside components usually updates consistently. These components that determine information are **digital-based components**.

In summary, there are four types of UI components (descending by the relevance with the real-world references): lower-analogy component, counterpart component, higher-analogy component, and digital-based component (Table 2).

Table 2

Classification for UI Components

Relevance with Reference (Descend)	Type Name	Recommendations for Volumetric Change
Less Functional	Lower-analogy Components	Adding None or Minor Dimension
Relatively Same Function	Counterpart Components	
More Functional	Higher-analogy Components	Suitable for Adding Dimensions
No Reference	Digital-based Components	

Back to the design decision of being volumetric or not, fundamentally speaking, they all have a certain degree of depth generated by the drop shadow, gradient ramp, transparency, or background layer. It is recommended to add a volumetric property to enhance the depth. Regarding the stereoscopic design decision, the lower-analogy and counterpart components are suitable for adding none or minor dimensions. The higher-analogy and digital-based components are suitable for adding certain dimensions. Indeed, except for converting the components from 2D UI to the spatial UI, the spatial UI always preserves the potential to fit in more innovations of virtual objects. In this section, the recommendations are one positive taxonomy to assist the transition from 2D interface to spatial UI.

To sum up, the following recommendations are displayed:

- *Avoid turning standardized graphics and readable texts volumetric.*
- *Consider providing volumetric graphics for presentive content.*
- *Classify UI components by the relevance with their analogs (Table 2), of which:*
    - *Adding none or minor dimension to lower-analogy and counterpart components (usually serves the cognitive purpose). If the inconsistency occurs, consider rephrasing the lower-analogy or counterpart components into other continuous interaction patterns;*
    - *Higher-analogy and digital-based components are compatible to add dimensions.*

4.1.2 Visual Representation Principles

Initial composed recommendation:

- In typography, the visual hierarchy principle remains universal for the XR interface;
- Metaphors should originate from the real world and expand metaphors beyond real-world counterparts.

The use of metaphors, visual hierarchy, Hick's Law, and Fitts's Law are the design principles worthy of illustrating.

The Use of Metaphors and Visual Hierarchy. A favorable object in the spatial interface is inevitably endowed with one or multiple metaphors. The metaphor could be a visual metaphor that originated from its analog. Usually, the visual metaphor is designed for lower-analogy components to avoid confusion from abstract geometries. Because a copy of the real-world counterpart (counterpart component) is self-explanatory enough, in the meantime, the metaphor also could be an auditory metaphor that enables the user to grasp the targeted details instantly. The use of metaphors requires objects to integrate rapid and conclusive psychological hints. Otherwise, it will mislead the user and cause a cognitive issue. A warning reddish pop-up window would not make any opposite sense in spatial UI. Reddish color and pop-up animation are commonly regarded as visual hierarchy elements that echo the level relationship in the visual hierarchy principle. The analysis of The VISION AVTR contains examples to prove the universality of the use of metaphors and the visual hierarchy principle. Compared to the spatial UI and current graphic UI, the core of the visual hierarchy principle stays the same because they share the same targeted user group – humans. Thus, it is universal in the spatial UI in most scenarios.

To sum up, the following recommendations are displayed:

- *The positive use of metaphor prompts the user with instant and conclusive hints. In most cases: lower-analogy components need more potent metaphors to serve the needs.*
- *The visual hierarchy principle is universally effective.*

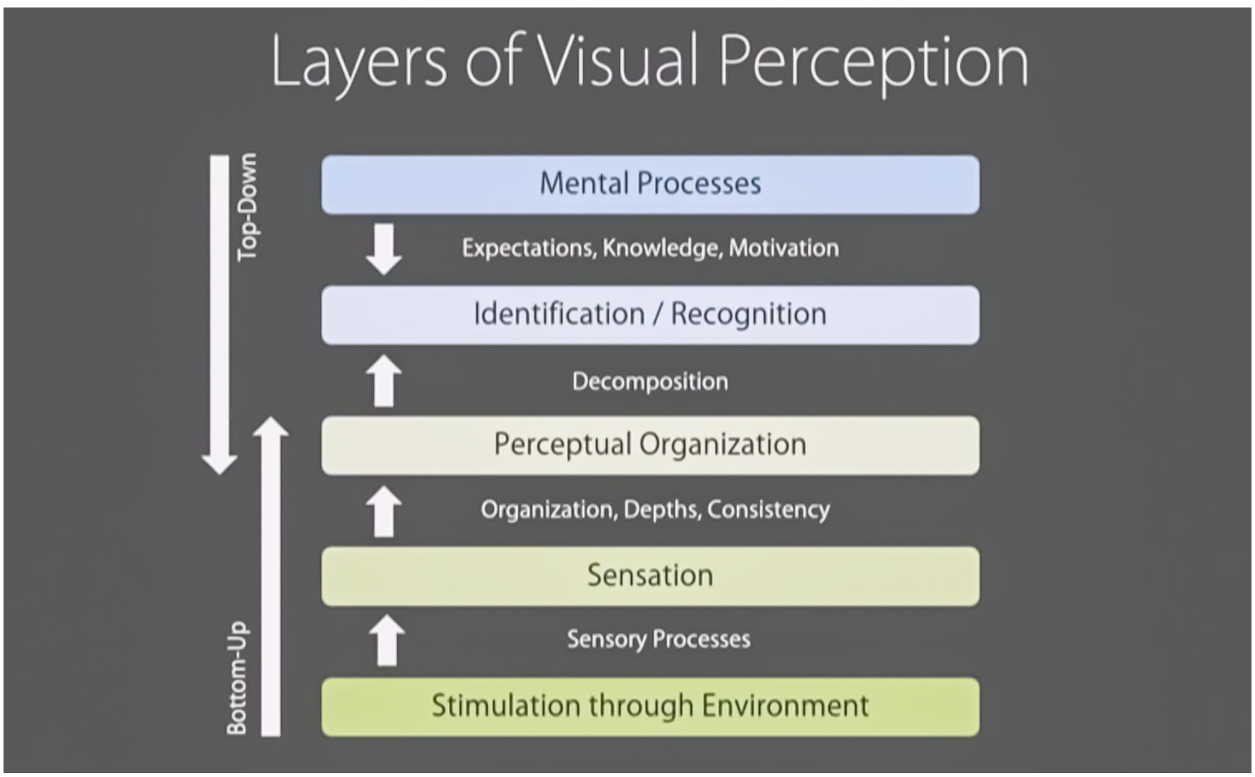
Cognitive Psychology. The use of metaphor has high relativity with Cognitive Psychology. The psychological aspect of users processing visual information has a specific model (Figure 34), named Layers of Visual Perception (Bedenk, 2016). The layers would turn cognitive load into an issue in the first experience with VR: the translation of a mental model, the consistent shifting of user's focus, memorization of first introduced command, and knowledge building of spatial interaction (Malaika, 2015). The cognitive tasks are usually forced to build in the Bottom-Up method (Figure 34).

The Top-Down (Figure 34) method theoretically has fewer errors than the Bottom-Up method. The Top-Down method requires specific knowledge of the user to guarantee validity so that the Top-Down method is more suitable to display for a subset of target users. In practice, the subset of the target users usually includes more professional users than most target users or users who have already learned the visual perception of elements.

The use of metaphor belongs to the process of sensation to the perceptual organization in the Bottom-Up method (Figure 34). However, any recognition issue during this more complex perceptual process would vary what designers want the user to understand. In order to improve the error-tolerance ability of metaphor, the design should be broken down and have necessary instructions added. More extensively, ensuring visual comprehension requires the sacrifice of illustration step or time. A thorough visual perception generated by the Bottom-Up method can be converted to the Top-Down method after ensuring that the user possesses the knowledge.

Figure 34

Layers of Visual Perception (Bedenk, 2016)



Hence, the following recommendations are displayed:

- *Consider preferentially choosing the Top-Down method to suggest the visual elements.*
- *Sacrifice the time promptness to ensure positive comprehension in the Bottom-Up method by:*

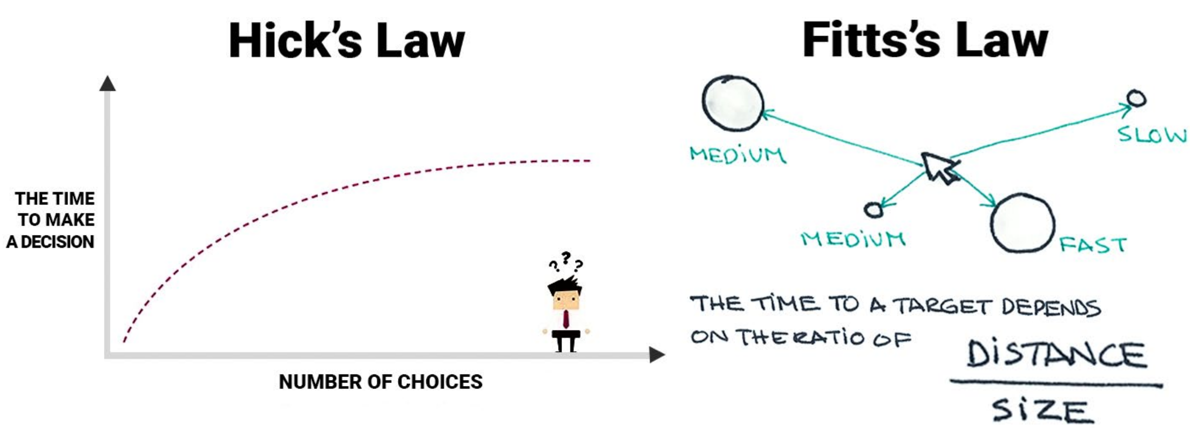
- *Breaking down the process during the procedure between sensory process and decomposition, then;*
- *Detailing and adding (Top-Down method) instructions to the process.*

- *Consider securing the comprehension built by the Bottom-Up method (e.g., bounding a unique symbol to the visual perception) and utilizing the Top-Down method in the later cognitive process.*

Hick's Law and Fitts's Law. Hick's Law (Figure 35) (equation: $RT = a + b \ \log_2(n)$) emphasizes that a user's vision choices should properly decrease, especially when the number of choices is low. Fitts's Law (Figure 35) (equation: $MT = a + b \ \log_2(2\frac{D}{W})$) addresses that designers should fine-tune the time of targeting elements with two factors – lower distance and larger size.

Figure 35

Illustrations of Hick's Law (Lavery, 2017) and Fitts's Law (Hey, 2021)



When it comes to the transition from screen-based interface to spatial interface, Hick's Law and Fitts's Law face a different situation. Due to the designer not sticking the interface right on the user's face but positing away from the user, the spatial interface has a significantly increased amount of the "n" (the number of stimuli) and "D" (the distance between the origin and the target). Also, the "W" (the "size" of target) would consistently shift due to the human eyes' depth of focus and the perspective relation (foreshortening effect). These two principles or equations are, without question, universally effective in spatial UI. "Classic interaction design rules like Fitts's Law still apply in VR for interacting with screens, but now with more space" (Dauchot, 2018). When substituting the significantly increased amount of "n" and "D" into the equation, the Movement Time (MT) and Reaction Time (RT) will have a decelerated growth. It will lead to the result that compared with the exposed objects in spatial UI, the tolerance of the user's vision will be much better than the exposed objects in screen-based UI. A game in practice showed that Fitts's Law in VR had ninety percent less error than Fitts's Law in game consoles (Malaika, 2015). The instance shows the extra dimension resulted in less constraint to Fitts's Law since the user would have two arms and more joints (the study claimed the phenomenon Bimanual Target Ambiguity (Malaika, 2015)) to participate in the interaction.

The primary purpose is still efficiently reducing "MT" as well as "RT". Positioning is the determinant. Back to the analysis of The VISION AVTR, the adverse choices of projection positioning (user's palm skin) would negatively affect the user experience. Combining Hick's Law and Fitts's Law, Hick's Law requires positioning the wireframe of components to have a cognizable boundary. Also, in general, Hick's Law requires the number of choices to be minimal. Fitts's Law requires the positioning of the components to be ergonomic (fit user's convention and close enough) to reach. The recommendations are based on the relative values of variates in Hick's Law and Fitts's Law so that the recommendations likely would not apply to extreme circumstances.

Thus, the following recommendations are displayed:

- *Consider applying Hick's Law and Fitts's Law to the spatial user interface by:*

- *Building a cognizable boundary for the wireframe of components (based on Hick's Law)*;
- *Determining an ergonomic positioning for each component (based on Fitts's Law).*

Foreshortening Effect. The uncertain value of "W" causes the foreshortening effect in spatial UI. Instead of treating it as an uncertain variate, this thesis concludes that, in general, the advantage outweighs the disadvantage for the following reason that biologically human vision has its limitation by spatial resolution. To overcome the limitation, the human can select the objects by moving eyes to focus them on the part of the retina, or the human can shift spatial attention without moving the eyes (Anton-Erxleben & Carrasco, 2013). Hence, when the spatial UI immerses the user enough, the foreshortening effect would benefit the interface to display anything hierarchically important by locating them in front of the user's spatial attention. For the hierarchically less essential elements, they would blur together with the background. What is noteworthy is that the hierarchically less essential elements should not have excessive movement. Because peripheral vision is sensitive to brightness or color shifting (Snail, 2019), unnecessary animation in an unfocused area would distract the user's attention. The same theory applies to the readability of text as well. A text floating on no surface is less readable (Alger, 2020) than texts within the text field because the sight will biologically converge on a vivid background or text (Figure 36). In addition, this could be one of the reasons that the background blur effect is popular in the current interface design.

Figure 36

To sum up, the following recommendations are displayed:

- *Consider bringing hierarchically essential elements to the user's spatial attention in the positioning process.*
- *Avoid stimulating visual changes from the user's spatial attention, e.g., dynamic, sharp, or vivid images.*

4.1.3 Summary

There are many new possibilities inside VR for visual design that have yet to be explored, but visual design fundamentals still apply (Dauchot, 2018). As long as the visual design serves humans, the industrial design principles apply. For example, "a good design is innovative, makes a product useful, is aesthetic, makes a product understandable, is unobtrusive, is honest, is longlasting, is thorough down to the last detail, is environmentally friendly, and Involves as little design as possible," according to Dieter Rams (Domingo, 2018, p. 3). Despite suggesting the graphic knowledge, designing spatial UI with principles eventually attributes the interface design into UX design. The following section is the broader scope analysis of UX design by focalizing the attention to the user and designer.

4.2 Design Recommendations for Embodiment

Table 3

Prefatory Guide Chart for 4.2

4.2.1 The Senses *(Recommendations at pp. 90-91 and p. 95)*	
Sensory Integration *(p. 87)*	**2D and 3D Mediums** *(p. 91)*
Proprioception starts being important	The benefits of using the relatively real properties
4.2.2 The Tangible Experience *(Recommendations at p. 97)*	
The spatial computing and the rounded route of tangible experience *(p. 95)*	

4.2.1 The Senses

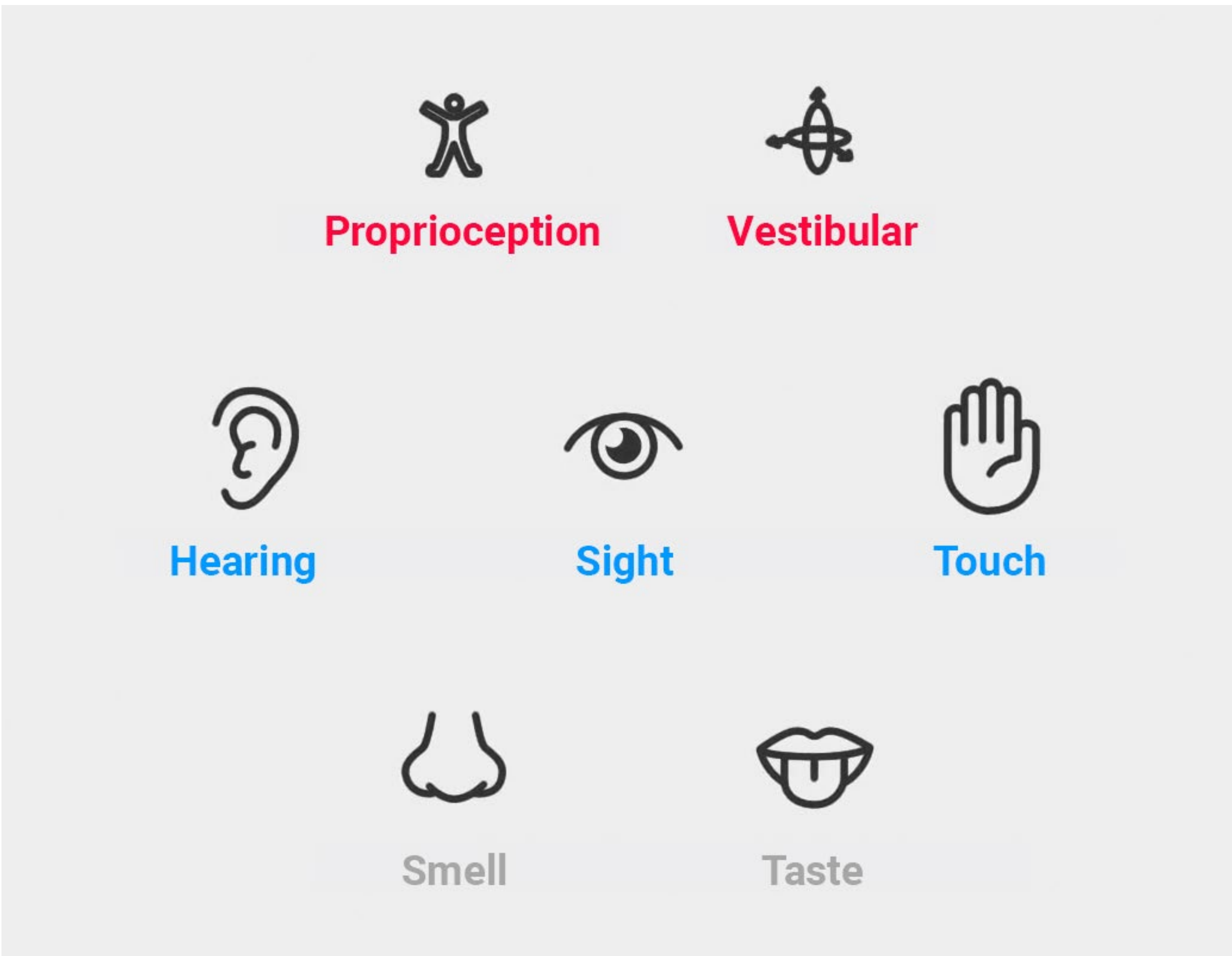
Initial recommendation:

- User experience requires the design consideration of triggering multiple senses by adding levels of design.

