Designing next-generation retail experiences via virtual reality and pseudo-haptics

Department of
ELECTRICAL AND INFORMATION ENGINEERING
Industry 4.0 Ph.D. Program
SSD: ING-IND/15 – DESIGN METHODS FOR INDUSTRIAL ENGINEERING
SSD: ICAR/13 – INDUSTRIAL DESIGN

Final Dissertation

Designing Next-Generation Retail Experiences via Virtual Reality and Pseudo-Haptics

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by
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Course n°36, 01/11/2020-31/10/2023

Politecnico di Bari

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del Politecnico di Bari

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Designing Next-Generation Retail Experiences via Virtual Reality and Pseudo-Haptics

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Table of Contents

Preface

Before going more into the research conducted over the past three years, I briefly explore the socio-cultural context within this research. Considering the extensive body of literature attesting to the dominant role of **visual representations** in our culture, I argue that today, we live in a society where *simulations are often more influential, fulfilling, and meaningful* than what they are supposed to represent. In this regard, digital technologies play a key role in our cycle of constructing *meaning* for everything around us. This should not necessarily be seen as bad; however, it has consequences for our concepts of *real* and *virtual*, which are more complementary than we imagine.

The concept of **simulation** has been a topic of discussion since ancient Greek times. In his famous Allegory of the Cave, Plato portrays humans as individuals confined within a cave, where they observe shadows on the wall, oblivious that these shadows merely represent what occurs outside their limited sensory perception. According to Plato's philosophy, tangible objects like a chair are merely shadows cast by the overarching concept of "chair." Consequently, the physical chair we sit on is always a replica, a simulation, of the abstract idea of a chair, thereby remaining one step removed from actual reality.

The idea of **simulation**, and the related idea of **hyperreality** (Baudrillard, 1987), represent for Jean Baudrillard the supreme form into which our reality, and the principles of the real itself, seem to have been "sucked in." According to the French philosopher, the reality is a *construction*, a *model*, a *formula* that men have structured throughout their lives, in which they have probably believed, but being a model can disappear liquefy. This reality, which today seems to exhale its last sighs, has been constructed in the duality that has opposed it to the imaginary, the dream, the digital, the virtual. In doing so, the "differentiated" world of the real has been firmly contrasted with the integrated world of the virtual, in which man rises to a second or other life.

Together with the *virtual*, we enter an entirely new age in which the very idea of representation, the idea that men have about themselves, of the world, and its space-time references, is questioned. As Baudrillard states in the interview with Claude Thibaud:

> The system of representation is in question.
> The image that man has of himself is virtualized.
> We are no longer in front of the mirror,
> we are inside the screen, which is something different.
> (Thibaud, 1998)

Then, the real will continue to exist under the effect of simulation. It will be exhumed as fictional and will become an icon represented under the veil of genetic reconstruction of computer engineering. And this seems to be a prediction of what, nowadays, has become the concept of the "Metaverse." As Baudrillard states in " L'échange symbolique et la mort":

> The unreality is no longer that of the dream or the ghost,
> of a beyond or a hereafter,
> it is that of the hallucinating resemblance of the real to itself.
> (Baudrillard, 1976)

Baudrillard then moves his analysis from McLuhan's observation according to which “Medium is massage” by inheriting the concept developed in "The Medium Is the Massage: An Inventory of Effects," so that:

> Indeed, the effects of technology do not occur,
> at the level of opinions or concepts,
> but constantly alter, without any resistance,
> sensory reactions, or forms of perception
> (McLuhan & Capriolo, 2015)

Like McLuhan, his student Derrick de Kerckhove later argued through laboratory experiments that mediums target the perceptual structures of subjects, modifying their sensory apparatus. Television, for example, like any new technology that enters the daily lives of individuals, produced effects on the body and nervous system, particularly in the way they combine within the neuromuscular system.

Our conceptions of perceiving change according to the mediums that characterize a given historical and social stage. As Derrick de Kerckhove states:

> It is our global electronic psychology
> that provides us with the common notions of
> time, space, and society
> (De Kerckhove, 2000)

Thus, each new technology, by changing individual arrangements and social dynamics, introduces new **relationships between subjects**. Therefore, it would not be the content that affects the criteria of social aggregation but the **medium** itself.

All digital technologies produce pseudo-events, manipulated artifacts, and create a **neo-real**, substituting the real, produced from the combination of the code elements, giving rise to simulation. The leap into the virtual, which is matched by the liquefaction of the real, causes the real world to continue to live and retrace itself tirelessly in a kind of eternal present, perpetual stasis, and ice age: that new perspective ushered in by the imminence of the world in the infinite day of its computer synthesis. The hyperreality becomes the pattern that absorbs the imaginary and the possibility of distance, the alibi of the real, in a world now dominated by the "more than real."

It is precisely on this soil that this doctoral thesis germinates, aiming to provide a perspective on designing experiences (specifically for the retail industry) for the present that goes “beyond” the experiences themselves by exploiting the current new media and improving the interaction and perception of individuals.

Abstract

Today, designing experiences that satisfy and engage users is not only a challenge but also a phenomenon of great interest in the interaction field. Indeed, advances in digital and virtual technologies and the development of new user interfaces offer the possibility to build - and live - more authentic, engaging, and compelling experiences.

This doctoral research exploits an interdisciplinary approach that supports the theoretical basis and methods to investigate how digital and virtual environments invoke the relationship between the natural experience of perception and the "extended" experience mediated by new technologies.

In this scenario, new simulation technologies offer the opportunity to create environments and, consequently, novel and more immersive experiences. We are increasingly hearing about Virtual Reality (VR) and haptic technology, yet too little, however, about pseudo-haptics.

These technologies, characterized by their ability to merge the digital and physical realms, have attracted considerable attention in academia and industry. Their advent marks a significant inflection point in enhancing human perception and interaction within digital and virtual spaces, prompting in-depth examination and exploration in various scientific and interdisciplinary domains.

This is amplified when it comes to experiences, such as shopping, which are complex to replicate in both digital and virtual environments. There are considerable critical issues associated with this type of experience linked, for example, to the impossibility of configuring a product in real-time and exploring it in an immersive mode. Or to the lack of sensory feedback (e.g., tactile) that causes the impossibility of perceiving the material properties of a product.

However, a thorough review of the scientific literature has revealed very few user studies about designing shopping experiences with technologies such as VR and haptics. In this regard, there are only literature reviews that refer to the retail field but are strictly related to the areas of Marketing/Business rather than

Design/Computer Science. What emerges from this analysis is that, due to scarce literature references and case studies, there is room for improvement in the field. Therefore, three different methodologies were developed in the research path and used to define and implement experimental evaluation protocols with users.

In the first, we investigated whether immersive VR technology (IVR) has the potential to provide better experiences than desktop (DVR), which is closer in terms of interaction to digital experiences. To do so, the shopping experience of a handbag was simulated, and results were compared concerning the metrics of user experience, cognitive load, experience time, and hedonic/utilitarian values.

A second methodology, on the other hand, was developed by exploiting the IVR together with physical reality, creating a 'hybrid' experience to allow users to configure products in real-time, immersed in an IVR scenario while touching and comparing physical samples of materials and testing the comfort of the furniture they are interested in.

A third, lastly, concerns the development of user interfaces (defined as 'interactive visualizations’) that exploit pseudo-haptic effects and shoogles (sequences of interactive images) to convey a 'visualized touch' and communicate the tactile properties of fabrics. User studies were conducted only for two properties (i.e., elasticity and weight) with the future aim of applying and testing the methodology concerning other tactile material properties.