Sensory Integration. From what this research mentions in Chapter Three, smell (olfactory) and taste (gustatory) usually are not considered in the UX design field in this research. Sight (vision), hearing (auditory), and touch (tactile) role essential parts of current UX design. When technology involving the human body (e.g., body movement tracking) transmits users to the spatial environment, **proprioception** and **vestibular** reveal their importance. Proprioception, vestibular, hearing, sight, and touch are the senses involved in this section (Figure 37).

Figure 37

Important (Highlighted) Senses in Spatial Environment (Alger, 2020)



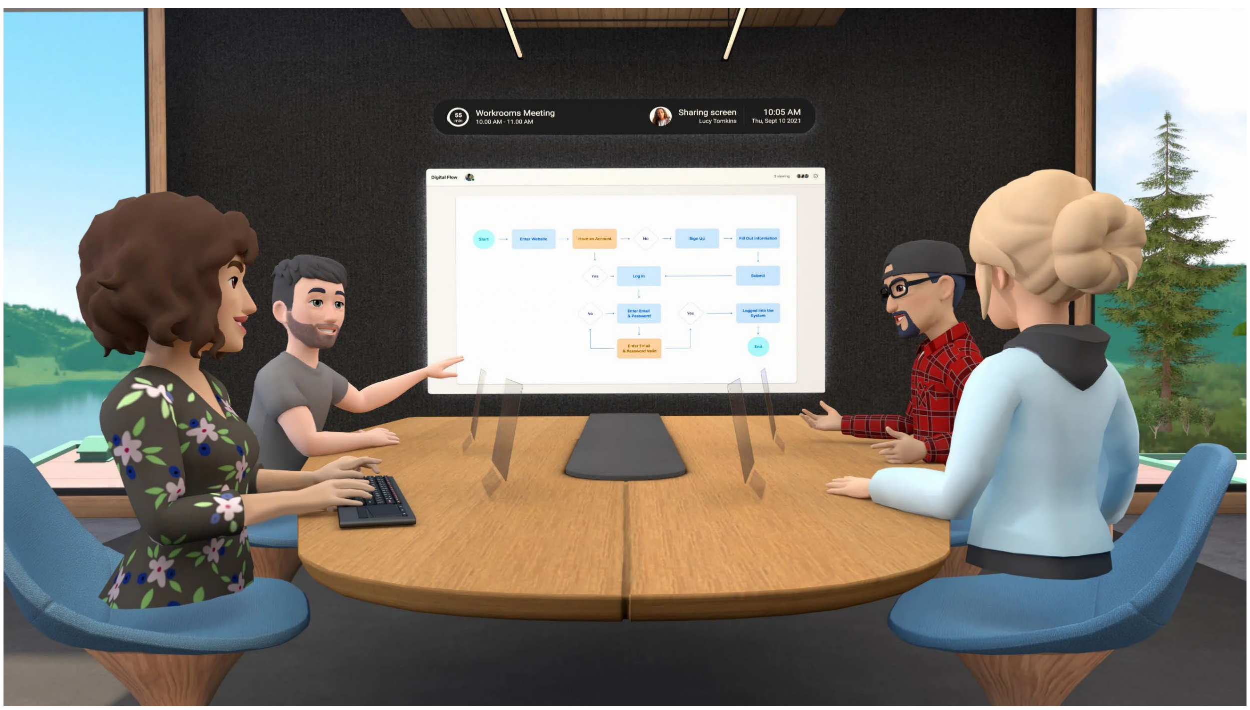
Proprioception and vestibular are the factors specializing spatial interfaces themselves from current screen-based interfaces. When it comes to the usage of proprioception in the spatial environment, it usually expresses two meanings: for users themselves, the awareness of interacting body part (e.g., hands) when the interaction occurs (without the confirmation from user's sight);

for others who are interacting with the environment, the subtle body languages. The usage of vestibular in the spatial environment usually is considered against the physiological discomfort. For instance, the VR game usually causes dizziness in the first several experiences because of noticeable lagging or discontinuity in virtual scenes.

Sensory Integration: "sensory integration is the process by which we receive information through our senses, organize this information, and use it to participate in everyday activities" (Pathways.org, 2020). Multiple senses are usually stimulated simultaneously; for example, proprioception appears when the interaction can be touching, hearing, and seeing. Hence, the sensory integration resolves the complexity. By taking account of the proprioception and vestibular senses, the sensory integration will have a stronger connection to the emotionality, sociability, and personality in UX. There are multiple methods to show users' emotions on traditional occasions, such as messaging, sending emojis, video calling, etc. No other than that they are individual tools, the emotion expression is segmental so that there are voices people prefer in-person social activities. Hence, the basics for the spatial environment are approaching the in-person social experience then exceeding it. A straightforward method to exceed it is utilizing the proprioception outside hearing. Currently, the nearest solution is the Horizon Workroom from Facebook (Figure 38). Except for prematurely merging the in-person meeting experience with volumetric objects in VR headset, Horizon Workroom has explored some features beyond the in-person meeting. For instance, TUI object – typing on the physical keyboard and privately showing visual feedback only on the operator's screen. Interface attachment – floating options menu (to adjust volume, send a private message, etc.) above participants. Back to the sensory integration, Horizon Workroom's core feature is manipulating the proprioception. It makes the proprioception expression optional (e.g., users are allowed to choose their appearance preferences) and proprioception intake acceptable (e.g., users can mute or hide an annoying person). The proprioception is primarily the result of multiple sensations working together or sensory integration. The vestibular in the spatial environment requires the virtual images to be realistic against the physiological discomfort, which is more connected to Usability Engineering. Crossing the streams between interactions and user body parts can cause an ocular-vestibular mismatch (Dauchot, 2018). The technology today has not inspired the possibility of full sensory integration. For instance, the characters in Horizon Workroom do not have a pair of legs to move, and teleportation moving solution is one of the compromises.

Figure 38

Horizon Workroom (Beta) from Facebook (Facebook, 2021)



To sum up the analysis so far, the following recommendations are displayed:

- *Consider utilizing multiple senses, including proprioception, vestibular, hearing, sight, and touch. Among the processes:*

- *Manipulating the proprioception (usually links to other senses) to exploit the advantages of the spatial technology;*
- *Paying attention to trigger the influence of emotionality, sociability, and personality;*
- *Avoid letting the user process untuned interactions that can cause an ocular-vestibular mismatch caused by the unnatural or non-sense phenomenon.*

2D and 3D Mediums. The analysis continues with specific senses in sensory integration. The analysis would not be individual senses but several of them. Comparing a screen-based website design that simulates a spatial interface as a navigation page (Figure 39) with a website designed for VR (Figure 39), they implement wireframes with perspective but presented in different platforms. The simulated spatial interface usually is termed a 2.5D interface.

For the 2.5D website (Figure 39), the visual stimuli are the floating text and dynamic movement with mouse cursor movement. The 2.5D website took advantage of the simulative spaciousness. It could fit in many more navigation tabs than a regular 2D website because the metaphor of floating tabs hints at the theoretically infinite boundary and triggers the user to move the cursor to explore more. When the metaphor (sense of sight) takes effect, proprioception drives the user to move the cursor. Incidentally, the 2.5D website is inclined to weigh the graphics much more than reading texts. On the one hand, it is an enhancement for visual stimuli; on the other hand, it limits the purpose of delivering correct information if metaphors do not work, which occurs on a few tabs in the figure.

For the VR website (Figure 40), viewers in the central point are surrounded by a cylindroid surface. Thus, with the VR devices, the practical vision is ergonomic like the real world. The spatial interface gathers the merits of the 2.5D website. It strengthens them, which are the theoretically infinite boundary due to the actual spaciousness (the actual depth of field) and motivation of exploring by moving head/eyes instead of the cursor. Meanwhile, the spatial interface resolves the readability issue from the 2.5D website because the practical vision is realistic for viewers' eyes. The spatial implementation takes positive effects on both visual stimuli and information delivery and reduces the potential confusion.

Figure 39

2.5D Website Navigation Page (Ukraine, 2021)

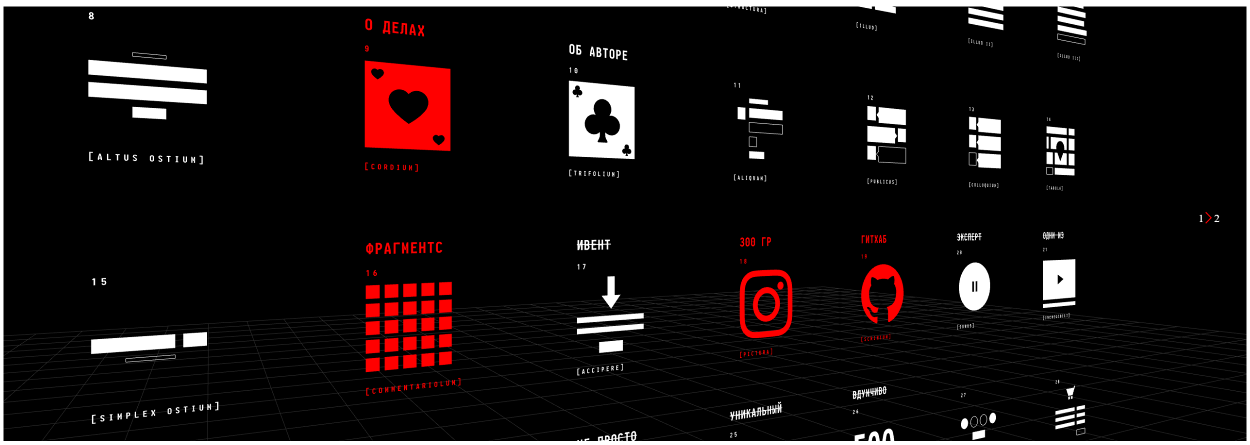
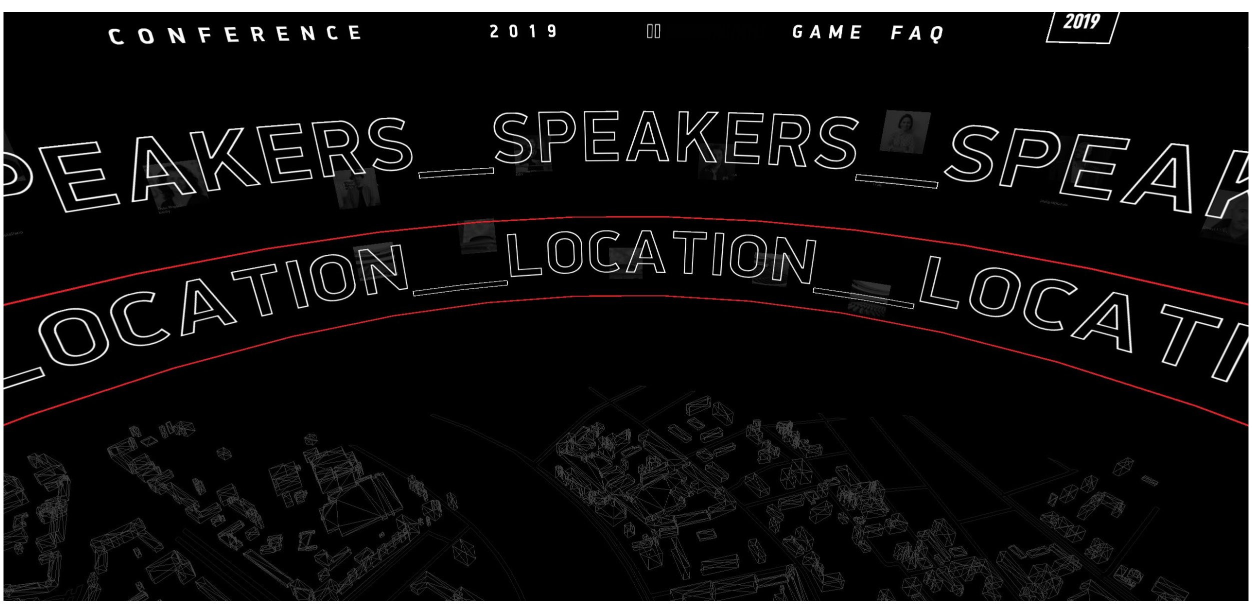


Figure 40

VR Website Navigation Page (Moscow, 2019)



In another pair of comparisons (Figure 41), the spatial information card (right-side) can add a dynamic light source to enhance the hierarchical relationship. Dynamic light sources probably would cause viewers' confusion in 2D design. More importantly, the simple light source indicates the property of the physical profile "card". Furthermore, the spatial interface is easier to endow the properties from the 3D rendering field, e.g., diffusion, roughness, and specularity. The iridescent card (Figure 42) feels like the rainbow film's physical material, and viewers would confirm it until they witness the rainbow color's realistic movement due to the light source. It is worth mentioning that the current screen-based UI can also implement material properties such as the Glassmorphism (Figure 11) mentioned in Chapter Two. However, Glassmorphism tends to universalize glass material to components which is the opposite purpose of restoring proper material. In the real world, no surface is perfect, and different roughness levels or ambient shade are much easier and more essential to express in spatial UI. The material properties connect with the sense of sight, the sense of proprioception, and the sense of touch. Controller vibration could provide the sense of touch, which is unreal, but the emotional reaction of seeing the surface then recalling the feeling of touch enhances metaphors. Overall, it usually enhances the cognitive experience. Positive cognitive experience is not the only target to design for. The situation varies in different scenarios. For example, video game interface usually treats the unity of aesthetic style as a priority instead of the cognitive experience.

Figure 41

Information Card with A Light Source (Guerron & Mitchell, 2017)