The methodologies developed and validated within the studies conducted during this research path show how new media and perceptual combinations, such as IVR, IVR in addition to real haptic feedback and pseudo-haptic effects, can shape the next generation of shopping experiences. Although user studies have only been conducted in two areas of retail - fashion and furniture - they pave the way for new models of interaction and experience design in retail (and beyond), with both academic and industrial implications.

Chapter 1. Introduction

This doctoral research is conducted as part of the Industry 4.0 Ph.D. program. This path is characterized by an interdisciplinary approach that embraces the competencies of the technical engineering area and Design, establishing a dialogue with industry stakeholders involved in the implementation of 4.0 standards, with a particular focus on the retail industry.

At present, the pervasive integration of digital and virtual technologies into our daily lives has given rise to a transformative change in the way individuals interact with and understand the world around them. The emergence of these technologies has not only expanded the boundaries of human perception but also redefined the parameters of human experience, opening new prospects of exploration in psychology, cognition, human-computer interaction, and even design. This thesis attempts to unravel the intricate interplay between the innate mechanisms of perception, shaped by millions of years of evolution, and the immersive digital and virtual environments gradually becoming an integral part of modern existence.

In the last few decades, digital and virtual environments have evolved from rough representations to sophisticated, immersive domains that offer a plethora of sensory stimuli. With the advent of technologies such as Virtual Reality (VR), Augmented Reality (AR), and eXtended Reality (XR), individuals can now transcend the limitations of physical space and time by delving into simulated worlds in which their senses are engaged in new and compelling ways. These environments provide a canvas for manipulating sensory input, offering a unique opportunity to study how the human mind responds to stimuli beyond the natural spectrum of perception. As we immerse ourselves in these digital realms, questions arise about the malleability of our perceptions and the resulting changes in our understanding of reality.

This research seeks to address the multiple implications of this technological transformation by shedding light on the intricate dynamics of perception and fruition in these new contexts, exploring how the interplay between natural and extended modes of experience affects our cognitive processes, emotional responses, and acceptance of a system. It also aims to identify the factors that contribute to the seamless integration of humans within these environments, as well as the potential consequences, both positive and negative, on individuals and society at large.

1.1 Motivation

The scope of this thesis is to investigate how digital and virtual environments invoke the relationship between the natural experience of perception and the "extended" experience mediated by new technologies. Thus, the research refers to the "extension" of the user experience to enhance the human sensory experience in the virtual context.

In particular, the doctoral research aims to improve the user experience by overcoming some of the limitations present in current online shopping platforms by implementing novel interactive systems through technologies such as VR and pseudo-haptic interfaces. There is no doubt that the emergence of digital innovation in the Industry 4.0 era towards the online retail industry has transformed the way consumers experience shopping. With the growing population of digital users gaining online consumption power, retail industries face evolutionary changes in attracting and maintaining online and offline customers. In our era where online purchases are increasingly important, it is necessary to keep in mind the consumer needs, especially since they are no longer forced to enter a store when they must buy something. Indeed, when they decide to visit a store, buyers are no longer need-driven but by the desire to live an experience. When consumers visit city center stores and shopping mall stores, they look for experiences: touch, see, feel, and discover products. Creating a unique one is essential to transform visitors into customers and increase loyalty. Whatever the field today, we must offer our consumers a continuous experience between the offline and online worlds. Digital media represents an exceptional opportunity to develop new shopping experiences, reach new customers, and pamper established ones. The main objective of a strategy that connects all its sales channels is to meet customer expectations through an experience that considers each stage of the buying process.

Therefore, it is necessary to develop design solutions that can enhance the role of human perception over experience and the different modes of interaction, also rethinking the designer role within this transition, which must make use of increasingly new and complex tools and technologies. In this regard, digital technologies such as VR, haptic interfaces, and the advent of the Metaverse become real case studies to be analyzed (in both their potentials and limitations), understood, and exploited to design.

To achieve these goals, this thesis deploys a multidisciplinary approach (See *Figure 1*), drawing from disciplines such as Interaction Design, Marketing, Cognitive Psychology, and Computer Science.

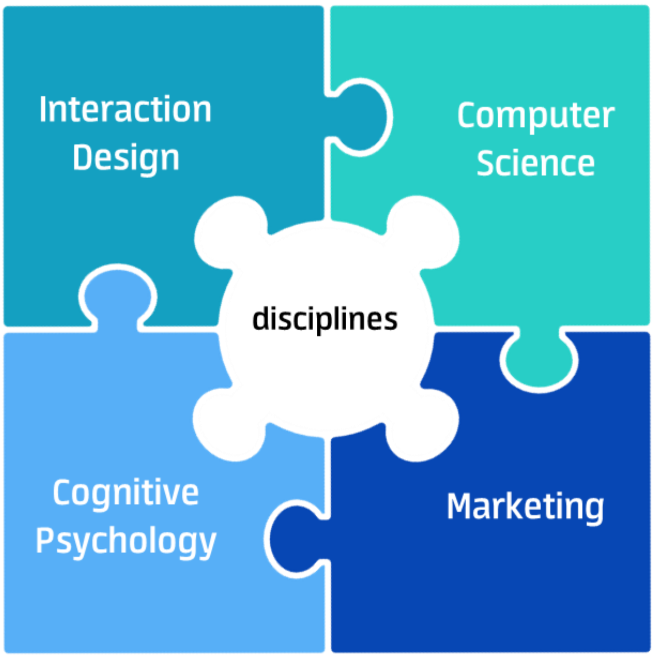

Figure 1. Scientific disciplines involved in the doctoral research.

Through a state-of-the-art analysis, methodologies development that led to interactive systems design, and user studies development and validation, this research offers a comprehensive understanding of the intricate relationship between human perception and digital/virtual. In doing so, it aims to contribute to the growing body of knowledge at the intersection of technology and human experience, providing insights that are not only of academic and industrial value but also socially relevant in an increasingly digital and interconnected world. The doctoral research addressed these baseline problems:

Problem 1 – Online shopping allows users to configure the products they want to buy in real-time, but not yet in a realistic and immersive way, as VR could (Billewar et al., 2022). The implementation of VR experiences is to give customers more real-world shopping experience without having to go outside. It also makes shopping online more attractive and reliable (Billewar et al., 2022). On the other hand, offline shopping does not allow users to view all possible product variants because they are often not in stock and only visible in paper or digital catalogs, which do not, however, convey a sense of realism or immersion.

Problem 2 – Online shopping presents a higher level of risk compared to offline shopping due to the absence of tactile information and the inability to examine the product directly (Phau & Poon, 2000). These shortcomings of online shopping increase the probability of the purchased product not meeting customers' expectations. Thus, there is a gap in the online shopping context since it does not allow for materials evaluation (e.g., fabrics). People need to evaluate materials and their properties, as happens in offline shopping, by touching and feeling them (Silva et al., 2021a).

Therefore, we developed some methodologies that led to the design and development of interactive systems based on the problems and consequent needs, tested, and validated with user studies:

Proposed Solution 1 – a) Desktop and Immersive VR shopping experiences that present storytelling about the product and allow configuring it in real-time while exploring all its features and the whole shop. b) Multi-sensory In-store VR experience that integrates the traditional customer journey with immersive product configuration in VR while gaining tactile sensations from in-store product samples and testing their comfort.

Proposed Solution 2 - Digital interfaces that communicate 'touch and feel' properties (e.g., elasticity and weight) of materials (i.e., fabrics) with pseudo-haptic effects.