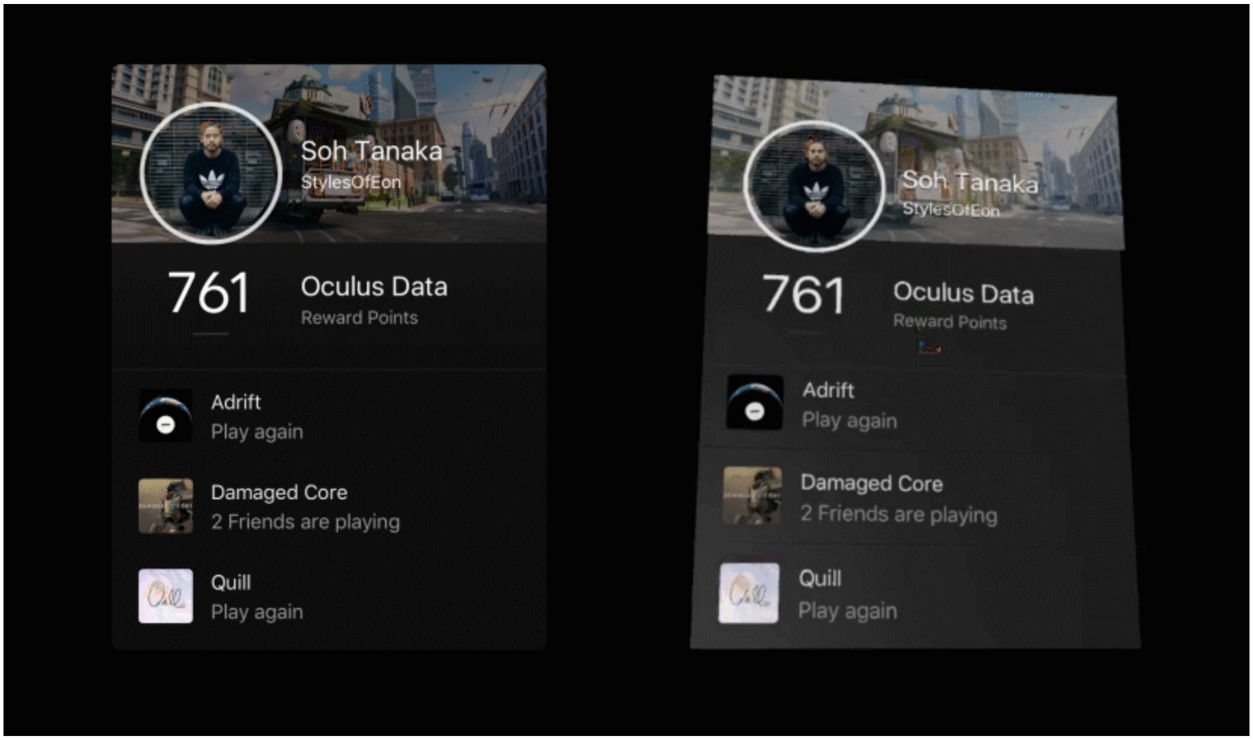
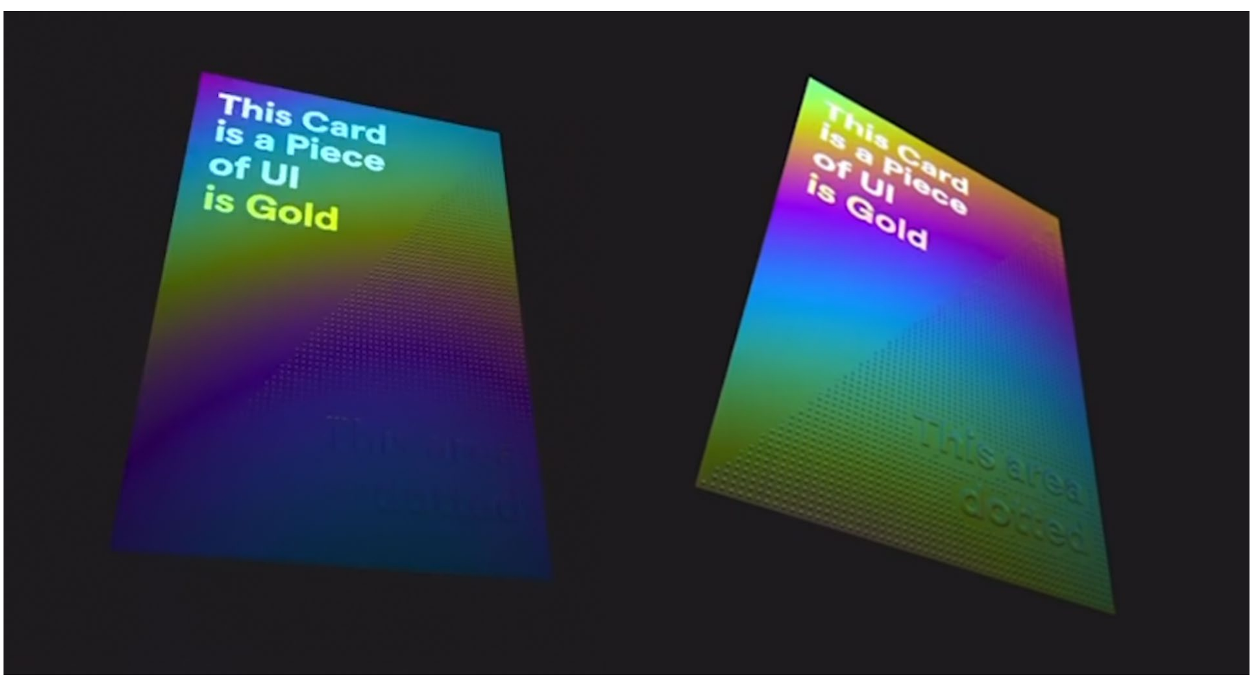


Figure 42

Iridescent (as One of The Physical Properties) Card (Guerron & Mitchell, 2017)



To sum up, the following recommendations are displayed:

- *Consider reproducing the physical properties (the better use of metaphors) for items to enhance the cognitive experience by:*
    - *Utilizing the relatively realistic light and shadow to express the properties;*
    - *Layering the relatively correct properties from the 3D rendering domain (e.g., specularity, roughness, etc.).*

4.2.2 The Tangible Experience

Initial recommendation:

- Tangible interaction should exceed real-world analogs and innovate features.

"Spatial computing is human interaction with a machine in which the machine retains and manipulates referents to real objects and spaces" (Greenwold & Paradiso, 2003). Compared with the concept of XR (Extended Reality), spatial computing emphasizes the interaction between human and machine. The tangible experience in spatial computing has been a task for Usability Engineering and Software Development since spatial computing technology became a hot topic. The tangible experience is a challenging technical barrier to break because the interaction for spatial computing is not technically tangible. The ideal scenario is the user getting rid of the additional controller and controlling with their bare hands. However, digital objects are weightless to interact with. The interface attachments and TUI objects can partly load the touch feedback from the physical world, but they are not universal and sometimes unrealistic.

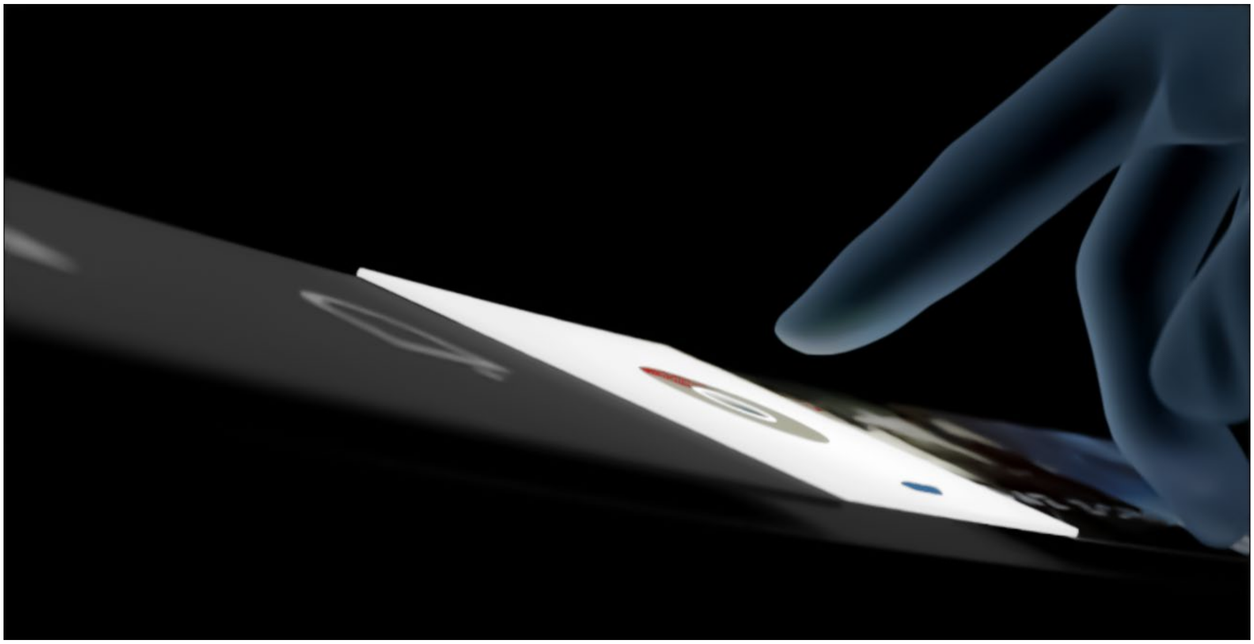
Historically, the touch screen technology on mobile devices was initially criticized because touch screens could not provide tactile feedback like physical dial buttons. Mobile devices back then provided feedback of vibration and tones for every touch of dial numbers. Gradually, the user got used to the touch screen dialing experience, and the vibration and tones became an optional function in the setting menu. Users' acceptability changed over time. Users adopt and practice new habits with the affordance changes of the digital dial pad. Hence, imparting the spatial interface new affordance is the ultimate target, and inevitably in practice, the spatial interfaces would have real-world analogs. In the sensory integration section, reappearing physical properties is a positive method to enhance the user's multiple sensations. The physical properties would have real-world references, but the same target possessing exclusive physical properties applies to them.

In terms of the tangible experience, one of the existing design references is from the menu interface of Oculus devices (Figure 43). The bodiless virtual hand is based on full hand-tracking. The target tile will light up when the virtual finger taps on and bounces back. This operation is ideal in prototype but not in practice. In the tangible experience, the user would merely have visual (visual and sound) feedback. It results in that the tapping motion being often too deep, and it penetrates through the graphics. Despite the technical barrier (e.g., insufficient refresh rate or inaccurate positioning), the flop of this interaction design is because of the misconception from the user, which is the expectation of physical resistances.

Further on, visual metaphors lead the user to unconsciously reckon the tiles are solid and on a solid platform. Hence, it loses its tangibility in the whole experience. When the touch registers, haptic feedback would anchor the user's proprioceptive system on a visceral level (Malaika, 2015) to provide a tangible experience. The route of developing the tangible experience would likely be critically full of twists and turns due to the factors of culture, policy, etc.

Figure 43

Oculus Main Menu Interface Prototype (Guerron & Mitchell, 2017)



To sum up, the following recommendations are displayed:

- *During the transition from the touch screen to spatial computing, consider creating a tangible experience to minimize the unacquaintance of the user in the ways of:*
    - *In the incipient stage, properly referencing (avoiding copying) the real-world analogs for the unprecedented types of interaction;*
    - *Optimizing the interaction for the intangibles in spatial computing;*
    - *Examining and upgrading the eventual interactions in spatial computing independent from the real-world analogs.*

4.3 Design Recommendations for Engagement

Table 4

Prefatory Guide Chart for 4.3

<table>
<tr><td colspan="6" align="center">4.3.1 Engaging Environment
(Recommendations at p. 101 and p. 102)</td></tr>
<tr><th colspan="3">Visible Environment (p. 99)</th><th colspan="3">Invisible Environment (p. 101)</th></tr>
<tr><td colspan="3" align="center">Ways to reduce the physiological errors</td><td colspan="3" align="center">The use of the emotional design theory</td></tr>
<tr><td colspan="6" align="center">4.3.2 The Practical Interactions
(Recommendations at p. 104, pp. 108-109, pp. 111-112, p. 114, and p. 116)</td></tr>
<tr><th>For Surface Components (p. 103)</th><th>For Interface Attachments (p. 104)</th><th>For TUI Objects (p. 105)</th><th colspan="3">For Volumetric Objects (p. 109)</th></tr>
<tr><td rowspan="2" align="center">Lowering the priority of 2D interaction</td><td rowspan="2" align="center">The feasibility and limitations</td><td rowspan="2" align="center">As the current solution and the potential</td><th>Gesture and Posture (p. 109)</th><th>Natural Gestures (p. 112)</th><th>The Features of 3D Interactions (p. 114)</th></tr>
<tr><td align="center">The importance to differentiate them</td><td align="center">The criteria for evaluation and goals</td><td align="center">Object intersections and micro-gestures</td></tr>
</table>

4.3.1 Engaging Environment

Initial recommendation:

- A conversational environment motivates the user to interact.

The environment is the fifth category of spatial UI Design, defined as immobile virtual or physical elements that opt-out from the interaction. Although the environment can be static images in common sense, it has much more verities when applied to the distinct focus of spatial computing. For instance, a VR environment could be a relatively quiet animation to improve the immersion; an AR environment could be a surface or wallpaper only serving to display information; a holography environment could be a colorful warning boundary of a specific area. The environment of interacting is various, but it is suggested to follow a few rules in this section. Another emphasized aspect of the environment in the initial recommendation is the setup for prompt users to interact with objects. It is an immaterial environment but ubiquitous before interaction occurs.

Visible Environment. The first contact point of spatial computing is the user's eyes. The spaciousness determines that the eyes would not be effective enough to gather most of the information. The effectivity of eyes appears different in different depths and different objects. The study from cognitive psychology classified and measured the effectivity of depth cues (Figure 44). The depth cues in the figure indicate some distinct categories for spatial computing. The range of value determines whether the human eyes can recognize the objects. In the environment case, despite the unavoidable categories, it would lower the hierarchical importance of the environment (serves the purpose of opt-outing user's spatial attention) by positioning the objects out of depth cues range. For instance, if the environment content is an animation, the motion in animation should happen outside of thirty meters according to the Motion Parallax data (Figure 44).

Figure 44

Effectivity of Depth Cues (Malaika, 2015)

Effectivity of Depth Cues

(Cutting und Visthon, 1995)

Depth Cue	0-2 m	2-30 m	> 30 m
Occlusion	✓	✓	✓
Relative Size	✓	✓	✓
Accommodation & Convergence	✓		
Motion Parallax	✓	✓	
Stereopsis	✓	✓	
Elevation		✓	✓
Aerial Perspective			✓

Human depth perception in VR is up to fifty percent closer than the depth perception in real-world, but the better the presence of boundary is, the less the error value occurs (Bedenk, 2016). For example, when a representation becomes less abstract and more concrete, it moves along the spectrum of higher expectations for the user. It creates a more significant disconnect when the interaction fails (Malaika, 2015). Except for improving the validity of the environment, creating a space (not requiring a high-fidelity duplication) similar to where the user is at also can help with the accuracy of the user's depth perception (Bruder & Valkov, 2010, p. 7). Besides, particularly in VR, the user's posture, such as sitting or standing, varies the depth perception because of the entire displacement of surroundings.

To sum up, the following recommendations are displayed:

- *Reference the experimental data of effectivity of depth cues (Figure 44) to achieve the disparate purposes of designing an environment for spatial computing.*
- *Consider minimizing the depth perception error between spatial computing and the real world by:*
    - *Increasing the fidelity of the virtual environment;*
    - *Building an acquainting imitation of the user's present environment.*

Invisible Environment. A conversational environment is the motivation of a user's interacting behavior. The motivation is ascribed to the user's eventual emotional reaction., the current interaction design has provided practical tools to prompt this reaction. For instance, the stimulus of the user's empathy can create a high interactivity context (Figure 45). Video games are usually in a high interactivity context; the spatial computing technology would significantly increase the empathy effect of users. In the figure, as a VR character, it will have direct eye contact with the user, and it will dynamically play its role. The real-time moving vision in VR immerses the user more into the scene. Utilizing empathy or emotionality could affect users' essential cognitive functions in conscious and unconscious minds (Gorp & Adams, 2012, p. 26). Hence, the emotional design theory not only applies to the interaction of spatial computing but also gets an effectivity boost due to the immersion advantage. The emotional stimuli can be designed into the objects in the environment, such as a blinking floating window to agitate the user.

Figure 45

Emotional (Empathy) Stimuli (Malaika, 2015)

To sum up, the following recommendations are displayed:

- *Emotional design should be ubiquitous before any interaction occurs.*
- *Consider choosing the types of emotion (e.g., empathy) to serve specific purposes.*
- *Consider ensconcing certain potential emotional stimuli into the objects in spatial computing.*

4.3.2 The Practical Interactions

Initial recommendation:

- Gesture design should be non-verbally congenial and effortless to perform.
- Gestures should balance intuitiveness and consciousness to gain naturality.
- Natural gestures should provide moderate customizability or adaptivity to gain ergonomics.

An intuitional interaction design decision for spatial computing is implementing more gestures than the screen-based platform. Screen-based products inspire the interaction for spatial computing, and the interaction will undoubtedly go further.

The interactions within spatial computing are technically **3D interactions** other than **2D interactions** (multi-touch technology), which is the current mainstream. Multi-touch surface typically registers to touch down, touch move, and touch release events (Steinicke et al., 2014, p. 54). Multi-touch technology has some fingered combinations criticized for the gestures being not natural and not intuitive (Cantuni, 2019). Since the 3D interaction is a dimension upscale, there are multiple mixtures of combinations between 2D interaction and 3D interaction. The different mixtures of interactions can reflect on the five elements in the spatial environment (defined in **Element Taxonomy**): surface components, interface attachments, TUI objects, and volumetric objects.

Practical Interactions for Surface Components. A study suggests that when the screen displays 3D stereoscopic objects, using 2D gestures would cause left or right offset (direction follows the user's dominant eye) (Valkov et al., 2011, p. 10). Also, combining 2D and 3D inputs and visuals is appropriate to assist engineering and art (Steinicke et al., 2014, p. 34). However, the gestures are often challenging to adapt, and sometimes it requires purpose-built accessories (Steinicke et al., 2014, pp. 75-86). However, the experiments built the 2D interactions separately from 3D interfaces in a VR environment in analogy with when illustrators first introduced drawing pen tablets.

The separation is pretty anti-intuitive so that the recommendation is displayed:

- *Avoid registering 2D interactions to manipulate 3D interfaces if they are not occurring on the same surface.*

When the original 2D interactions apply to surface components in different situations, the occasion varies. In the 4.3.2 Tangible Experience section, an initial reveal of the surface component prototype explains that the lack of tactile sense would impact the primary function. A study showed that when the user expects tangible feedbacks, the user has a problem discriminating whether they touched an object or not (Valkov et al., 2010, p. 2). Therefore, surface components in the spatial scenario are often going against the usability of interaction design. From its essential advantage, surface components are more applicable to display information. From its potential, surface components usually were transited to alternative forms – interface attachments or TUI objects (interface attachments or TUI objects are often volumetric and no longer considered as surface components).

Practical Interactions for Interface Attachments. A study showed the user had a low detection threshold of stereoscopic parallax when appending a physical surface as a passive method for providing tangible feedback even while the virtual object was not posited on the physical surface (Valkov et al., 2010, p. 8). Hence, an additional surface would substantially reduce the operation mismatch. This passive method is equivalent to the interaction for interface attachment. For example, the Sony Xperia Touch (Figure 46) is a device capable of projecting a touch interface on any surface and providing multi-touch interaction.

Nevertheless, the product is yet not an upscale of interaction (2D interaction). The product concept is close to the concept of AR – using the interface as a complement to reality. Hence, the interactable interface attachment is an alternative solution for optimizing the interaction of surface component. The uncertainty of interface attachment is the location of the interface. Different textures, weights, or tenacity could cause certain operation inconsistencies; for instance, a coarse plane is a non-ideal surface for touch-and-drag operation. In the Case Study, the hand UI projection (Figure 24) was criticized because the human palm is a non-ideal surface to display information. The irregular surface (palm) would be adverse to the visual representation, visual metaphor, affordance, etc.

Converting a surface component to an interface attachment is an approach to promote the usability of interaction by investing in a physical touch surface. Differing from the previous method, the conversion to TUI objects is potentially another positive approach.

Figure 46

Sony Xperia Touch (Montgomery, 2017)

Practical Interactions for TUI Objects. The pervasive TUI objects are the accessories for operation of 3D objects. There are a variety of gadgets on the market or during development, such as a VR controller, a stylus for 3D interaction (Steinicke et al., 2014, p. 71-74), hand-tracking technology from Leap Motion (Ariza et al., 2016, p. 2), and a glove for simulating tactile feedback (Ariza et al., 2016, pp. 3-7). The gadgets are the TUI input devices (not the objects they interact with) that usually map the finger input to virtual behavior. The standard game console controller default (Figure 47) is mapping the left rocking bar to the character's leg behavior (movement), the right rocking bar to the character's head behavior (eye pointing), and the button to the character's body behavior (actuation). The market has proved for this mapping method (in short, fingertip to behaviors) that the layout is intuitive and natural for the user (Malaika, 2015). The current preferred solution for VR operation is also the controller (Figure 48), and the button layout continued the mapping method and achieved the same functions. There is a vital difference – the controllers separately represent the user's two hands. Alongside the enhancement of intuitiveness, the issues are revealed.

The existing guideline indicates that VR interaction should use continuous controls (Lanier, 2017, p. 235). In the video game, the continuousness of control connects to the experience of immersion. A simple door open actuation would theoretically break down to the continuous actuation of grabbing lever, pushing down lever, releasing and pushing the door instead of traditional one-click. However, in practice, the detailed actuation would cause **simulation fatigue,** especially when the actuation is less meaningful in gameplay than other interactions. On the contrary, when the more relevant and meaningful actuation is continuous, natural, and intuitive, the experience brings satisfaction (Malaika, 2015). Hence, design thinking and numerous evaluations and decisions should be processed and resolved behind the continuous controls.

Figure 47

Break out Input Streams of The Controller (Malaika, 2015)

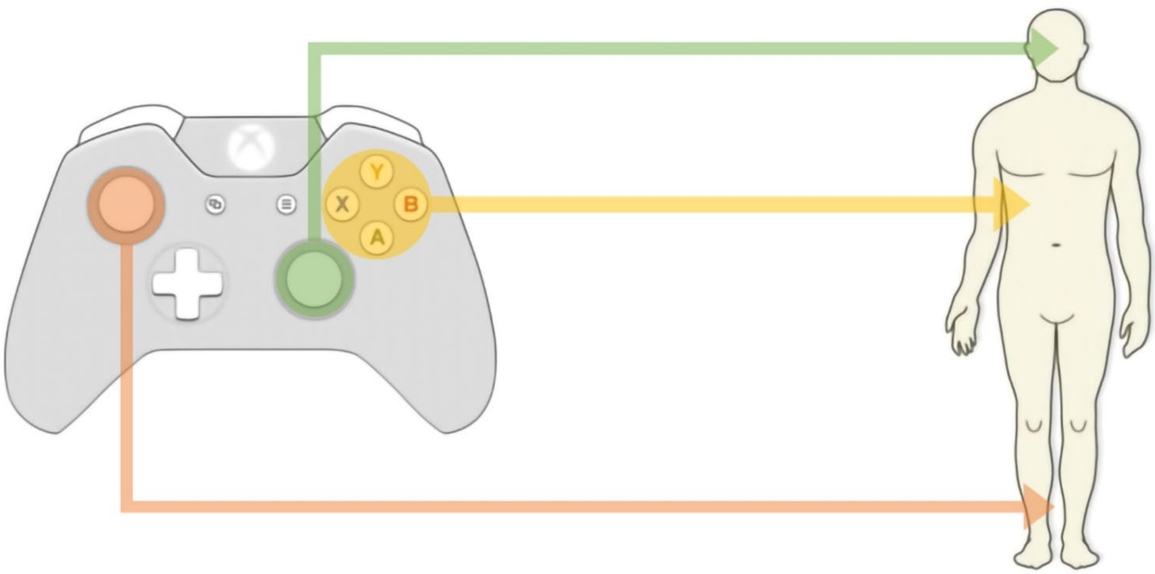


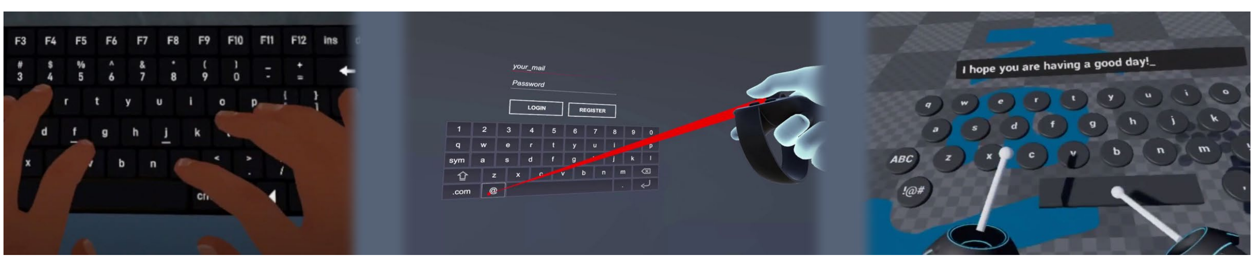
Figure 48

Oculus Rift Controllers (BeachAV8R, 2019)

In UI interaction, the two separated controllers are not precisely defined as two hands. One design decision that causes struggle occurs with the typing experience. The keyboard was nearly represented as a surface component floating in front of the user. There are three developed solutions for typing (Figure 49). First, the (controller simulated) **fingertip typing**, which has a similar issue of penetration and cognition (analyzed in **4.3.2 Tangible Experience**); second, the **laser pointing**, which is accurate but less productive; third, the **drumstick typing**, which has less of a penetration issue and barely a cognition issue. The drumstick typing experience is the most intuitive solution for the controller state because the drumstick has bouncy and vibrant metaphors. The design significantly reduced the penetration cooperating with controller vibration (the penetration still could happen). Even though the drumstick design overcame the common issue, generally, while the controller is phasing out and the proven hand-tracking technology is entering, the traditional typing form would still retain the tangible experience issue. On occasion, **ambient invocation** such as proven voice input technology (Malaika, 2015) would be the preferred solution.

Figure 49

Current Solutions for Typing in VR (from left to right): Full Hand-tracking (Carter, 2020), Laser Pointing (Weelco Inc., 2017), Knocking Sticks (BananaKing, 2017)



To sum up, the TUI object as another alternative possibility for providing better usability for the surface component is a solution that commences visual (and auditory) design orientation.

Alongside the interface attachment that commences haptic (and auditory) design orientation, the sectional recommendations are displayed:

- *Avoid directly adding interactions to surface components, but they are ideal mediums for displaying information.*

- *To provide better usability for interactions in surface components:*
    - *Consider converting surface components to interface attachments;*

      For the interactions of interface attachments (apply to this category):
        - *The dimension of attachments would not affect the user's cognition or interaction;*
        - *Be aware of choosing an appropriate physical surface because the haptic experience varies by factors (e.g., textures, weights, tenacity, etc.).*
    - *Consider converting surface components to TUI objects;*

      For the interactions of TUI objects (apply to this category):
        - *Consider referencing and user testing the intuitiveness and naturality of the input mapping method;*
        - *Consider planning the priority of interactions then designing for correlative needs to avoid simulation fatigue.*
    - *Utilize the knowledge from 4.1 (recommendations for interface) to achieve positive visualization;*
    - *Take advantage of haptic feedback from input devices (e.g., vibration, button damp, and rebounding);*
    - *Consider utilizing ambient invocation (e.g., voice input) as an alternative solution.*

Practical Interactions for Volumetric Objects.

Gesture and Posture. Interactions for volumetric objects are revolutionary with the leap from 2D interaction to 3D interaction. The entire 3D hand gesture design is the most prominent one within the design process. Using the term "gesture" in a generalizing way to describe direct-touch interaction can be problematic (Steinicke et al., 2014, p. 59). In the context of 3D interaction, a touch **gesture**'s definition is: "a way to invoke manipulations in a direct-touch environment that is started by touching the surface in a well-defined initial configuration and that is continued for some time in a well-defined motion pattern" (Wobbrock et al., 2009). A touch **posture**'s definition is: "a way to invoke manipulations in a direct-touch environment that is characterized by touching the surface in a well-defined initial configuration whose effect can be parametrized by a subsequent dynamic action" (Steinicke et al., 2014, p. 56). The difference between gesture and posture is whether the registry object is characterized. The gesture usually requires the user to learn and memorize it, and it registers to a system-defined command (e.g., a tap motion that brings the screen to a new page). The posture usually registers to a dynamic result (e.g., an opening pinch motion that magnifies the object the user orients to). Hence, in 3D interaction, it is essential to differentiate posture and gesture while making diverse design decisions within the design process. Differing from 2D screen-based interaction design, the number of **postures** would increase and take up a dominant position. For example, modern operating systems have girds for snapping on their desktop page to organize icons. However, in the spatial environment of a 3D desktop, users would barely prefer snapping their items to the set-up grid. A cheerful interaction design is exoteric to let the posture happen while providing revocation to an extent (such as teleporting the dropped item back to the user). This continuous interaction design ensures the user anticipation principle and takes advantage of the virtual environment.

The consequences (visual, auditory, sometimes haptic) of postures are easily recognizable since the user usually continuously participates in the whole sequence of interactions. Relatively, the **gestures**, which have system-defined consequences, require user anticipation and a more substantial user autonomy than postures. A more substantial user autonomy reflects on more radical visual, auditory, and, most importantly, haptic representations. Oculus equipped a full hand-tracking sensor to implement hand gestures (Figure 50). In the Figure, the left is the home bottom activation, for which the user should stare at the virtual hand and shut the index finger and thumb for two seconds. The right one is the wrist control center, for which the user should stare at the virtual hand and tap the wrist with another hand to pop out the control panel. These two interactions require a clear command and low error tolerance because they would bring drastic changes to the screen (going back to the homepage and controlling system options). In order to achieve the user autonomy of informing the user that the actuation is undergoing and the actuation has been done, the autonomy gets enhanced in the following ways: one-to-one mapping of the hand motion to the virtual world; rapid and repetitive sound effect; and haptic feedback confirmation between physical contacts (two fingertips touch and wrist tap). In addition, during the animation, the user can cancel the gesture effortlessly (moving finger/hand away), which achieves the better principle of forgiveness (making actions reversible).

Figure 50

Oculus Hand Gesture Confirmation Icon and Wrist Control Panel (Guerron & Mitchell, 2017)

To sum up, the recommendations are displayed:

- *Consider applying different design thinking processes among gestures and postures by:*
    - *Distinguishing the gestures and postures;*

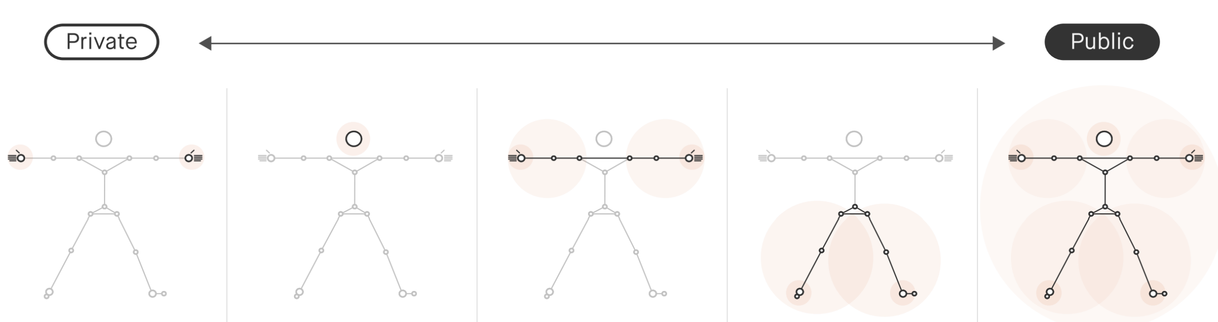
- *For gestures:*
    - *Consider assigning the higher-level function (such as system-level option shortcuts) to gesture;*
    - *Consider enhancing the user autonomy in the ways of:*
        - *Increasing the length of interaction duration for forgiveness;*
        - *Strengthening the sensory feedback, especially for continuous interactions (e.g., volume slider, unlock pattern, and dragging windows). Instances for sensory feedback: designing iridescent visual representation, remarkable sound engineering, and haptic feedback from body part contact.*
- *For postures:*
    - *Consider providing greater freedom of consequences than 2D interaction;*
    - *Take advantage of the virtual environment, such as implementing object teleportation to obtain certain conveniences.*

Natural Gestures. A user-driven gesture principle (McAweeney et al., 2018, pp. 554-555) listed five aspects of gesture design analysis: Time, Position, Posture, Motion, and Touch. The factor naming has a setting disparity with 3D interaction terms of gesture and posture. Thus, for refinement of the term, the five aspects of **gesture/posture design** in 3D interaction: **time**, illustrates the sequence of motion and pattern; **position**, stop or ending points relative to the rest of the body; **pattern**, the shape of the hand to enact the gesture/posture; **motion**, the medium from pattern to pattern; **touch**, (both tangible and intangible) touchpoints that trigger the output. Each of the factors covers one entire user-driven gesture for optimizing the experience.

In the scenario of non-verbal communication, the gesture/posture was framed in two types: informative and communicative (Abner et al., 2015, p. 2). **Informative gestures** provide passive non-semantic information (Krauss et al., 1996, p. 21). **Communicative gestures** are conversational gestures relevant to the user (Krauss et al., 1996, p. 5). Figure 51 shows a chart of gesture usage of the body parts in different privacy levels (Huh, 2020, p. 39). Most of the gestures tend to be more private due to the commands that should be effortless to perform; most postures tend to be more public since the design consideration of postures is trying to provide the user with much freedom. A concept of **natural gesture** was pursued as a guideline for modern digital device gesture design. The natural gesture represents the effortless operation, non-verbal context, lack of cultural limits, simple performance, intuitive discoverability, and easy memorization (Cantuni, 2019). The analysis in **Insight of Engagement** (the VISION AVTR's hand UI projection (Figure 24) addresses well the criteria of natural gesture. For 3D interactions, there is value for extraordinary experiences to emphasize (but not overwhelm the user), even sacrificing partial effortlessness (Dauchot, 2018). Based on the non-verbal purpose, the body part usage, the requirements of natural gesture, and the 3D interaction user experience, the gesture/posture design is defined as communicative gestures/postures that will mainly involve the hands cooperating with fewer arms and the head to efficiently control the spatial UI in daily usage (not game interaction).

Figure 51

Privacy Level of Gesture (Huh, 2020, p. 39)



To sum up, the following recommendations are displayed:

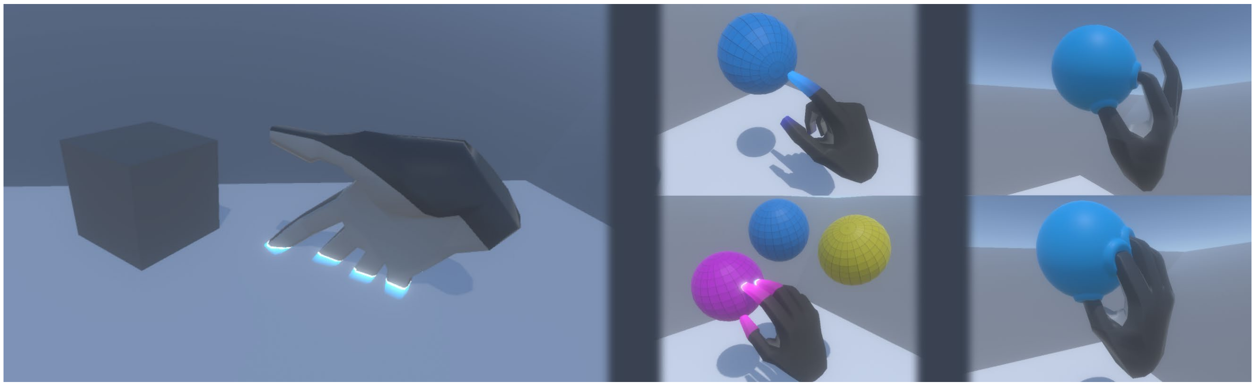
- *Refine the gesture/posture design by evaluating factors: Time, Position, Pattern, Motion, and Touch.*
- *An intact gesture should be communicative instead of informative.*
- *Consider utilizing the wisdom of natural gesture precepts.*

The Features of 3D Interactions. Initially, controller solution is compromised before hand-tracking technology became proven, but controller technology has its prospect. When there is no accessory, the portability becomes ultimate in user experience. In this section, the analysis is the leap from accessories to the user's body parts. The research subjects of practical interactions mainly apply to volumetric objects (including volumetric UI components) with the user's gestures and postures.