1.2 Research Agenda and Research Questions

This research started not only from a personal interest in simulated reality in shopping experiences but also from the need found in the literature to improve the user experience concerning interaction and perception. While working with Head-Mounted Displays (HMDs) in my environment and research group, the belief emerged that the current online shopping experiences needed to be more comprehensive. Lacking, on the one hand, was the immersiveness of the experience and the ability to fully immerse oneself in a shopping environment, much more impactful than the 2D flat screen (the *interaction problem*). On the other hand, a component of the experience needed to include a tactile experience within the online shops. Apart from information about the material properties of garments or videos of models parading around wearing the garment, there needed to be simulations of the touch of the garment itself (the *perception problem*).

The doctoral research consists of three main phases:

1. Desk phase: data collection from the state of the art, identifying critical issues related to the user experience, with a focus on the shopping experience and the creation of a framework related to the technologies of interest (approximately 12 months).
2. Field phase: development of methodologies and related applications starting from the problems identified and development of user studies by testing and validating them (approximately 12 months).
3. Synthesis: the systematization of the results extrapolated from both phases, definition of scientific contributions, and drafting of scientific articles on this topic, disseminating this knowledge (approximately 12 months).

In the desk phase, the field of Interaction Design faces off concerning methods, state-of-the-art, and case studies with the fields of:

- Marketing - for the retail industry references.
- Cognitive Psychology - for the focus on the psychophysical dimension of perception.
- Computer Science - on the one hand, concerning the integration of VR technology within the shopping experience; on the other hand, using haptic interfaces to communicate material properties through pseudo-haptic effects.

The field phase of the research involves the development of applications to address and solve the previously identified problems. Therefore, on the one hand, two user studies were designed. The first, the comparative study, is conducted to answer the following research question: "Does the immersive VR shopping experience offer better results than the desktop VR shopping experience in terms of hedonic and utilitarian values, user experience, cognitive load, and time of the experience?". The second, instead, aims to answer to the questions: “Did customers value the experience?”, Were the virtual scenes perceived as realistic by customers?”, “Did customers view the experience as a useful and helpful tool in their decision-making process?”. On the other hand, the "visualized touch" is implemented through interactive visualizations to answer the following research questions: "How can pseudo-haptic effects be used to communicate the properties of fabrics in an online shopping context?" and "What influence do pseudo-haptic feedback of fabrics have on users in an online shopping context?".

In the synthesis phase, the results gathered from the user studies were processed and systematized, shaping the contribution of this thesis.

1.3 Expected Impact

In the early stages of the research, we drafted a list of properties that this thesis should have presented, imagining the impact that its developments would have. The following is a bulleted list summarizing the initial expectations of the doctoral research in the first few months. Subsequent achievements concerning the various points will be discussed later in **Chapter 6** in more detail.

Research Objectives: The thesis investigates how digital and virtual environments invoke the relationship between the natural experience of perception and the "extended" experience mediated by new technologies. The long-term goal is to implement interactive systems available for academia and industry by exploiting VR and haptic interfaces to design novel experiences.

Theoretical Contributions: Develop a framework from existing research related to the technologies of VR, haptics, and pseudo-haptics.

Practical Contributions: Design novel user experiences mediated by digital technologies, particularly shopping experiences.

Interdisciplinary Impact: The research bridges different disciplines - Interaction Design, Computer Science, Cognitive Psychology, and Marketing - thus promoting interdisciplinary research.

Long-term Effects: This research may address several issues related to the user experience, such as within the retail industry, by reducing the costs of physical display showrooms, the size of inventories and sample collections, and investing in virtual and e-commerce.

Broader Impacts: The overall expected impact of the research is presented within the scientific papers written during this research path (See *Section 1.5*).

1.4 Structure of Dissertation

In the early stages of the doctoral path, we designed a Gantt chart with all the scheduled activities reported in *Figure 2*:

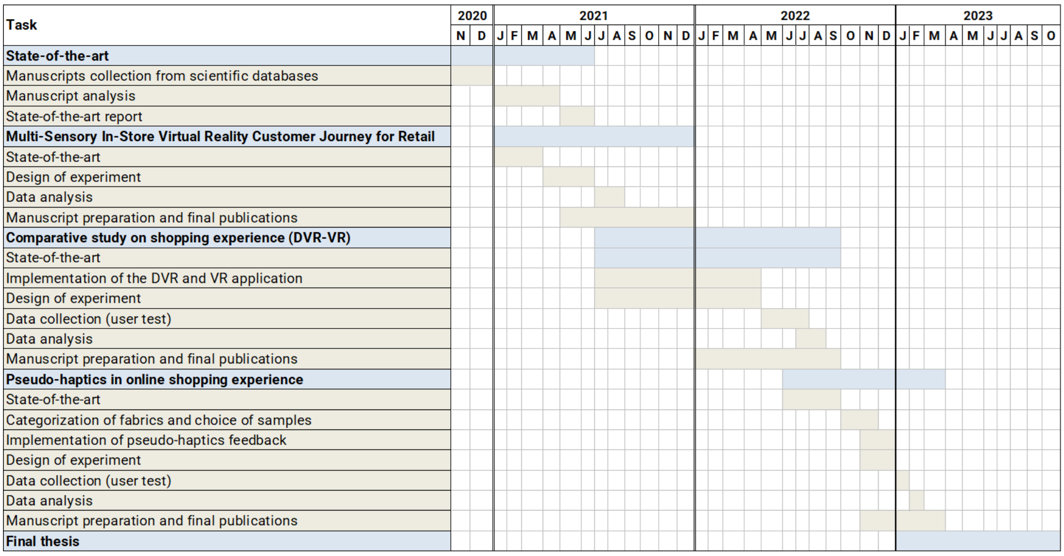

Figure 2: Gantt Chart of the planned doctoral tasks.

Thus, we present the structure of the thesis. In **Chapter 2**, we designed a framework related to the digital technologies of interest after a thorough literature review. The framework refers to VR technology, haptics, and pseudo-haptics, analyzed also concerning the field of retail.

In **Chapter 3**, we present a comparative study between desktop and immersive VR shopping experiences within the fashion industry. We conducted a within-subject experiment involving 60 participants in a simulated shopping experience. The objective is to understand which experience performs better regarding time duration, hedonic and utilitarian values, user experience, and cognitive load.

In **Chapter 4**, we present a Multi-Sensory In-Store Virtual Reality Customer Journey (MSISVRCJ) by exploiting a virtual product configurator to facilitate furniture sales. Customers are assisted by sales experts who help them modify furniture's colors, textures, and finishes while manipulating real samples of materials and testing the comfort.

In **Chapter 5**, we investigate how material properties of fabrics, such as elasticity and weight, can be conveyed through pseudo-haptic effects. Here, a visualized touch is delivered through interactive visualizations using pseudo-haptic effects and shoogles that simulate the real-life interaction of the hand with fabric by altering the fabric movement at the click of the mouse based on a variable gain value.

Finally, in **Chapter 6**, we report our conclusions by focusing on contributions to the theory and practice of the research, implications, limitations, and future works.