Interaction-wise, most volumetric objects have the following basic properties: weightless, penetrable, and unable to reflex real force. It is feasible to define the weight, substance, or applying force in a no physical interaction simulation. However, when the interaction happens, the feint of simulation would be exposed instantly. Therefore, in the interaction stage, the virtual interaction design should inevitably have its particularity to differentiate from real-world interaction. Experiments from Leap Motion suggest three visual ways to embrace the basic properties (Figure 52): based on the consideration of acknowledging the intersection and penetration, first, intersection highlights; second, gradient color indicators; third, dimple contacts (Schubert & Fox, 2017). The intersection also helps the recognition of command. There are always moveable and immovable items in a virtual scene. The visualization of intersection can suggest to both users and designers if the command is moving an object or if the object is moveable. Through innovating the interaction beyond the real-world analogy, the philosophy could also apply to other categories of spatial elements for 3D interaction.

Figure 52

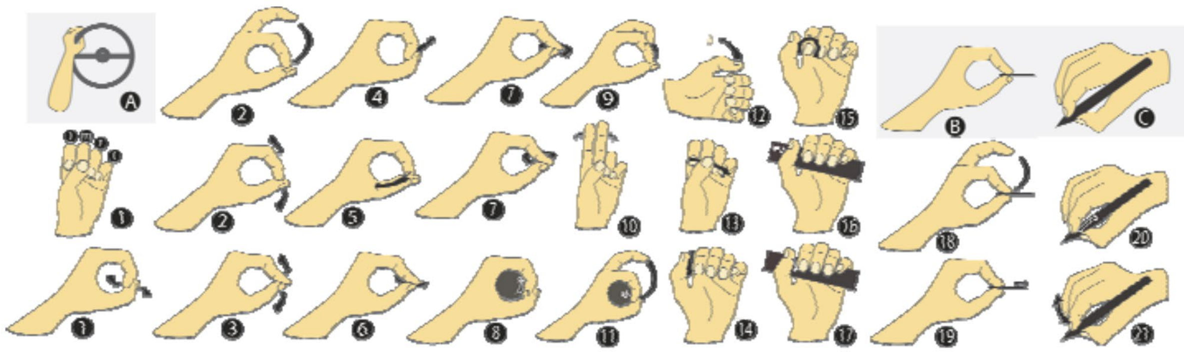
Acknowledge The Intersection Properties (Schubert & Fox, 2017)



The impact from subconsciousness to interaction is commonly named micro-interactions. The micro-gestures are an essential part of micro-interactions. For the same gestural task, a large variety of micro-interactions (Figure 53) have a high risk of being performed unintentionally during the primary task (Wolf et al., 1970, p. 572). In 3D interactions, the micro-interactions would become more pronounced and affect the gesture/posture recognition, learnability, and responsiveness. Study shows that the interaction design should, by virtue of micro-interactions, fine-tuning the immersive experience (Malaika, 2015).

Figure 53

Micro-gestures for Several Types of Interactions (Wolf et al., 1970, p. 565)



To sum up, the following recommendations are displayed:

- *Acknowledge the intersection in virtual 3D interaction in the ways of:*
    - *Allowing the intersection of virtual body parts and objects;*
    - *Reflecting the intersections in sensory feedback to the user (triggering sight, hearing, or touching to build exclusive proprioception in spatial computing).*
- *Be aware of the unintentional micro-interactions and ensure learnability and responsiveness.*

4.4 Summary

In Chapter Four, this research conducted recommendations for the visual representation, embodiment, and engagement in the spatial environment to assist designers, engineers, and developers in obtaining a better vision of spatial computing platforms. This research gathered precepts from experience summed up by design analysis and predecessors. In the next chapter, the recommendations will apply to practical spatial interface prototypes to illustrate the positive considerations from previous recommendations.

Chapter Five

Applications

The applications in spatial computing technology relatively obtain more freedom for designing interaction than traditional graphic design. When the various demands are proposed, the user experience design varies, such as the different interaction focuses between video games and productivity tools. Video gaming is a diverse category to design interaction, so part of the recommendations from Chapter Four would apply, but often it preferentially serves the immersion, marketing, artistry, etc. In the fifth chapter, the applications would prioritize the factor of user experience for the fundamental spatial user interface.

The applications would be a software demonstration of previous recommendations (the sequence may vary). The demonstration would modularly present in the scenario of Virtual Reality due to currently the Virtual Reality being relatively more accessible and recipient than other Extended Reality platforms. The application is a possible visualization of the recommendations, which could always vary with the design proposal.

The demonstration proposal is based on the VR platform: the physical setup is a furnished bedroom. The user is sitting on a chair that is in the center of the bedroom with VR gear activated and intending to interact with the virtual interfaces, including quick setting, dashboard, body, image, object, etc. The following content on the VR platform would continue to use this basic user scenario.

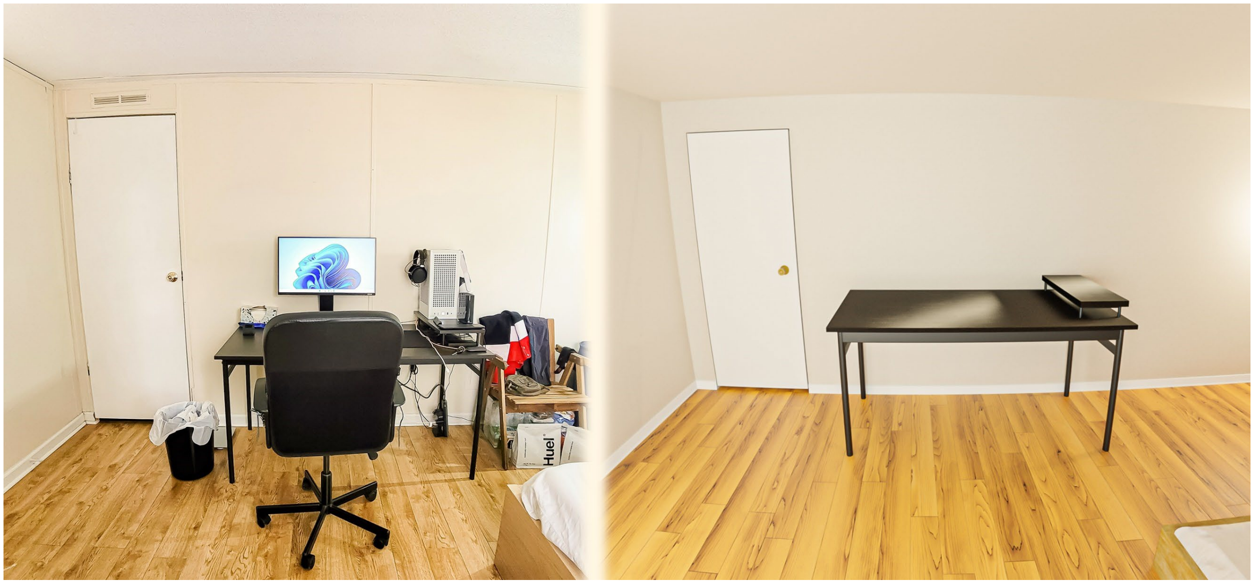
Meanwhile, to ensure the demonstration segments logically apply to the user, the user has no noticeable location shift during the interaction. The user has hypothetically learned the commands given by the designer. The user is familiar with the implemented visual, auditory, or haptic elements. The user is a sane person. The hardware and software of the VR and AR devices are already seamlessly blended into the user's life.

5.1 Application: Environment Setup

According to the recommendations from **Visible Environment**, an environment with less misposition and confusion requires higher fidelity or familiar surroundings. Combined with the recommendations from **2D and 3D Mediums** – restoring realistic physical properties, this demonstration would ensure the object's fidelity with high-resolution texture maps, similar lighting conditions, and choosing essential furniture (usually immovable) for cognization among real-world furniture (e.g., table, chair, cabinet, and door). In addition, the imitated appliances usually match the effectivity of depth cues (Figure 44) since they are sampled from the real world. The demonstration (Figure 54) addresses the side-by-side comparison of the physical environment and virtual environment. The realistic virtual ectype of the real-world environment would run through the entire demonstration in VR, and further scenes would considerably apply the recommendations from **2D and 3D Mediums**. Also, a static environment could prevent drastic background change, which would cause a loss of spatial attention, referring to the recommendations in the **Foreshortening Effect**.

Figure 54

Visible Environment Side-by-side Comparison



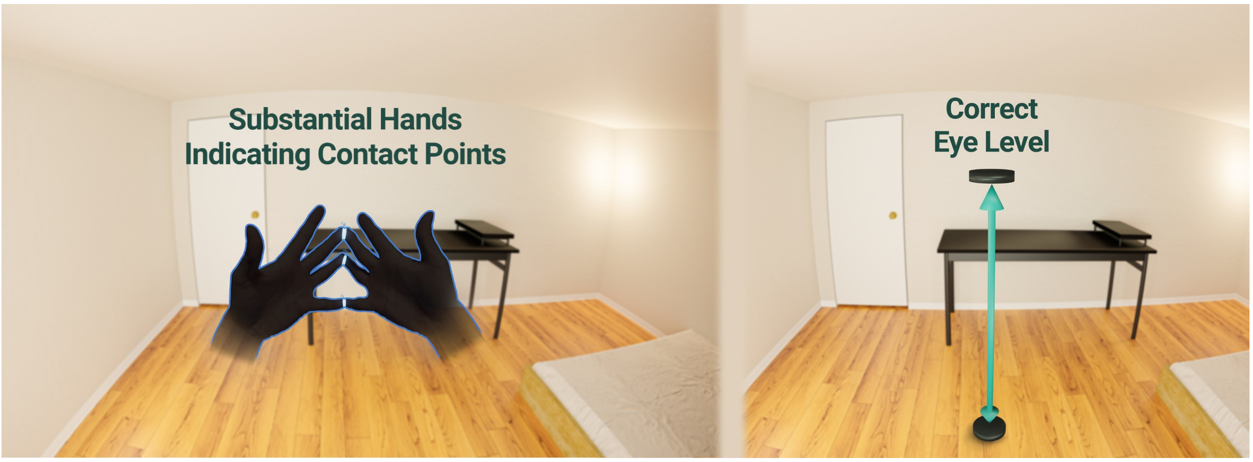
Note. the left side is a photograph taken by a smartphone camera; the right side is a rendering scene produced by Blender. The rendering scene minimized the flaws in texture from real-world reference and restored the material as accurately as possible.

5.2 Application: User Status Preset

According to the recommendations from **Sensory Integration**, the correction of proprioception significantly impacts the user's experience. The positive influence can be executed by mapping the exact motion of hands, head, and eyes to the virtual world. Within the same recommendations, the design should avoid ocular-vestibular mismatch (usually caused by unnatural or non-sense phenomena such as tunneling body part models). Combining conditions above, the hands should be substantial and allow collision (Figure 55); the head (eye level) should be posited to a correct height based on the real world (Figure 55); the virtual vision of the user should track and implement the correct foreshortening effects (approximately 55 mm focal length).

Figure 55

Hand Tracking and Correct Eye Level



Note. on the left side is a pair of virtual hands sampled from the photograph. The abruption between arm and hand was eased out to reduce the ocular-vestibular mismatch. The hands reserved a slight texture from real hands; the right side of eye level should be variable depending on the user's status (sitting, standing, crutching, etc.).

5.3 Application: 3D Interactions

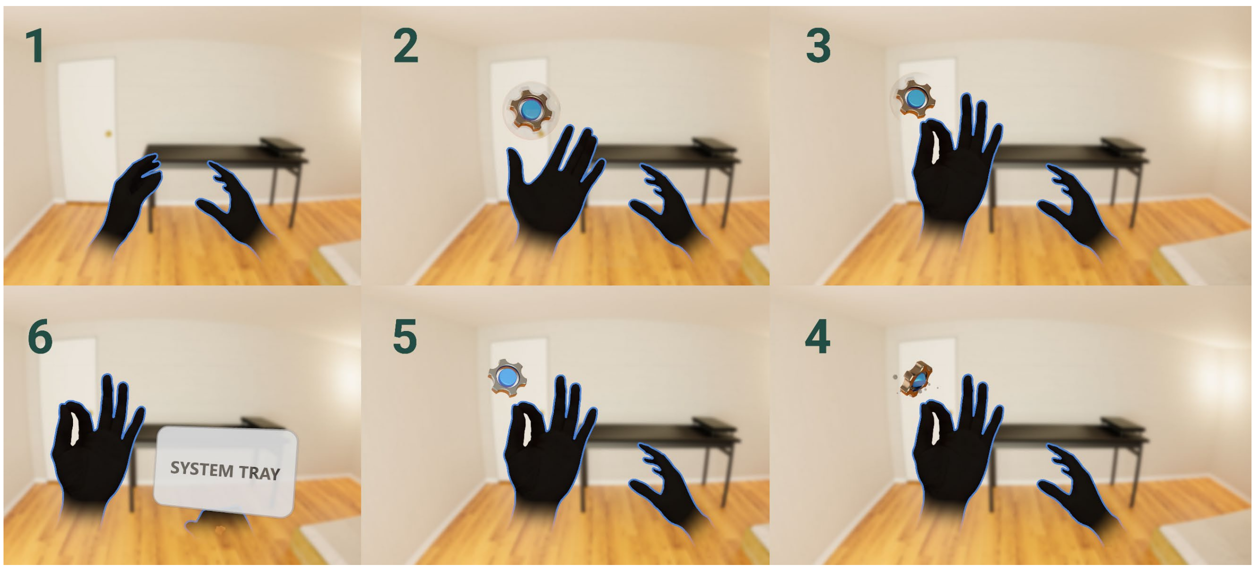
According to the recommendations from **Gesture and Posture**, there are significant differences between gesture and posture. The following content would separately demonstrate gestures and postures.

5.3.1 Application: Gestures

For **gestures**, the motion sequence of hands is defined, and they are usually assigned to higher-level functions. The following demonstration would design a gesture to trigger the system control panel from the side of the wrist. The gesture would need to create buffer time and haptic feedback for operation confirmation. The system should allow the user to customize the awake gesture to achieve the factor of personality in emotional design theory. This research would choose an enclosing of thumb and index finger while moving towards a floating setting icon (within a fragile bubble) for command recognition. The fragile bubble connects to the recommendations from **The Use of Metaphors and Visual Hierarchy Principle**. The gesture (Figure 56) requires the palm to face the user's vision first, then utilize a non-linear, ease-in, and enlarging animation to awake the control panel. In addition, according to the **Sensory Integration**, to avoid ocular-vestibular mismatch, any visual mapping or animation should not take root from the user's body part. Thus, the control panel should appear in the air beside the hand.

Figure 56

Gestures



Note: with the serial number, the images are the sequence of gestures: the setting icon is contained in a transparent bubble which indicates the metaphor of frangibility; having a waiting animation lengthens the confirmation time for the user to cancel the command anytime.

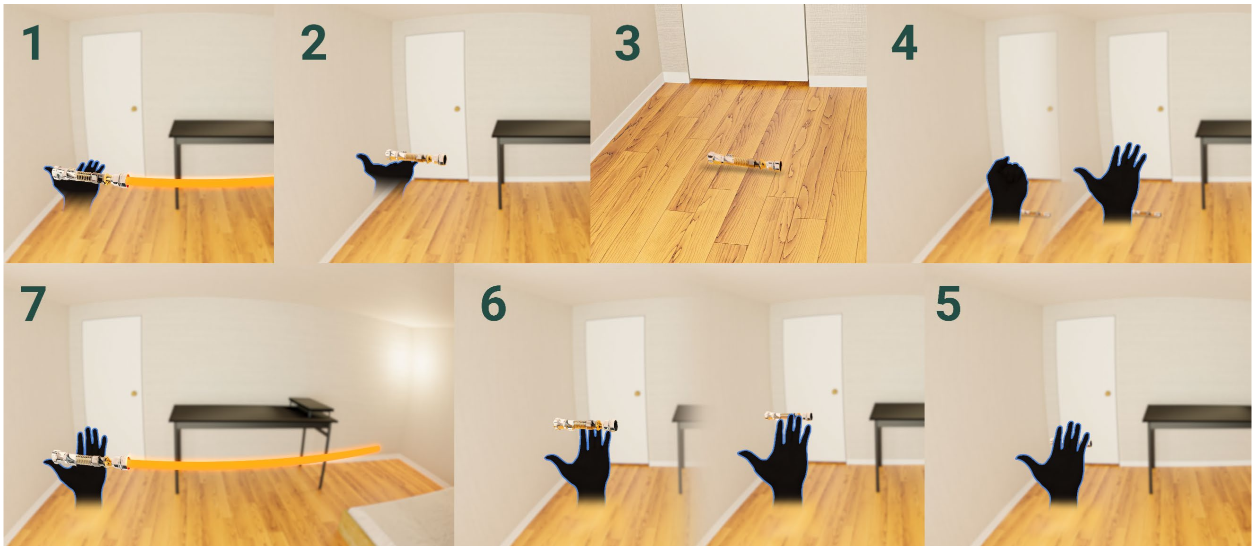
In Figure 56, this is one possible way to associate with the recommendations. The bubble could be replaced with anything that hints at a message of moving toward it (e.g., a flying bird finding landing space or a "hit me" text). The pinch gesture could be replaced with any hand sign if it gives tactile feedback from the user's body parts.

5.3.2 Application: Postures

For **postures**, the motion sequence and consequence are free to perform. The active motion (in this case, throwing motion) is a sequence of command inputs and, regardless of the outcome, is defined as posture (Figure 57). However, the recalling motion (enclose and open) is a gesture with a specific outcome. The gestures and postures usually were presented as mixed. According to the recommendations, based on the present model, the gesture/posture design should take advantage of the character of the virtual world. This demonstration would utilize the freedom of teleportation to resolve the accidental drop of the passive object (Figure 57). Also, according to the recommendations from **Invisible Environment**, it is suitable to ensconce some reward stimuli by animating with the teleportation function (in this case, the deactivation and activation of light blade) (Figure 57). Combining with the recommendations from **The Features of 3D Interactions**, interacting with a virtually substantial object is a typical example of posture. Also, taking the wisdom from the experiment of Leap Motion (Figure 52), distinguishing the intersection between active motions (user's hands approaching) and passive objects should be more diverse, cognizable, bidirectional, and ubiquitous. The posture could visualize the intersection in the way of contacting a floating display (system tray) (Figure 58); another situation is interacting with a moveable object (Figure 52).

Figure 57

Postures, Teleportation and Emotional Stimuli

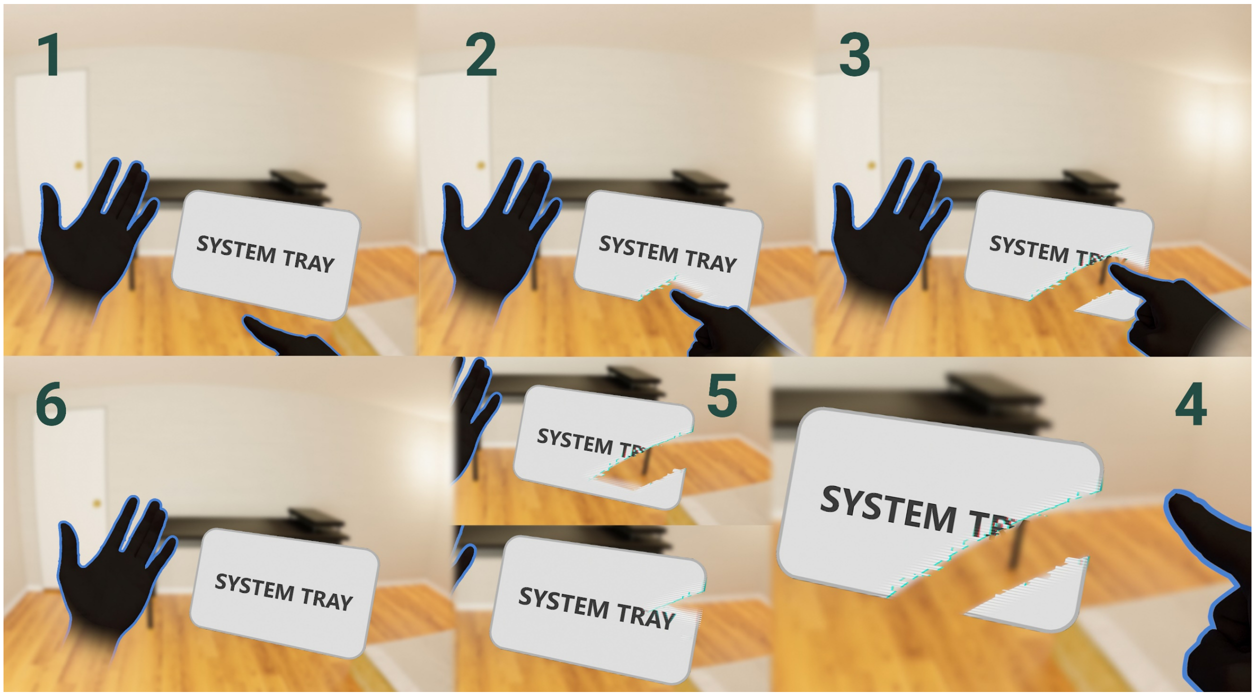


Note: with the serial number, the image presents a sequence of throwing lightsaber away (posture) and recall motion (gesture) with the activation of the blade as a visual stimulus. The saber restores the physical property of metallicity (handle) and emission (blade), referred from the *Star Wars* movie and prototypes. The recall animation referred to the Power of *Force* from the movies as well to gain engagement.

In Figure 57, the recall gesture could be any user-defined and unique gesture, and the teleportation animation could be any instant teleportation (e.g., disappearing, lightning effect, then appearing). The emotional stimuli could have more variety, such as a checkmark or a line of texts.

Figure 58

Object Intersections



Note: with the serial number, the image presented a swipe posture and addressed a contact between the floating interface and the user's virtual finger. The glitchy effect gave the metaphor that this object is designed not to be penetrated.

In Figure 58, the transparent intersection informs users not to penetrate the interface, but the visualization of contact points could have more varieties. For instance, the effect could be emission light or iridescent waves (Figure 59).

Figure 59

Intersection visualization examples

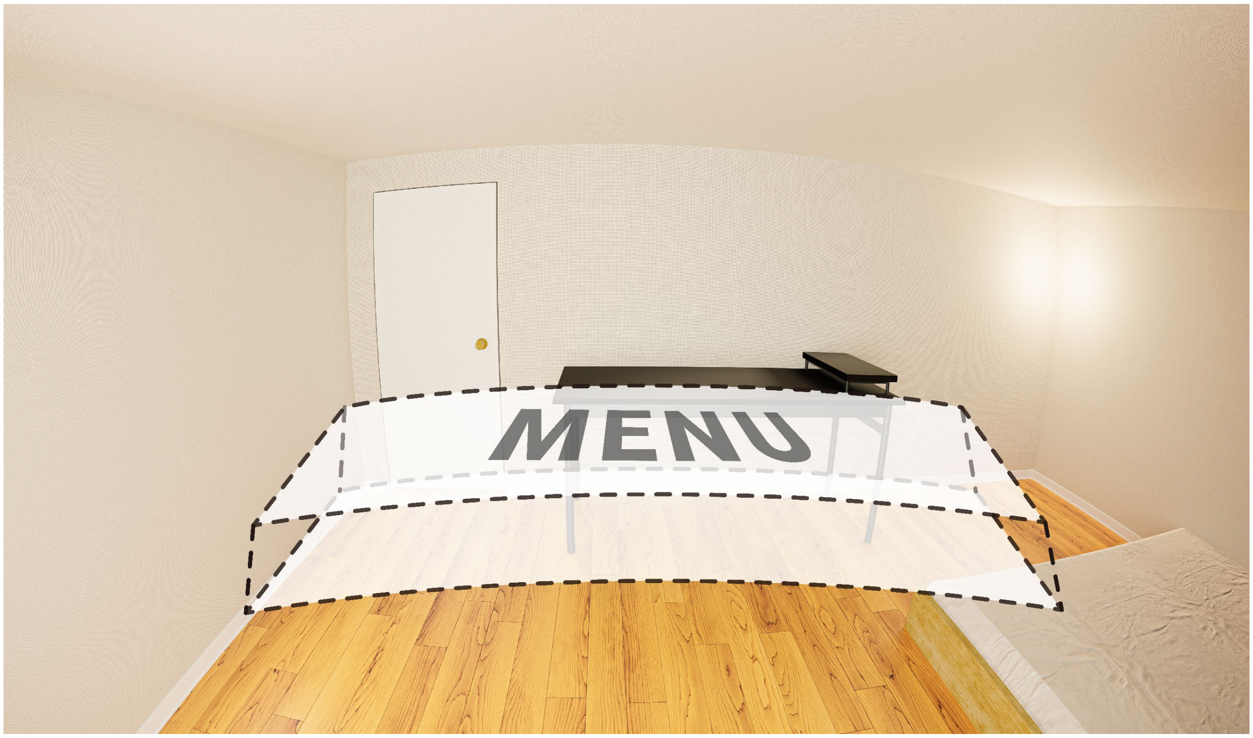
5.4 Application: Spatial User Interface Design

5.4.1 Application: Hick's Law and Fitts's Law

According to the recommendations from **Hick's Law and Fitts's Law**, the Spatial UI would need an initial frame to posit the interface with a background that has no drastic variation. Also, the frame should stay in the user's spatial attention and arrange each distance of components ergonomically (Figure 60).

Figure 60

Interface Wireframe



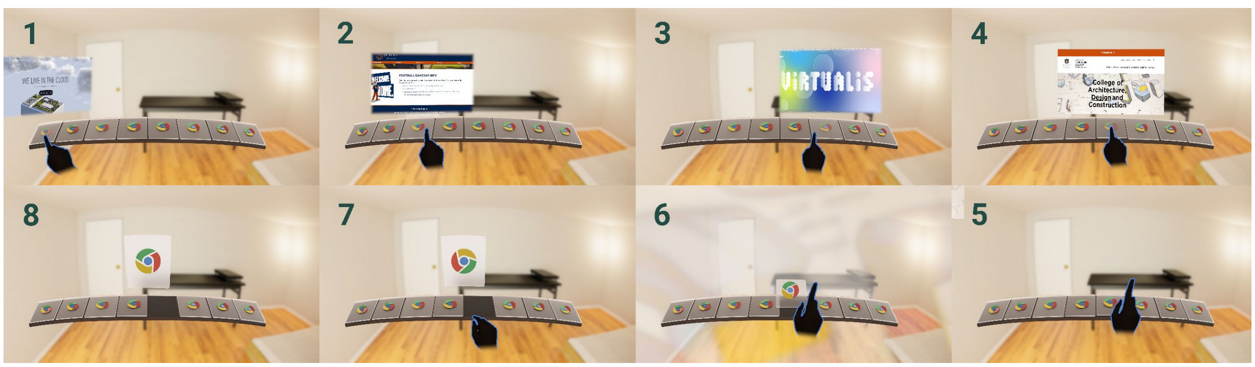
Note: the frame is a spatial space.

5.4.2 Application: Cognition Improvements

Top-Down Method. According to the recommendations from **Cognitive Psychology**, a Top-Down method (Figure 34) is the best scenario to perform a cognitive task once. The virtual 3D interface obtains an advantage compared to the 2D graphic interface, referencing the recommendations from **2D and 3D Mediums** and the experiment in Figure 33. First, the user would achieve a better recognition with items with 3D shapes than icons with 2D shapes; second, when an item in 3D shape acquires detailed physical properties (e.g., specularity, roughness, etc.), the metaphors that prompt the user with instant and conclusive hints would further enhance the recognition; third, the cognitive task meets the conditions of the Top-Down method. This research would apply a touchable texture in common sense (plastic matte black finish) to the dashboard of the main menu (Figure 61). For the application shortcuts, the icons are already formed with the visual hints in the Top-Down method. An optional step further is a preview window for the highlighted application (Figure 61). The preview window (no thickness) is designed only for displaying information referring to the recommendations for **Surface Components**. Also, the dashboard design is a step-further assumption of Figure 43, which indicates the recommendations in **The Tangible Experience**, designing beyond the real-world interaction.

Figure 61

Dashboard Design

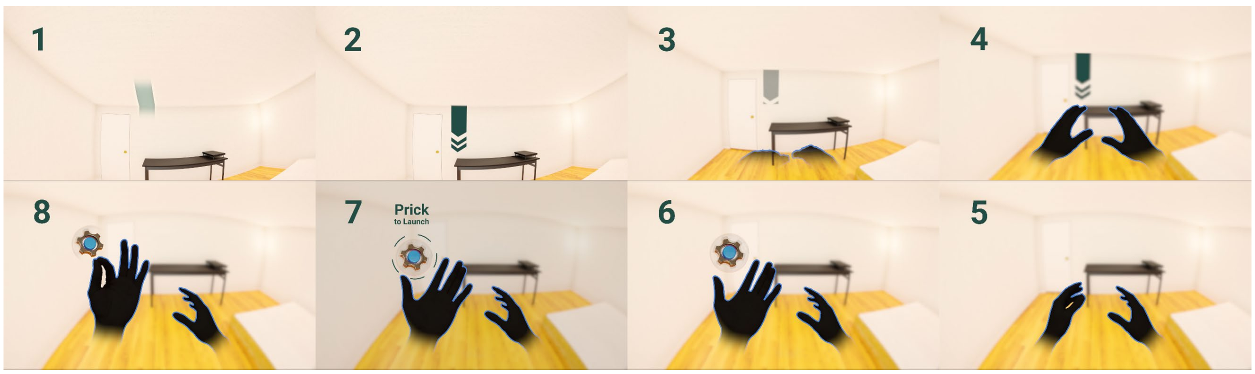


Note: while the finger is pointing towards the tail, there will be a slight lift-up animation for the target until a launch gesture (swiping the finger up) for further control.

Bottom-Up Method. With an unacquainted cognitive task, the Bottom-Up method (Figure 34) is usually the solution. The Bottom-Up method requires more steps to build up a correct cognition. The sequence of steps usually works as a tutorial in the digital system. The following content would suggest a complete sequence of Bottom-Up methods from *Stimulation through Environment* to *Sensation* to *Perceptual Organization* to *Recognition* (Figure 62) to accomplish the tutorial for triggering the system control panel from the side of the palm (from **Application: Gestures**). Also, according to the recommendations from **Cognitive Psychology**, the tutorial should be designed for only showing up till the user memorizes (usually once). This sequence of gestures should bound a metaphor (e.g., icon, symbol, notification) to turn this Bottom-Up method into a Top-Down method. In this case, the floating animated icon and bubble (Figure 63). Besides the demonstrated visualization, the visual stimulation technique has numerous other examples in the 2D graphic design domain for reference.

Figure 62

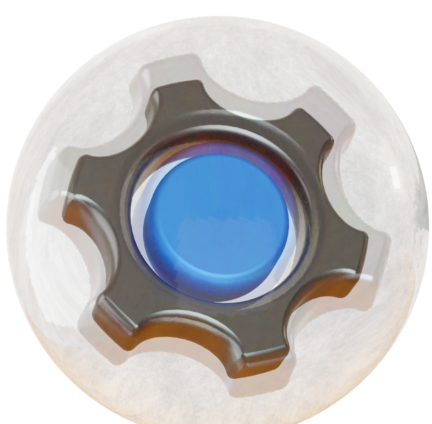
The Build of Bottom-Up Method



Note: with the serial number, from one to four, the demonstration uses a view instruction as *Stimulation through Environment*; from five to eight, the visual *sensation* of words and the touch *sensation* intention send the information of "pricking the bubble" to the user's *Perceptual Organization*; finally, the *Recognition* is defined and becomes reusable.

Figure 63

Indicators of Learned Gestures



Note: the icon has its affordance to represent the meaning of setting/opinion/system; the bubble secures the icon's metaphor of touching/pricking.

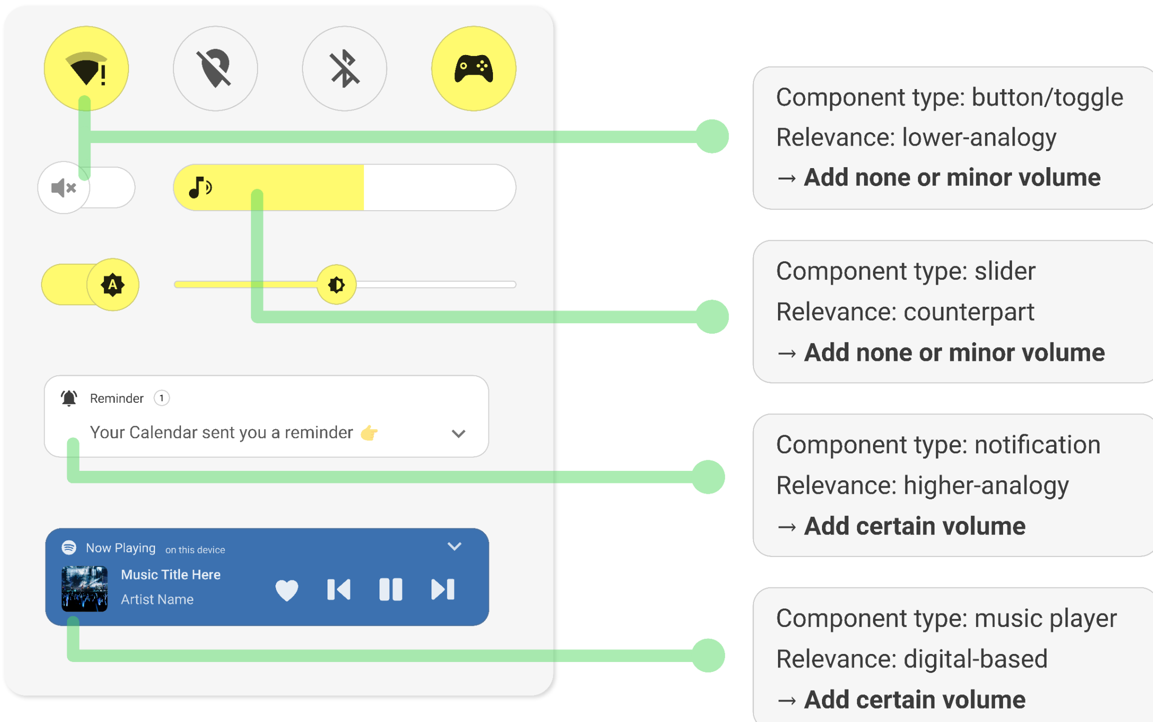
5.4.3 Application: Components

According to the recommendations from **Volumetric Change Decision**, the design decision about the 3D volume of components would vary in a specific range of considerations. The brand, marketing, use scenario, user group would possibly change the outcome. In the current scenario, this research would address the design of UI components within the control panels from the previous build. The previous palm system control panel has established the wireframe for UI components. According to the recommendations, the UI component's volumetric conversion is based on the relevance of their real-world reference (Table 2). The following content would address the design decisions of each component with similar procedures. First, defining the type of the component by referencing Table 2; second, evaluating the influence of avoiding/adding volume to the original interaction (e.g., dragging, tapping, etc.); third, (according to the recommendations from **The Tangible Experience for Spatial Computing**) prototyping the initial interaction of the component to its analogy (if it has one) or reinventing the interaction (if not); fourth, user-testing and improving the interactions. In the fourth procedure, the interactions usually are gestures/postures. However, sometimes the ambient invocation (e.g., voice input) can be the ideal solution (according to **Practical Interactions for TUI Objects**).