1.5 Scientific Publications

The following papers have been produced as part of this work:

- Fiorentino, M., Ricci, M., Evangelista, A., Manghisi, V. M., & Uva, A. E. (2022). A Multi-Sensory In-Store Virtual Reality Customer Journey for Retailing: A Field Study in a Furniture Flagship Store. Future Internet 2022, Vol. 14, Page 381, 14(12), 381. https://doi.org/10.3390/ FI14120381
- Ricci, M. (2022). Exploiting Virtual Reality for Enhancing the Shopping Experience in the Fashion Industry: Between Interaction and Perception. Proceedings - 2022 IEEE International Symposium on Mixed and Augmented Reality Adjunct, ISMAR-Adjunct 2022, 938–941. https:// doi.org/10.1109/ISMARA00DJUNCT57072.2022.00210
- Ricci, M., Scarcelli, A., D'Introno, A., Strippoli, V., Cariati, S., & Fiorentino, M. (2022). A Human-Centred Design Approach for Designing Augmented Reality Enabled Interactive Systems: A Kitchen Machine Case Study. In Lecture Notes in Mechanical Engineering (pp. 1413–1425). Springer, Cham. https://doi.org/10.1007/978-3- 031-15928-2_123
- Ricci, M., Scarcelli, A., & Fiorentino, M. (2023). Designing for the Metaverse: A Multidisciplinary Laboratory in the Industrial Design Program. Future Internet 2023, Vol. 15, Page 69, 15(2), 69. https://doi.org/10.3390/FI15020069
- Ricci, M., Evangelista, A., Di Roma, A., & Fiorentino, M. (2023). Immersive and desktop virtual reality in virtual fashion stores: a comparison between shopping experiences. Virtual Reality 2023, 1, 1–16. https://doi.org/10.1007/S10055-023-00806-Y

- Ricci, M., Wijntjes, M., Huisman, G., & Pont, S. (2023). Vision Helps Touch: Pseudo-Haptic Effects for Conveying Fabrics Properties. IEEE World Haptics 2023. https://doi.org/10.5281/ZENODO.8430417
- Ricci, M., Di Roma, A., Scarcelli, A., Fiorentino, M. (2023). Bio-Sustainable Materials for Tailor-Made Well-Being: A Case Study of Behavioral Packaging for Cosmetics Self-Production. In: Duarte, E., Di Roma, A. (eds) Developments in Design Research and Practice II. Senses 2021. Springer Series in Design and Innovation, vol 31. Springer, Cham. https://doi.org/10.1007/978-3-031-32280-8_26
- Ricci, M., Di Roma, A., Scarcelli, A., & Fiorentino, M. (2023). Impact and Challenges of Design and Sustainability in the Industry 4.0 Era: Co-Designing the Next Generation of Urban Beekeeping. 359–371.https://doi.org/10.1007/978-3-031-36922-3_21
- Ricci, M., Di Roma, A., & Fiorentino, M. (2023). Assessing the impact of immersive versus desktop virtual reality shopping experiences in the fashion industry metaverse. In Cumulus Antwerp 2023: Connectivity and creativity in times of conflict (pp. 271–275). Academia Press.
- Ricci, M., Di Roma, A., & Fiorentino, M. (2023). Designing Virtual Reality Shopping Experiences for the Fashion Industry: A Luxury Handbag Case Study. Proceedings of Inaugural Designing Retail and Service Futures Colloquium, 51–54.
- Zhao, C., Ricci M., Baghaei, N., & Fiorentino, M. (2023). A Systematic Review on Avatar Design in Virtual Retail Environments (under review)
- Ricci, M., Wijntjes, M., Huisman, G., & Pont, S. (2023). Elastic or stiff? Light or heavy? The challenge of pseudo-haptic effects and shoogles for fabric perception (to be submitted)
- Ricci, M., A., Di Roma, A., & Fiorentino, M. (2023). FRID 2023: Extending the Shopping Experience Design for the Fashion Industry (accepted in press)

- Ricci, M. (2023) SID 2023. Verso una percezione “pseudo-aptica” dei materiali del design. Metodologia di progettazione sinestesica per la trasmissione delle qualità tattili nei media digitali (accepted in press)
- Vangi, F., Ricci, M., A., Di Roma, A., & Fiorentino, M. (2023). ADM 2023. Designing a Business-To-Business Virtual Fashion Showroom in the Metaverse: A Padded Jacket Case Study (accepted in press)

Chapter 2. Research Framework of Technology Adoption in Retail Experiences

Considering the current scenario as of 2020, when this research started, there was a transition to online sales, inevitably accelerated by COVID-19, representing a significant problem for companies. Many companies had to close their stores, and by reducing in-store sales opportunities, they had to try to rethink their services, favoring online. Therefore, as people were beginning to spend more time in their homes, either by choice or by imposition, there was a sudden change in their shopping experience. This phenomenon impacted the scientific literature, which attests to using the virtual experience of products and services, not just the purchasing ones.

VR, as a technology with great application potential, can develop new sales models. For example, thanks to VR, it is possible to customize the product you would like to buy in real-time and to have a greater perception of it and its variants, as well as to perceive the dynamism of finishes. Therefore, the challenge is no longer to overcome the fear of online shopping but to make this experience more engaging and avoid customer dissatisfaction. In addition, hybrid forms of retail should be experimented with that involve the creation of true experiential "journeys" that include a combination of real and virtual landscapes.

Thus, designing retail experiences that exploit these digital technologies is an issue of great scientific and industrial interest, even if, in the scientific literature, there needs to be more user studies showing the strengths and weaknesses of this technology within this sector.

Also, as far as we know, within online shopping, consumers have limited access to tactile information about the products they are interested in. For items where the sense of touch plays a crucial role or for consumers who consider tactile feedback essential, the absence of this sensory input can significantly impact their product experiences. Therefore, stimulating the imagination of touch can be a viable approach to enhance the online shopping experience.

In interactions between humans and products, consumers continually receive sensory information through their senses. This sensory feedback also serves as input for operating the product (Akamatsu et al., 1995). Various sensory modalities can convey multiple aspects of product information, although there may be some overlap. In the daily lives of consumers, situations may arise where not all sensory modalities can be engaged in the interaction with a product. As previously mentioned, in an online store, consumers cannot physically touch the products they are searching for. The absence of the tactile modality significantly influences the product experience because the act of touching a product alone can instill a sense of ownership and lead consumers to assign a higher value to the product, a phenomenon known as the 'endowment effect' (Kahneman et al., 1990; Knetsch & Sinden, 1984; Thaler & Richard, 1980).

According to Desmet & Hekkert (2007) and Schifferstein & Cleiren (2005), product experience is the comprehensive array of psychological effects a product elicits in a consumer. Consequently, the product experience encompasses the identification process, the cognitive associations it may evoke, the memories it activates, the emotions and feelings it may generate, and the evaluative judgments it can prompt. For instance, a tactile experience will likely incorporate significant emotional components (Fisher et al., 1976).

Numerous studies have explored the impact of the absence of a sensory modality on the overall product experience. Calvert et al. (2004) demonstrated that individuals can extract information from one sensory modality and apply it to another. Additionally, research has indicated that people can amalgamate impressions arising from different sensory modalities into a cohesive, multifaceted perception (Stein & Meredith, 1993). Hence, it is reasonable to assume that a product experience can remain comprehensive even when a specific sensory modality is unavailable. Schifferstein & Desmet (2007) study revealed that obstructing a person's vision resulted in the most significant loss of functional information, followed by touch, which contributes a substantial amount of detailed product information. Intriguingly, their findings aligned with the research conducted by Welch (1978), who posited that individuals tend to develop adaptive strategies to compensate for sensory perception deficits. Schifferstein & Desmet (2007) indicated that participants relied more on their other senses when one modality was impaired. As per this research, this shift in sensory reliance led to a different product experience in which certain product characteristics, previously unnoticed when all sensory modalities were engaged, now played a role.

When considering a potential solution for the absence of touch-related information, prior research has highlighted the impact of haptic imagery on perceived ownership (Peck & Childers, 2018). This study revealed that haptic imagery can substitute for physical touch when individuals mentally envision touching a product with closed eyes. Remarkably, they reported experiencing a similar level of perceived ownership when mentally simulating product touch as compared to when they were physically touching the product.

Therefore, when designing next-generation retail experiences, we considered VR technologies and haptic interfaces as tools for their development, focusing on “pseudo-haptics.”

2.1 E-commerce and Online Shopping

The most widely recognized form of electronic commerce (e-commerce) is categorized as business-to-consumer (B2C) or simply online retail and online shopping. This includes online purchases made from traditional physical retailers (e.g., IKEA) and from "pure-click" online retail giants (e.g., Amazon).

On August 11, 1994, the retail market changed when the first online purchase was made: the first product (See *Figure 3*) to be purchased was a copy of Sting's Ten Summoner's Tales album.

Over the next two decades, while the principles of commerce are still unchanged, the ways of shopping have multiplied. In recent years, e-commerce has become an essential component of the global retail landscape. Like various other industries, buying and selling goods has undergone a significant transformation with the advent of the Internet. Thanks to the continued digitization of modern life, consumers around the globe now enjoy the advantages of online transactions.

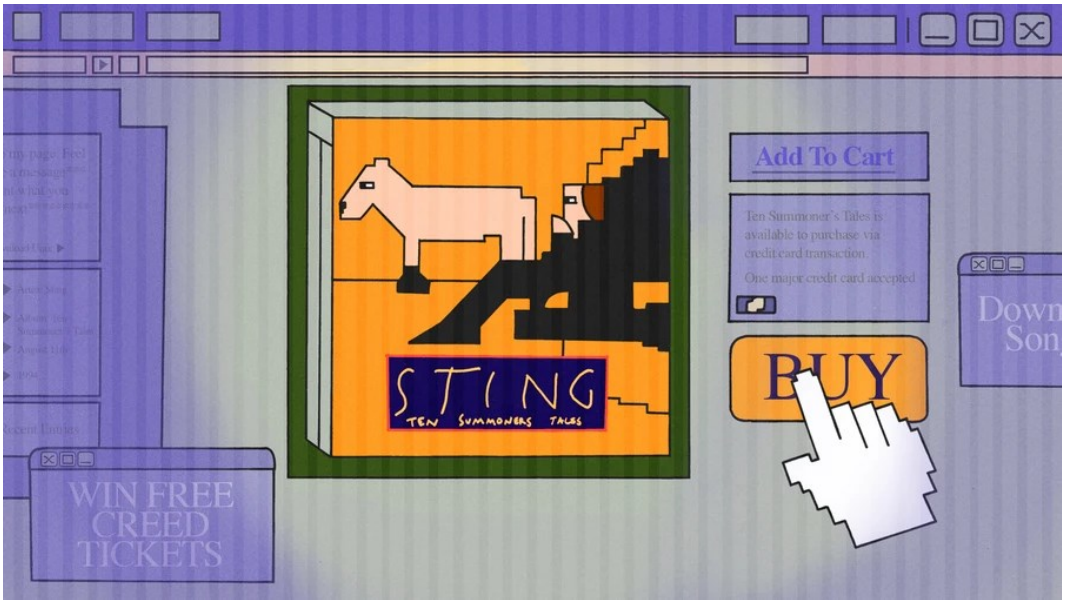

Figure 3. Illustration by Hunter French of the very first thing securely sold on the Internet.

With more than five billion internet users worldwide, the number of individuals engaging in online purchases continues to grow steadily. In 2022, it was estimated that global retail e-commerce sales exceeded an impressive 5.7 trillion U.S. dollars, poised to reach even greater heights in the years ahead (Statista, 2023).

Online shopping, often called electronic shopping or e-shopping, is a specific subset of e-commerce. It refers to consumers using electronic platforms, typically websites or mobile applications, to browse, select, order, and purchase goods or services from online retailers or sellers. Online shopping involves the entire consumer journey, from product discovery and selection to payment and delivery, all completed through digital channels.

Of course, it was demonstrated that online shopping offers several advantages. Firstly, it provides high accessibility to consumers regarding time and location. Shoppers can place orders online at their convenience, enabling merchants to maintain flexibility in establishing e-businesses. Online stores eliminate regional constraints, facilitating direct and comprehensive information communication. Consumers can easily access various product details and make product comparisons. Additionally, product reviews from previous buyers hold a significant influence on online shopping. Also, the cost of establishing an online shop is relatively low for merchants, as it does not necessitate the expensive overhead of a physical store. Ultimately, consumers can benefit from reduced product prices than in physical stores.

Nonetheless, online shopping also presents some weaknesses. Security concerns, especially regarding payment processes and privacy protection, are paramount factors that deter people from engaging in online transactions. Furthermore, perceived risks related to product quality, merchant reputation, and logistics also come into play. Finally, in online stores, the absence of direct interaction between customers and products or sellers can lead to reduced trust levels and an increased likelihood of product mismatches.

Nonetheless, online shopping also presents valuable opportunities. For instance, one of the biggest opportunities is developing new technologies and offering better online shopping experiences to consumers. This includes information security, delivery systems, and website design. Especially for the design of online shops, retailers should investigate not only the features of consumers, such as consumer psychology but also the potential of adopting richer content and interaction. In mobile commerce, the use of mobile devices brings limitations as well as opportunities. Smaller screens might hinder the information display, while the new way of interaction (touch instead of clicking) brings opportunities for enhancing the online shopping experience.

2. 2 How Do Consumers Shop?

Compared to traditional brick-and-mortar retailers, e-commerce retailers enjoy several advantages, including the ability to operate 24/7, offer a more extensive range of products, and overcome geographical constraints (Adelaar et al., 2004).

Past research showed that while e-commerce represents a significant portion of retail sales and is expected to keep growing, it still accounts for only about 7.3% of total retail sales and is not projected to surpass traditional retail sales shortly (DeNale, 2023). Despite the increasing number of online consumers, over 90% of sales still occur in traditional brick-and-mortar stores, and 85% prefer offline shopping (TimeTrade, 2015). The market suddenly changed during and after COVID-19, which forced customers to purchase only online, avoiding physical contact in offline stores.

As reported in *Figure 4*, the days of customers trekking to their local stores to spend hours browsing various stores quickly fade into the past (Insider Intelligence, 2023). Nowadays, the initial point of contact between customers and businesses typically occurs online, particularly if the company maintains a presence on social media. As aspiring entrepreneurs aim to launch new businesses with minimal overhead, the leasing of physical retail spaces may no longer be a primary concern. Instead, the focus is shifting towards establishing a robust online presence that can effectively capture digital sales. Code-free website builders are making this transition accessible with a low entry barrier.

By 2026, it is anticipated that online transactions will account for 24% of all retail purchases. The undeniable truth is that online shopping has become immensely popular in the contemporary era. Research indicates that in the coming years, customers are likely to consistently turn to the internet whenever they wish to make a retail purchase (Insider Intelligence, 2023).

Figure 4. Growth in retail e-commerce sales 2021-2026 (Source: Insider Intelligence).

Nonetheless, it becomes crucial to understand how the limitations of e-commerce can still hinder consumers' acceptance of online shopping technologies and influence their loyalty to online retailers.

Among the constraints of e-commerce, the most significant is its inability to provide customers with tangible product experiences involving sensory stimuli like touch (Childers et al., 2001a; Klatzky & Peck, 2012; Peck & Childers, 2018).

The absence of physical interaction with products diminishes familiarity, amplifies uncertainty, and can result in consumer frustration (Peck & Childers, 2003; Vieira, 2012). Furthermore, as consumers generally derive satisfaction from physically handling products while shopping, the enjoyment they experience during their shopping journey is curtailed when their ability to touch products is limited (Burke, 2005). The inability to touch products stands out as the most frequently cited reason why consumers express a preference for traditional brick-and-mortar stores over online shopping (Havas Worldwide, 2013). Given these considerations, it is essential, both from a theoretical and managerial perspective, to explore how e-commerce platforms can address the challenge of compensating for the absence of opportunities for consumers to physically interact with products for sale online (Yazdanparast & Spears, 2013).