This demonstration would conclude the volumetric decision of button, slider, notification, and music player components. The analysis result of components (Figure 64) decides to add minor volume to the button and slider (Figure 65). The minor volumetric button and slider increase the cognition, and the result could vary with the design style, target user, scenario, etc. For notification and music player, the representation of volume can reflect on the utilization of space. According to the recommendations in **Practical Interactions for Interface Attachments**, the notification and music player would be implemented into the AR scenario (Figure 66).

Figure 64

Analysis of 2D Components



Note: the flat design of the system panel is built referencing the screen-based device operating system. The analysis investigated what types of components they are then started with the result to prototype. When the type is vague or contains multiple types (in this case, the music player has lower-analogy (buttons) and digital-based components, but overall, it could be digital-based components), the volumetric change decision might take effect on partial visualization.

Figure 65

Minor Volumetric Change of Button and Slider

Note: the minor volume that is added to the button and slider is the depth information. The button is designed for one-click but not the structure of multi-clicks in the spatial environment because it could cause cognitive issues because it is not technically tangible. The same idea applies to the slider. In addition, usually, they are not designed to be controlled by touching or pushing postures but aerial gestures to activation.

Figure 66

Visualization of Notification and Music Player

Note: the AR scenario is in front of a dresser, and the user gets a message while playing music. The notification visualization designs the volume to sender as emotional stimuli and keeps the text field flat and readable, appending to the clean wall. The music player appends on the surfaces of the cabinet and wall. The volumetric change of the music player takes advantage of the spatial environment to display information (in this case, displaying lyrics and playlists simultaneously). The message or music player controls are not on the surface but should hand over the controls to gesture/posture designs.

5.5 Summary

The application chapter modularly applies the recommendations to VR and AR scenarios to explain and visualize. In general, the recommendations could prompt designers with multiple design works. The applications are part of possible visualizations from the author's perception.

Chapter Six

Conclusion

6.1 Summary

This thesis aims to conduct recommendations to assist designers and developers. The recommendations would help practitioners design user interface, interaction, and tangible experience in the spatial computing environment (currently the Extended Reality platform) in the near future when the technologies are refined. The recommendations are step-further assumptions that are extensive, suggested with literature, case studies, and experiments support. The applications are the explanation and one of the possible visualizations for recommendations. The suggestive, broad scope context of recommendations opens the possibility of design works. However, in a certain way, if designers or developers fail to match the criteria in recommendations during the design procedures, users would feel discomfort in the virtual world, interact without engagement, or have error marks in their minds. In other words, the recommendations could help designers and developers implement functions in the virtual world because the consistent goal throughout this thesis is achieving a better user experience in the spatial computing environment.

6.2 Limitations and Future Studies

The recommendations in this thesis are built on the prediction of future technologies. The future is technically uncertain, and the recommendations would not ensure whether there would be critical uncertain factors that drastically change the technology, business, or design industry.

The applications provide a visual representation of the recommendations that could be applied. However, the design outcomes could vary on different occasions, such as platforms, design purposes, target users, etc.

The future studies would mainly be the development of computing technology. The future refreshing of computing technology could provide a better vision for designers and better implementation for design concepts. The recommendations could be expended, refined, or augmented to achieve different design purposes, such as focusing on accessibility for the disabled. Finally, the eventual design goal for designers and developers is consistent with achieving an exceptional user experience.

Reference

A&D. (2020, January 7). MERCEDES-BENZ AVTR, FOUR-WHEELED AVATAR. *Auto&Design*. https://autodesignmagazine.com/en/2020/01/mercedes-benz-avtr-four-wheeled-avatar/

Abner, N., Cooperrider, K., & Goldin-Meadow, S. (2015). Gesture for Linguists: A Handy Primer. *Language and Linguistics Compass*, *9*(11), 437–451. https://doi.org/10.1111/lnc3.12168

Alger, M. (2020, February 7). *XR Design Theory and Practice for Digital Eyewear*. https://www.youtube.com/watch?v=4o__z7aPlMw

Anton-Erxleben, K., & Carrasco, M. (2013). Attentional enhancement of spatial resolution: Linking behavioural and neurophysiological evidence. *Nature Reviews Neuroscience*, *14*(3), 188–200. https://doi.org/10.1038/nrn3443

Ariza, O., Freiwald, J., Laage, N., Feist, M., Salloum, M., Bruder, G., & Steinicke, F. (2016). Inducing Body-Transfer Illusions in VR by Providing Brief Phases of Visual-Tactile Stimulation. *Proceedings of the 2016 Symposium on Spatial User Interaction*, 61–68. https://doi.org/10.1145/2983310.2985760

Babich, N. (2016, December 1). Best Practices for Microinteractions. *Medium*. https://uxplanet.org/best-practices-for-microinteractions-9456211aeed0

BananaKing. (2017, April 18). *VR Virtual Keyboards in Blueprints—UE Marketplace*. Unreal Engine. https://www.unrealengine.com/marketplace/en-US/product/vr-virtual-keyboard

Bank, C. (2015, January 7). *Understanding Web UI Elements & Principles*. https://www.awwwards.com/understanding-web-ui-elements-principles.html

Banks, N. (2020, July 10). *Mercedes Design Chief Gorden Wagener Would Like To Make The Marque The Most Loved Lifestyle Brand. This Is How* [Interview].

https://www.forbes.com/sites/nargessbanks/2020/07/10/mercedes-design-director-gorden-wagener/

Batchu, V. (2019, April 30). How gestures are shaping the future of UX. *Medium*. https://uxdesign.cc/how-gestures-are-shaping-the-future-of-ux-ce2c9e6d7a9f

Batoufflet, M. (2019, July 1). Why Cognitive Science is a powerful tool for good UX. *Medium*. https://medium.com/@MBatoufflet/why-cognitive-science-is-a-powerful-tool-for-good-ux-1f60df2bff04

BeachAV8R. (2019, May 1). *VR News—Hardware & Tech Questions* [May '19]. Mudspike Forums. https://forums.mudspike.com/t/vr-news/1457?page=60

Bedenk, T. (2016, April 10). *Cognitive Psychology of Virtual Reality: Basics, Problems and Tips*. https://www.gdcvault.com/play/1023656/Cognitive-Psychology-of-Virtual-Reality

Billinghurst, M., Grasset, R., & Looser, J. (2005). Designing augmented reality interfaces. *ACM SIGGRAPH Computer Graphics*, *39*, 17–22. https://doi.org/10.1145/1057792.1057803

Bowers, M. (2019). *The Power of Touch – The Evolution of Button Design (with Infographic)*. https://www.toptal.com/designers/ui/button-design

Boyle, A. (2013, November 1). Smashing UX Design: Foundations for Designing Online User Experiences. *Technical Communication*, *60*(4), 329.

Bradley, S. (2014, March 29). Design Principles: Visual Perception And The Principles Of Gestalt. *Smashing Magazine*. https://www.smashingmagazine.com/2014/03/design-principles-visual-perception-and-the-principles-of-gestalt/

Brown, A. (2010). Gesture Viewpoint in Japanese and English: Cross-Linguistic Interactions between Two Languages in One Speaker. In M. Gullberg & K. de Bot (Eds.), *119304* (Vol.

1–viii, 139, pp. 113–133). John Benjamins Publishing Company. https://doi.org/10.1075/bct.28.08bro

Brown, M., & Longanecker, C. (2013, May 29). How to Design for the Gut. *UX Magazine*. https://uxmag.com/articles/how-to-design-for-the-gut

Bruder, G., & Valkov, D. (2010). *Augmented Virtual Studio for Architectural Exploration*.

Cantuni, R. (2019, September 3). Natural gestures are the best gestures. *Medium*. https://uxdesign.cc/natural-gestures-are-the-best-gestures-990e2ca3d3b6

Cao, J. (2015, May 21). Why Attraction Matters for Interaction Design. *Why Attraction Matters for Interaction Design*. https://www.awwwards.com/why-attraction-matters-for-interaction-design.html

Carter, R. (2020, December 11). Immersed Introduces Virtual Keyboard Overlay. *XR Today*. https://www.xrtoday.com/virtual-reality/immersed-introduces-virtual-keyboard-overlay/

Convergent thinking. (2020). In *Wikipedia*. https://en.wikipedia.org/w/index.php?title=Convergent_thinking&oldid=993308276

Cue, H. (2020, April 15). 4 Cognitive Psychology Tricks for UX Design Excellence. *Studio by UXPin*. https://www.uxpin.com/studio/blog/cognitive-psychology-for-ux-design/

Dam, R. F. (2021, January). The MAYA Principle: Design for the Future, but Balance it with Your Users' Present. *The Interaction Design Foundation*. https://www.interaction-design.org/literature/article/design-for-the-future-but-balance-it-with-your-users-present

Daniels, A. (2020). *Social Network for Programmers and Developers*. https://morioh.com/p/2d9b259a656a

Darvall, A. (2020, January 6). *This Mercedes can drive sideways | AVTR* (G. Wagener, Interviewer) [Interview]. https://www.youtube.com/watch?v=4A62mpfAJMo

Dauchot, N. (2018, June 8). The User Experience of Virtual Reality. *UXXR*. https://medium.com/uxxr/the-user-experience-of-virtual-reality-c464762deb8e

Davidson, P. (2020, January 7). *Mercedes-Benz VISION AVTR Inspired by AVATAR | eMercedesBenz*. https://emercedesbenz.com/autos/mercedes-benz/concept-vehicles/mercedes-benz-vision-avtr-inspired-by-avatar/

DeepAI. (2019). Artificial Intelligence. *DeepAI*. https://deepai.org/machine-learning-glossary-and-terms/artificial-intelligence

Designboom. (2020, January 7). Avatar-inspired mercedes-benz VISION AVTR concept lands at CES 2020. *Designboom | Architecture & Design Magazine*. https://www.designboom.com/technology/mercedes-benz-vision-avtr-avatar-ces-01-07-2020/

Dinh, D.-L., Kim, J., & Kim, T.-S. (2014). Hand Gesture Recognition and Interface via a Depth Imaging Sensor for Smart Home Appliances. *Energy Procedia*, *62*. https://doi.org/10.1016/j.egypro.2014.12.419

Divergent thinking. (2021). In *Wikipedia*. https://en.wikipedia.org/w/index.php?title=Divergent_thinking&oldid=1021599675

Dobry, W. (2017). Button Design Over the Years – The Dribbble Timeline. *Toptal Design Blog*. https://www.toptal.com/designers/ui/button-design-dribbble-timeline

Domingo, M. (2018, January). Dieter Rams: 10 Timeless Commandments for Good Design. *The Interaction Design Foundation*. https://www.interaction-design.org/literature/article/dieter-rams-10-timeless-commandments-for-good-design

Domingo, M. G. (2015). Making sense of new UX words: A first dictionary for UX Ecosystem Design. *The Interaction Design Foundation*. https://www.interaction-design.org/literature/article/article-5602a4f3ecc4c

Euclideon Holographics. (2020, August 6). Hologram Wall. *Euclideon Holographics*. https://euclideonholographics.com/hologram-walls/

Extended reality. (2021). In *Wikipedia*. https://en.wikipedia.org/w/index.php?title=Extended_reality&oldid=1034629353

Fallon, D. (2020, December 10). *Glassmorphism Login form with pure CSS*. http://damianfallon.blogspot.com/2020/12/glassmorphism-login-form-with-pure-css.html

Fellbaum, Christiane. 1998. *WordNet: An Electronic Lexical Database*. MIT Press.

Fiell, C., & Fiell, P. (2012). *Design of the 20th century* (LADC Auburn NK 1390 .F525 2012). Taschen.

Fogg, B. J. (2003). *Persuasive technology: Using computers to change what we think and do* (Auburn RBD Library (1st Floor) BF 637 .P4 F55 2003). Morgan Kaufmann Publishers, /. http://spot.lib.auburn.edu/login?url=https://search.ebscohost.com/login.aspx?direct=true&db=cat07161a&AN=aul.2055265&site=eds-live&scope=site

Forceville, C. J. (2011). Multimodality: A Social Semiotic Approach to Contemporary Communication: Gunther Kress, Routledge, London, 2010, 212 pp., 45 b/w illustrations + 15 colour plates, ISBN 13: 978-0-415-32061-0 (pbk). *Journal of Pragmatics*, *43*(14), 3624–3626. https://doi.org/10.1016/j.pragma.2011.06.013

Gajendar, U. (2016, February 26). Notes on “The Future of Interaction Design.” *Medium*. https://medium.com/@udanium/notes-on-the-future-of-interaction-design-78c0b171491b

Garrett, J. J. (2010). *The Elements of User Experience: User-Centered Design for the Web and Beyond* (2nd edition). New Riders.

Gelsinger, P. (2021, September 7). *Intel CEO Keynotes at IAA Mobility (Event Replay)*. https://www.intel.com/content/www/us/en/newsroom/news/ceo-keynotes-iaa-mobility-livestream-replay.html

Google LLC. (2020, March 31). Material Design. *Material Design*. https://material.io/design

Gorp, T. van, & Adams, E. (2012). *Design for Emotion*. Elsevier.

Greenwold, S., & Paradiso, J. A. (2003). *Spatial Computing*.

Guerron, E., & Mitchell, N. (2017, October). *Oculus—Dash Virtual Desktop*. http://www.eliguerron.com/oculus-dash-virtual-desktop

Halarewich, D. (2016, September 9). Reducing Cognitive Overload For A Better User Experience. *Smashing Magazine*. https://www.smashingmagazine.com/2016/09/reducing-cognitive-overload-for-a-better-user-experience/

Hall, K. (2020, October 20). *A cognitive psychologist explains how immersive technologies are improving the human experience* (US). https://www.3m.com/wps/portal/en_US/3M/particles/all-articles/article-detail/~/virtual-vs-augmented-reality-glasses-headset-medical-uses/?storyid=7ad6bb5d-0ac4-4a76-a4ac-aa052734a437

Han, X., Gast, T. F., Guo, Q., Wang, S., Jiang, C., & Teran, J. (2019). A Hybrid Material Point Method for Frictional Contact with Diverse Materials. *Proceedings of the ACM on Computer Graphics and Interactive Techniques*, *2*(2), 17:1-17:24. https://doi.org/10.1145/3340258

Heijden, H. V. der. (2004). User Acceptance of Hedonic Information Systems. *MIS Quarterly*, *28*(4), 695–704. https://doi.org/10.2307/25148660

Hempel, Carl G. 2019. "Rudolf Carnap - Career in the United States." *Encyclopedia Britannica*. https://www.britannica.com/biography/Rudolf-Carnap (December 10, 2019).

Henderson, K. (2015, May 14). An Illustrated History of American Design Trends by Decade. *Complex*. https://www.complex.com/style/2015/05/an-illustrated-history-of-american-design-trends-by-decade/

Hey, J. (2021). Fitts' Law. *Sketchplanations*. https://sketchplanations.vercel.app/fitts-law

Hoang, F. (2020, January 11). *Mercedes-Benz unveiled its vision for the future of mobility: The VISION AVTR*. https://abduzeedo.com/node/85779

Huh, J. (2020). *HUMAN(e) EXPERIENCE: Natural Gestures for Natural Interactions* [Thesis, Carnegie Mellon University]. https://doi.org/10.1184/R1/12555809.v1

IDSA. (2019, September 17). What Is Industrial Design? *Industrial Designers Society of America - IDSA*. https://www.idsa.org/what-industrial-design

IEEE. (2020, January 10). New Level 3 Autonomous Vehicles Hitting the Road in 2020. *IEEE Innovation at Work*. https://innovationatwork.ieee.org/new-level-3-autonomous-vehicles-hitting-the-road-in-2020/

IoT Automotive News. (2020, June 10). THE MERCEDES-BENZ VISION AVTR. *IoT Automotive News*. http://iot-automotive.news/mercedes-benz-vision-avtr/

IxDF. (2017, April 13). What is Design Thinking? *The Interaction Design Foundation*. https://www.interaction-design.org/literature/topics/design-thinking

IxDF. (2017, February 18). What is Interaction Design? *The Interaction Design Foundation*. https://www.interaction-design.org/literature/topics/interaction-design

IxDF. (2017, February 18). What is User Experience (UX) Design? *The Interaction Design Foundation*. https://www.interaction-design.org/literature/topics/ux-design

IxDF. (2017, June 15). What is User Interface Design? *The Interaction Design Foundation*. https://www.interaction-design.org/literature/topics/ui-design

IxDF. (2017, October 5). What is Information Overload? *The Interaction Design Foundation*. https://www.interaction-design.org/literature/topics/information-overload

IxDF. (2018, December 7). The Five Languages or Dimensions of Interaction Design. *The Interaction Design Foundation*. https://www.interaction-design.org/literature/article/the-five-languages-or-dimensions-of-interaction-design

IxDF. (2018, October 5). What is Visual Hierarchy? *The Interaction Design Foundation*. https://www.interaction-design.org/literature/topics/visual-hierarchy

IxDF. (2019). Fitts's Law: The Importance of Size and Distance in UI Design. *The Interaction Design Foundation*. https://www.interaction-design.org/literature/article/fitts-s-law-the-importance-of-size-and-distance-in-ui-design

IxDF. (2019, June 17). What is Augmented Reality? *The Interaction Design Foundation*. https://www.interaction-design.org/literature/topics/augmented-reality

Kambria. (2019, January 11). The Next Frontier: Why Frontier Technologies Are Important. *Kambria Network*. https://medium.com/kambria-network/the-next-frontier-why-frontier-technologies-are-important-f1456d8ef992

Kiselev, V., Khlamov, M., & Chuvilin, K. (2019). Hand Gesture Recognition with Multiple Leap Motion Devices. *2019 24th Conference of Open Innovations Association (FRUCT), Open Innovations Association (FRUCT), 2019 24th Conference Of*, 163–169. https://doi.org/10.23919/FRUCT.2019.8711887

Kolko, J. (2010). *Thoughts on Interaction Design* (1st edition). Morgan Kaufmann.