Compared to physical stores, the ability of people to assess products in online stores is improved by the need for physical contact. Years ago, Kempf & Smith (1998) introduced the concept of "perceived diagnosticity," which refers to the perceived capability of a shopping experience to provide relevant product information that assists consumers in accurately evaluating product attributes. It is often measured by asking consumers how helpful they found the shopping experience in assessing the quality and performance of products. Kempf & Smith (1998) discovered that perceived diagnosticity positively contributes to the cognitive evaluation of product attributes.

While the primary focus of Kempf & Smith (1998) research was understanding how advertising influences trial processing and response, it is highly relevant to online shopping. This is because the product information provided in online stores essentially serves as another form of advertising from the retailer. After customers receive the product, they engage in a "trial" (as most online shops accept returns).

In online stores, the lack of physical contact with the product results in customers' inability to evaluate the product's experience attributes, which can be crucial for certain products, such as clothing. However, research has shown that an interface with image interactivity can increase the perceived diagnosticity of the experience attributes of a product, such as a scarf, compared to a static interface that uses only pictures. This effect is attributed to *visually induced tactile sensations*, and the ability of users to actively control the online product (rather than merely observing it being moved around) is essential in generating these tactile sensations (Overmars & Poels, 2015b).

In this research area, we could also refer to "Sensory marketing," which engages consumers' senses and affects their behavior. The focus of this topic is on how sensory aspects of products (i.e., touch, taste, smell, sound, and look of products) affect our emotions, memories, perceptions, preferences, and choices (Petit et al., 2015).

2.3 Image Interactivity Technologies

To address the primary drawbacks of online shopping, the absence of physical contact with products, such as the impossibility of configuring a product in real-time and in an immersive/realistic way, various Image Interactivity Technologies (IIT) have been developed to enhance online product interaction experience. According to Steuer (1992), interactivity is defined as "the extent to which users can participate in modifying the form or content of a mediated environment in real-time." IIT enables users to manipulate objects in a virtual environment directly, resulting in dynamic changes in graphics that closely mimic physical actions, creating an illusion of events occurring in the real world (Schlosser, 2003).

Many online stores currently employ a basic form of IIT, typically featuring static images with zoom-in capabilities or short videos featuring models wearing the items to provide dynamic visual presentations, such as Zalando or Asos (See *Figure 5*). Despite its limited interactivity, research has shown that increased use of the zoom feature is associated with fewer product returns (De et al., 2013).

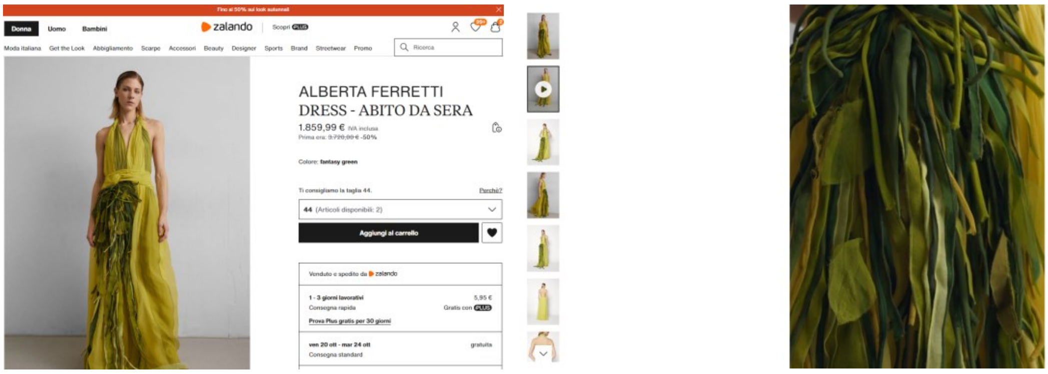

Figure 5. Zalando: product presentation.

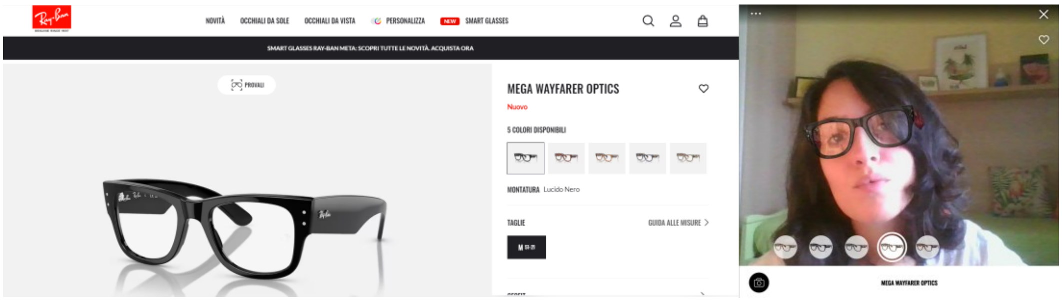

Figure 6. RayBan: product presentation.

More advanced forms of IIT include 360° views, product videos, and try-ons. For example, RayBan, a sunglasses retailer (See *Figure 6*), allows online customers to view products from various angles by displaying interactive photos that change as the user drags. Also, recently, RayBan developed a virtual mirror that allows customers to see themselves while wearing a specific type of glasses in order to reduce returns and customer dissatisfaction.

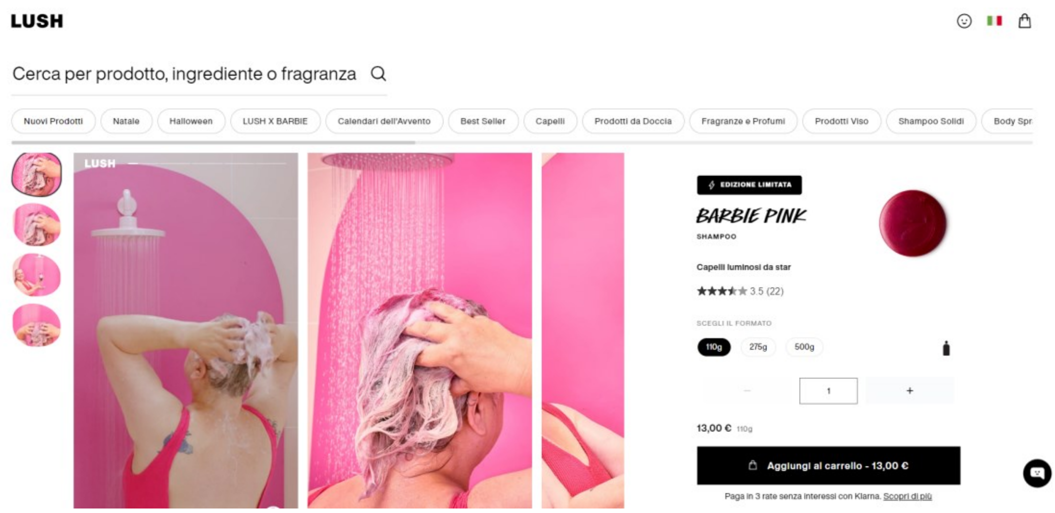

Figure 7. Lush: product presentation.

Cosmetic retailer Lush uses short movies in online stores to convey the sensory experience of using their products (See *Figure 7*), including the intended effect of inducing the sensation of smell while using them. Although these video examples may not be technically interactive, they serve the same purpose of enhancing the online shopping experience.