Krauss, R. M., Chen, Y., & Chawla, P. (1996). Nonverbal Behavior and Nonverbal Communication: What do Conversational Hand Gestures Tell Us? In M. P. Zanna (Ed.), *Advances in Experimental Social Psychology* (Vol. 28, pp. 389–450). Academic Press. https://doi.org/10.1016/S0065-2601(08)60241-5

Krippendorff, K. (2006). *The semantic turn: A new foundation for design* (LADC Auburn NK 1505 .K755 2006). CRC/Taylor & Francis.

Krippendorff, K., & Butter, R. (1984). Product Semantics: Exploring the Symbolic Qualities of Form. *Innovation*, *3*(2), 4–9.

Krug, S. (2014, April 1). Don't Make Me Think, Revisited. *California Bookwatch*. http://spot.lib.auburn.edu/login?url=https://search.ebscohost.com/login.aspx?direct=true&db=edsglr&AN=edsglr.A367197658&site=eds-live&scope=site

Kujala, S., Roto, V., Väänänen-Vainio-Mattila, K., Karapanos, E., & Sinnelä, A. (2011). UX Curve: A method for evaluating long-term user experience. *Interacting with Computers*, *23*(5), 473–483. https://doi.org/10.1016/j.intcom.2011.06.005

Kuznetsov, G. (2019, January 23). Designing Emotional Interfaces Of The Future. *Smashing Magazine*. https://www.smashingmagazine.com/2019/01/designing-emotional-interfaces-future/

Lanier, J. (2017). *Dawn of the New Everything: Encounters with Reality and Virtual Reality*. Henry Holt and Company.

Lavery, T. (2017, April). What is Hick's law? - Definition from WhatIs.com. *WhatIs.Com*. https://whatis.techtarget.com/definition/Hicks-law

Li, Y., Huang, J., Tian, F., Wang, H.-A., & Dai, G.-Z. (2019). Gesture interaction in virtual reality. *Virtual Reality & Intelligent Hardware*, *1*(1), 84–112. https://doi.org/10.3724/SP.J.2096-5796.2018.0006

Ligertwood, G. (2018, March 1). How Do You See The Future of UX Design? *Medium*. https://uxplanet.org/how-do-you-see-the-future-of-ux-design-8654c62c3279

Liu G. (2020). *Guanzhong Liu: Design is not a craft industry, not a commercial explosion, but a reformatted innovative thinking* (p. 1). https://zhuanlan.zhihu.com/p/336744923

Lyonnais, S. (2017, August 28). Where Did the Term "User Experience" Come From? *Adobe Blog*. https://blog.adobe.com/en/publish/2017/08/28/where-did-the-term-user-experience-come-from.html

MacKenzie, A. (2016, March 7). BMW Vision Next 100 Concept Previews Future Tech, Design. *MotorTrend*. https://www.motortrend.com/news/bmw-vision-next-100-concept-previews-future-tech-design/

Malaika, Y. (2015, October 9). *Interaction Design in VR: Valve's Lessons*. Interaction Design in VR: Valve's Lessons, GDC Europe 2015. https://www.youtube.com/watch?v=_vQo0ApkAtI

Malewicz, M. (2020, November 22). Glassmorphism in user interfaces. *Medium*. https://uxdesign.cc/glassmorphism-in-user-interfaces-1f39bb1308c9

Marques Brownlee. (2021, April 11). *Top 5 Mercedes EQS Features: Electric Luxury!* https://www.youtube.com/watch?v=wUqZQTp_gpI

Mauriello, J. (2021, January 25). *Autonomous Cars Industrial Design Analysis—Cruise, Zoox, Waymo*.

https://www.youtube.com/watch?v=CcprD1KNpKU&list=PLx2TWlGH3gUIYFYT0mnh6JZBHeXYGT6QX&index=4&t=10s

McAweeney, E., Zhang, H., & Nebeling, M. (2018). User-Driven Design Principles for Gesture Representations. *CHI*, 547–560. https://doi.org/10.1145/3173574.3174121

Mercedes-Benz AG. (2016, March 30). *Mercedes-Benz: The definition of sensual purity.* https://www.mercedes-benz.com/en/design/insights/mercedes-benz-the-definition-of-sensual-purity/

Mercedes-Benz AG. (2020, January 8). INSPIRED BY THE FUTURE: THE VISION AVTR. *We Are Motor Driven*. https://wearemotordriven.com/inside-lane/inspired-by-the-future-the-vision-avtr/

Mercedes-Benz. (2020, January 8). *Mercedes-Benz VISION AVTR: The Vision of Tomorrow's Next Big Thing*. https://www.youtube.com/watch?v=l5ZK0S8Q7JU

Moggridge, B. (2007). *Designing interactions* (Auburn RBD Library (4th Floor) QA 76.9 .H85 M64 2007). MIT Press. http://spot.lib.auburn.edu/login?url=https://search.ebscohost.com/login.aspx?direct=true&db=cat07161a&AN=aul.2501828&site=eds-live&scope=site

Montgomery, L. (2017, September 5). Sony Xperia Touch Video Projector Acts as a Touchscreen; Responds to Voice Commands. *Electronic House*. https://www.electronichouse.com/smart-tv/sony-xperia-touch-video-projector-acts-as-a-touchscreen-responds-to-voice-commands/

Morris, M. R., Wobbrock, J. O., & Wilson, A. D. (2010). Understanding users' preferences for surface gestures. *Graphics Interface*, 261–268.

Morville, P. (2016, October 11). User Experience Honeycomb. *Intertwingled*. https://intertwingled.org/user-experience-honeycomb/

Moscow, P. (2019, August 27). *Digital Marketing Conference—Awwwards SOTD*. https://www.awwwards.com/sites/digital-marketing-conference

Moule, J. (2013, July 1). Killer UX Design. *California Bookwatch*, 268.

Snail. (2019, November 5). *Whether the weak light is easier to catch by peripheral vision than envisage vision?* https://www.zhihu.com/question/352725432

Nordquist, R. (2018, February 3). What Are Visual Metaphors? *ThoughtCo*. https://www.thoughtco.com/visual-metaphor-1692595

Norman, D. (2002). Emotion & design: Attractive things work better. *Interactions*, *9*(4), 36–42. https://doi.org/10.1145/543434.543435

Norman, D. A. (2013). *The design of everyday things* (LADC Auburn TS 171.4 .N67 2013; Rev. and expanded edition.). Basic Books.

O'Kane, S. (2020, December 14). Zoox unveils a self-driving car that could become Amazon's first robotaxi. *The Verge*. https://www.theverge.com/2020/12/14/22173971/zoox-amazon-robotaxi-self-driving-autonomous-vehicle-ride-hailing

Olsen, P. (2018). *Cadillac Tops Tesla in Consumer Reports' First Ranking of Automated Driving Systems*. https://www.consumerreports.org/autonomous-driving/cadillac-tops-tesla-in-automated-systems-ranking/

Park, J. J., Florence, P., Straub, J., Newcombe, R., & Lovegrove, S. (2019). *DeepSDF: Learning Continuous Signed Distance Functions for Shape Representation*. 165–174. https://openaccess.thecvf.com/content_CVPR_2019/html/Park_DeepSDF_Learning_Con tinuous_Signed_Distance_Functions_for_Shape_Representation_CVPR_2019_paper.html

Pathways.org. (2020, May 2). Learn Sensory Integration Basics. *Sensory Integration: Know the Basics*. https://pathways.org/topics-of-development/sensory/

Phaidon Design. (2006). *Phaidon design classics* (LADC Auburn NK 1320 .P438 2006). Phaidon Press.

Plattner, H., Meinel, C., & Leifer, L. (2012). Design thinking research. [electronic resource]: Studying co-creation in practice. In *2012 Springer Business and Economics eBooks Collection.* (AU Electronic Resource T49.5 .D47 2012 ELECTRONIC Access is via ID, with unlimited simultaneous users.). Springer.

Premaratne, P. (2014). Historical Development of Hand Gesture Recognition. *Human Computer Interaction Using Hand Gestures*, 5.

Provine, R. R. (2000). *Laughter: A scientific investigation* (Auburn RBD Library (1st Floor) BF 575 .L3 P76 2000). Viking. http://spot.lib.auburn.edu/login?url=https://search.ebscohost.com/login.aspx?direct=true&db=cat07161a&AN=aul.1907561&site=eds-live&scope=site

Reeves, B., & Nass, C. I. (1998). *The media equation: How people treat computers, television, and new media like real people and places* (Auburn RBD Library (3rd Floor) P 96 .A83 R44 1998). CSLI Publications. http://spot.lib.auburn.edu/login?url=https://search.ebscohost.com/login.aspx?direct=true&db=cat07161a&AN=aul.1988805&site=eds-live&scope=site

Rusinkiewicz, S., Hall-Holt, O. A., & Levoy, M. (2002). Real-time 3D model acquisition. *ACM Trans. Graph.*, *21*(3), 438–446. https://doi.org/10.1145/566654.566600

Schubert, M., & Fox, B. (2017, December 8). Exclusive: Leap Motion Explores Ways to Make Controller-free Input More Intuitive and Immersive. *Road to VR*. https://www.roadtovr.com/leap-motion-explores-ways-to-make-controller-free-input-more-intuitive-and-immersive-vr-design/

Sharma, L. (2020, May 29). Cognitive psychology in UX. *Medium*. https://uxplanet.org/cognitive-psychology-in-ux-cd7afed87886

Sharp, H., Preece, J., & Rogers, Y. (2019). *Interaction Design: Beyond Human-Computer Interaction* (5th edition). Wiley.

Smith, F. (2020, September 26). *VISION AVTR: The Road Test* (G. Wagener, V. Schmidt, & A. Dang, Interviewers) [Interview]. https://www.youtube.com/watch?v=ChqM3zqTREQ

Soegaard, M. (2020). Hick’s Law: Making the choice easier for users. *The Interaction Design Foundation*. https://www.interaction-design.org/literature/article/hick-s-law-making-the-choice-easier-for-users

Sparklin. (2019, January 31). Yet another design trends article—On UX & digital possibilities of 2019. *Medium*. https://medium.muz.li/yet-another-design-trends-article-on-ux-digital-possibilities-of-2019-6423b23e50cb

Steinicke, F., Benko, H., Krüger, A., Keefe, D., de la Rivière, J.-B., Anderson, K., Häkkilä, J., Arhippainen, L., & Pakanen, M. (2014). *The 3rd dimension of CHI (3DCHI): Touching and designing 3D user interfaces*. 106. https://doi.org/10.1145/2212776.2212698

Stone, P., Brooks, R., Brynjolfsson, E., Calo, R., Etzioni, O., Hager, G., Hirschberg, J., Kalyanakrishnan, S., Kamar, E., Kraus, S., Leyton-Brown, K., Parkes, D., Press, W., Saxenian, A., Shah, J., Tambe, M., & Teller, A. (2016). Artificial Intelligence and Life in 2030. *Stanford University*, 52.

Strait, G. (2018, April 18). What is Frontier Technology? Introducing the Next Generation of Gensuite. *Gensuite*. https://www.gensuite.com/what-is-frontier-technology-introducing-the-next-generation-of-gensuite/

Streamline Moderne. (2019). In *Wikipedia*. https://en.wikipedia.org/w/index.php?title=Streamline_Moderne&oldid=929450286

Stuttgart. (2021, March 28). The new EQS: Design concept (exterior). *MarsMediaSite*. https://media.daimler.com/marsMediaSite/en/instance/ko/The-new-EQS-design-concept-exterior.xhtml?oid=49404488

Takikawa, T., Litalien, J., Yin, K., Kreis, K., Loop, C., Nowrouzezahrai, D., Jacobson, A., McGuire, M., & Fidler, S. (2021). *Neural Geometric Level of Detail: Real-time Rendering with Implicit 3D Shapes*. http://arxiv.org/abs/2101.10994

Thagard, P. (2020). Cognitive Science. In E. N. Zalta (Ed.), *The Stanford Encyclopedia of Philosophy* (Winter 2020). Metaphysics Research Lab, Stanford University. https://plato.stanford.edu/archives/win2020/entries/cognitive-science/

The News Wheel. (2016, May 25). Mercedes-Benz's Sensual Purity Design Philosophy Explained. *The News Wheel*. https://thenewswheel.com/mercedes-benzs-sensual-purity-design-philosophy-explained/

Tim. (2021, February 2). Managing Information Overload in UX Design: Miller's Law. *Medium*. https://medium.cobeisfresh.com/managing-information-overload-in-ux-design-millers-law-707a01348f54

Toffler, A. (1971). *Future shock* (Auburn RBD Library (3rd Floor) HN 17.5 .T64 1971; Bantam ed.). Bantam.

http://spot.lib.auburn.edu/login?url=https://search.ebscohost.com/login.aspx?direct=true&db=cat07161a&AN=aul.1087878&site=eds-live&scope=site

Tognazzini, B. (2014, March 6). First Principles of Interaction Design (Revised & Expanded). *AskTog*. https://asktog.com/atc/principles-of-interaction-design/

Tubik Studio. (2018, May 8). UX Design Glossary: How to Use Affordances in User Interfaces. *Medium*. https://uxplanet.org/ux-design-glossary-how-to-use-affordances-in-user-interfaces-393c8e9686e4

Ukraine. (2021, April 23). *uxblonde—Awwwards Nominee*. https://www.awwwards.com/sites/uxblonde

Ullrich, C. (2019). Integrating Haptic Feedback into Design: Create interfaces that give users greater functionality than ever before. *Appliance Design*, *67*(2), 18.

Usability.gov. (2013). *User Interface Elements*. Department of Health and Human Services. https://www.usability.gov/how-to-and-tools/methods/user-interface-elements.html

Valkov, D., Steinicke, F., Bruder, G., & Hinrichs, K. (2011). *2D touching of 3D stereoscopic objects*. 1353–1362. https://doi.org/10.1145/1978942.1979142

Valkov, D., Steinicke, F., Bruder, G., Hinrichs, K., Schöning, J., Daiber, F., & Krüger, A. (2010). *Touching Floating Objects in Projection-based Virtual Reality Environments.* 17–24. https://doi.org/10.2312/EGVE/JVRC10/017-024

Villar, N., Cletheroe, D., Saul, G., Holz, C., Salandin, O., Regan, T., Sra, M., Yeo, H.-S., Field, W., & Zhang, H. (2018, April). Project Zanzibar: A Portable and Flexible Tangible Interaction Platform. *2018 ACM Conference on Human Factors in Computing Systems (CHI)*. https://doi.org/10.1145/3173574.3174089

Virtual reality. (2021). In *Wikipedia*. https://en.wikipedia.org/w/index.php?title=Virtual_reality&oldid=1041510556

Visual spatial attention. (2021). In *Wikipedia*. https://en.wikipedia.org/w/index.php?title=Visual_spatial_attention&oldid=1035981015

Walter, A., & Spool, J. M. (2011). *Designing for emotion*. A Book Apart/Jeffrey Zeldman.

Weelco Inc. (2017, July 7). *VR Authorization plugin for Unity*. https://www.youtube.com/watch?v=-nV_snPtiHI

Wobbrock, J. O., Morris, M. R., & Wilson, A. D. (2009). User-defined gestures for surface computing. *Proceedings of the 27th International Conference: Human Factors in Computing Systems*, 1083–1092.

Wolf, K., Naumann, A., Rohs, M., & Müller, J. (1970). *A Taxonomy of Microinteractions: Defining Microgestures Based on Ergonomic and Scenario-Dependent Requirements*. 559–575. https://doi.org/10.1007/978-3-642-23774-4_45

Wroblewski, L. (2008, March). *Communicating with Visual Hierarchy*.

Wu, H., Gai, J., Wang, Y., Liu, J., Qiu, J., Wang, J., & Zhang, X. (2020). Influence of cultural factors on freehand gesture design. *International Journal of Human-Computer Studies*, *143*. https://doi.org/10.1016/j.ijhcs.2020.102502

Xiao, M., Feng, Z., Yang, X., Xu, T., & Guo, Q. (2020). Multimodal interaction design and application in augmented reality for chemical experiment. *Virtual Reality & Intelligent Hardware*, *2*(4), 291–304. https://doi.org/10.1016/j.vrih.2020.07.005

Yablonski, J. (2020). *Laws of UX: Using Psychology to Design Better Products & Services* (1st edition). O'Reilly Media.

Zilch, D., Bruder, G., & Steinicke, F. (2014). Comparison of 2D and 3D GUI Widgets for Stereoscopic Multitouch Setups. *Journal of Virtual Reality and Broadcasting*, *11(2014)*(7). https://doi.org/10.20385/1860-2037/11.2014.7