Another example of advanced IIT is Shoogleit (Padilla et al., 2011) (See *Figure 8*). This interactive interface allows users to virtually "move" fabric by touching the screen or dragging their mouse, simulating tactile gestures such as stroking. Research indicates that this technology leads to higher perceived diagnosticity (i.e., the ability to assess product features) and more favorable emotional responses. Interestingly, minimal differences were observed between using an interactive interface and physically touching the product.

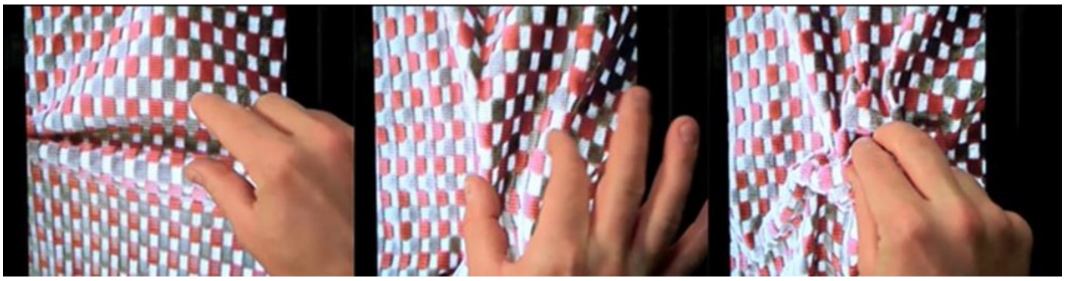

Figure 8. Shoogleit interaction.

Studies have found that the level of IIT positively influences shopping enjoyment and reduces the perceived risk associated with online retailers. This suggests that online apparel retailers may need to continually develop innovative, yet engaging IIT features to meet consumer demands and secure customer loyalty (Fiore et al., 2005).

Also, IIT aims to bridge the gap between physical and online shopping experiences by providing customers with more immersive and informative interactions with products before purchasing. There are seven different types of IIT categorized in the scientific literature, as follows:

1. 360-Degree Product Views: This category allows users to view products from all angles through a 360-degree perspective interactively. It provides a comprehensive product view, enabling users to rotate and inspect it

virtually. Research has shown that 360-degree views positively impact consumers' perception of product attributes (Mallapragada et al., 2016; Yoo & Kim, 2014)

2. Zoom and Pan Features: Zoom and pan features allow users to zoom in on product images for a closer look and pan across the image to explore details. These features enhance the visual inspection of products. Scientific studies have found that zoom and pan functionalities positively affect users' perceived product quality and their purchase intentions (Song Southworth et al., 2012).
3. Product Videos: Product videos showcase the product in action, such as a demonstration or a model wearing clothing. They provide dynamic visual presentations that help users understand how the product works or appears in real-life scenarios. Research indicates that product videos influence consumers' purchase decisions and reduce product returns (Cheng et al., 2022; Schulz et al., 2019).
4. Virtual Try-On: Virtual try-on technology uses AR to allow users to virtually "try on" products like clothing, accessories, or makeup. It enables users to visualize how a product would look on them. Scientific literature suggests that virtual try-ons significantly impact purchase intentions and reduce uncertainty in online fashion shopping (X. Chen et al., 2023; J. Kim & Forsythe, 2008).
5. Interactive Fabric Simulation: This category allows users to interactively manipulate the texture or fabric of products interactively, typically clothing or upholstery. Users can virtually touch or stroke the material to simulate the tactile experience. Such interactivity can positively influence users' sensory perceptions of products (Overmars & Poels, 2015b, 2015a).
6. Customization Tools | Product Configurators: These tools enable users to personalize products, such as choosing colors and sizes or adding custom text or graphics. Research has shown that customization tools increase user engagement and satisfaction, leading to higher conversion rates (Heim & Sinha, 2005; McKinsey, 2021; Roy et al., 2023).

7. Augmented Reality (AR): AR technology overlays digital information, suc.h as product details or virtual objects, onto the real-world environment viewed through a device like a smartphone or tablet. AR can be used for tasks like visualizing furniture in a room or trying on makeup virtually by enhancing the interactive and immersive aspects of online shopping (Lavoye et al., 2023; Smink et al., 2020).

All IIT categories previously examined will be considered and implemented in the applications developed within the user studies to build different types of experiences, as follows:

- In Chapter 3, the categories (1) 360-Degree Product Views, (2) Zoom and Pan Features, (3) Product Videos, (6) Customization Tools | Product Configurators.
- In Chapter 4, the categories (1) 360-Degree Product Views, (2) Zoom and Pan Features, (4) Virtual Try-On, (6) Customization Tools | Product Configurators.
- In Chapter 5, the category (5) Interactive Fabric Simulation.

"To the question:

Are virtual realities experiences?

I would not hesitate to answer in the affirmative."

Maldonado T.

Reale e virtuale.

Feltrinelli, p. 58, Milano, 2007

2.4 Virtual Reality Technologies

VR has emerged as a transformative technology with significant potential to revolutionize the landscape of online shopping in the retail industry. By seamlessly blending the physical and digital realms, VR enables consumers to embark on immersive and interactive shopping experiences from the comfort of their own homes. Through VR headsets and specialized applications, customers can explore virtual stores, visualize products in three dimensions, and even interact with virtual representations of products before purchasing. This technology holds the promise of enhancing the sensory aspects of online shopping, such as touch and vision, by providing a more realistic and engaging shopping environment. Furthermore, it can address some of the limitations of traditional online shopping, such as the inability to inspect products physically. As VR continues to evolve and become more accessible, its role in online retail is poised to offer consumers novel and captivating shopping experiences while providing retailers with innovative tools to engage customers and boost sales. This presents a fascinating intersection of technology and commerce, with the potential to reshape the future of online retail.

But first, a brief historical overview of VR development is necessary. The term "Virtual Reality," which is essentially an oxymoron, has existed for quite some time, although its true widespread appeal has only recently become apparent to the public. "As early as the 1990s, there were concepts outlining how VR could “enhance the e-commerce shopping experience” (Walsh & Pawlowski, 2002) or “transform our work environments” (Wienrich et al., 2021), even if there have been several VR conceptualizations so far (Berg & Vance, n.d.; Cowan & Ketron, 2019; Goldman Sachs, 2016; Isaac, 2016; KPMG, 2016; Meißner et al., 2019; Merriam-Webster, 2018; PricewaterhouseCoopers, 2018; Sanderink, 2017).

Nonetheless, during that period, it was evident that the limited bandwidth infrastructure could pose a barrier to the widespread adoption of VR technology (Walsh & Pawlowski, 2002).

Therefore, VR often faced declarations of its demise (Slater & Sanchez-Vives, 2016) until the emergence of the Oculus Rift Kickstarter campaign in 2012, which aimed to make high-quality HMDs affordable for a broader consumer base (Anthes et al., 2016). Remarkably, this campaign achieved its initial funding target of US$250,000 in less than 24 hours, ultimately raising over US$2.4 million by the campaign's conclusion (Anthes et al., 2016).

In 2016, several HMD models (that are still popular today), including the HTC Vive, Oculus Rift, PlayStation VR, Google Daydream VR, and Samsung Gear VR, were introduced. This marked a significant breakthrough in the consumer market for VR. Consequently, it took nearly half a century from Ivan Sutherland's initial vision of a head-mounted three-dimensional display, often referred to as "the Sword of Damocles" (See *Figure 9*) (Sutherland, 1968), to the actual commercial viability of consumer-grade HMDs.

Figure 9. The Sword of Damocles.

Whenever VR is discussed, the concept of **'immersion'** naturally arises. However, it is frequently observed that the scientific literature needs to provide a comprehensive explanation of this term. The term 'immersion' is inconsistent throughout the literature and is defined and employed in two distinct manners by scholars (Cummings & Bailenson, 2016). The primary point of contention revolves around whether immersion is considered *objective* (a quantifiable system configuration, as seen in Slater & Wilbur (1997) or *subjective* (an individual's response to a VR system, as exemplified by Witmer & Singer (1998).

To prevent any potential misunderstandings, it is important to clarify that in this thesis, we adhere to the perspective of Slater & Wilbur (1997), defining **immersion exclusively as an objective measurement**.

While immersion pertains to the technical capabilities of a system, it represents the physics of the system (Slater & Sanchez-Vives, 2016). Conversely, **presence** is a subjective attribute associated with immersion (Slater & Sanchez-Vives, 2016). The proposed relationship between these two variables can be articulated as follows: The higher the degree of immersion in a VR system, which translates to a more convincing and engaging sensory experience, the stronger the user's perception of presence within the virtual environment (Schultze, 2010).

Immersion comprises technological concepts regarding whether a system is inclusive, extensive, surrounding, and vivid (Steuer, 1992).

- **Inclusive.** Inclusiveness refers to the capability of a VR system to fully obscure any aspect of physical reality (Slater & Wilbur, 1997). This concept primarily pertains to visual aspects, exemplified by an HMD that completely covers the user's field of vision, effectively blocking out physical reality from their visual perception. This contrasts with desktop environments where physical reality remains visible around the screen and in the peripheral field of vision, depending on the screen size. However, inclusiveness extends beyond visual isolation to encompass other aspects of physical reality. This includes the suppression of ambient acoustic noise, as noted by Slater & Wilbur (1997), who also highlight the weight of an HMD as a factor influencing inclusiveness. Ideally, an HMD would be completely weightless, allowing users to be oblivious to the lingering presence of physical reality (Slater & Sanchez-Vives, 2016). Therefore, when compared to Ivan Sutherland's "Sword of Damocles (Sutherland, 1968), contemporary consumer-grade HMDs would be rated higher in terms of inclusiveness.

- **Extensive.** Extensiveness refers to the number of sensory systems that are engaged, meaning that "displays are more extensive when they accommodate a greater range of sensory systems" (Slater et al., 1995). On the other hand, it also considers the stimulation intensity for each sense. For instance, it distinguishes between systems that offer a purely visual experience and those that incorporate auditory sensations. Moreover, the degree of intensity for each sensory aspect can also be evaluated. Therefore, if all other factors are equal, a system that supports spatialized sound is considered more extensive than one that only provides non-spatialized sound, subsequently offering a higher level of immersion (Slater et al., 1995). While visual and auditory senses have been the primary focus, haptic feedback, and even olfactory sensations may potentially play a role in the future (Mihelj et al., 2014).
- **Surrounding.** Surrounding refers to the degree to which a VR system can create a comprehensive 360° immersive experience. This can depend on whether a system's supported field of view is expansive and panoramic (e.g., HMD) or limited to a narrow field of view (e.g., a small desktop screen) (Slater & Wilbur, 1997). However, the concept of surroundings is not solely restricted to the visual sense. To illustrate this, Slater et al. (1995) explain that systems are considered surrounding "to the extent that a person's sense organs can receive information from any (virtual) direction and to what extent the individual can turn in any direction while remaining within the environment." To distinguish it from the concept of inclusiveness, consider the following example: A system that achieves inclusiveness does not necessarily have to be surrounding, and vice versa. Noise-canceling headphones can effectively isolate a person from physical reality, aligning with the inclusiveness concept, but they are not surrounding.
- **Vivid.** According to Steuer (1992), vividness is defined as "the richness of representation in a mediated environment, as determined by its formal attributes; that is, how an environment presents sensory information." He further suggests that vividness can be divided into two components:

breadth (referring to whether multiple senses are stimulated simultaneously) and depth (about the specific quality of each sensory channel) (Steuer, 1992). When analyzing the conceptual framework presented by Slater & Wilbur (1997), some aspects of these factor definitions are already integrated into the concept of extensiveness, especially in the case of breadth. As for the depth factor, Slater & Wilbur (1997) primarily emphasize the naturalness, variety, informational content, and richness of the representation. Factors influencing vividness include a display's pixel resolution, rendering parameters, and even the support for dynamic shadows (Slater & Wilbur, 1997). So far, the display quality of state-of-the-art HMDs (e.g., Oculus Quest 2) is increasingly growing, and we hope that in about 5-10 years, issues such as limited pixel resolution and screen door effect will be reduced.

In addition to the previously discussed concepts, Slater et al. (1995) introduce '**matching**' as another concept, which assesses the extent to which information presented by the immersive system (e.g., visual data displayed in an HMD) aligns with the user's proprioceptive feedback resulting from their body movements. Essentially, the better the body mapping, the more accurately the system can reproduce body movements, leading to a higher potential for alignment between proprioception and sensory data (Slater et al., 1995).

Similarly, Steuer (1992) introduces '**mapping**' as a concept, defining it as the system's ability to link its controls to changes in the virtual environment naturally and predictably. Steuer doesn't treat mapping in isolation but incorporates it as one of the factors that constitute interactivity alongside 'speed' (system responsiveness to user input) and 'range' (the scope of parameters that can be modified in the virtual environment). Collectively, Steuer (1992) defines 'interactivity' as the degree to which users can actively participate in altering the form and content of a virtual environment in real time. So, as Slater & Wilbur (1997) emphasized the technological aspect in their concepts of immersion, Steuer (1992) underscores that the properties of the immersive system also influence interactivity in use.

In summary, Slater & Wilbur (1997) argue that each immersion dimension inherently possesses associated scales, signifying the extent to which they are realized. Additionally, they emphasize that these dimensions exist across multiple levels within VR systems. Consequently, VR systems can be classified based on how prominently the individual immersion dimensions are manifested. Various classification schemes have been proposed in the literature, with some scholars making a simple "immersive" vs. "non-immersive" distinction. In contrast, others differentiate between "fully immersive," "semi-immersive," and "non-immersive" VR. However, the categorization proposed by Gutierrez et al. (2008) is primarily based on the degree to which users perceive physical reality during their VR experience, following a descending order of isolation: HMDs are considered fully immersive, CAVE systems are semi-immersive, and desktop environments are non-immersive. According to Slater & Wilbur (1997), this categorization predominantly corresponds to the concept of inclusiveness and neglects consideration of all other immersion dimensions. In contrast to the previous distinctions, this thesis will differentiate between **immersive VR systems and desktop VR systems.**

2.4.1 VR Systems

VR systems can be categorized based on their level of immersion. However, to establish a comprehensive understanding of VR systems and differentiate them from other immersive systems, it is crucial to delineate VR systems from the rest. In a broader sense, immersive systems are recognized for their ability to alter or enhance the user's perception of reality intentionally (Cummings & Bailenson, 2016). Perhaps the most well-known framework for distinguishing among various types of immersive systems is the **Reality-Virtuality Continuum,** developed by Milgram and Kishino in 1994. This continuum encompasses physical reality on one end and a wholly artificially generated environment (VR) on the opposite end. In this thesis, we adhere to the definition of physical reality proposed by (Pfeiffer et al., 2020), which implies that "in physical reality, we directly perceive the physical world, and first-order sensations and actions yield direct consequences following the laws of physics. "Anything that falls between these two extremes on the continuum, where "real-world and virtual-world elements coexist within a single display," is referred to as Mixed Reality (MR) (Milgram & Kishino, 1994). Depending on the extent and manner of integration, further distinctions are drawn between AR, where virtual elements overlay reality, and Augmented Virtuality (AV), where reality overlays virtuality (Flavián et al., 2019). It is important to emphasize that the continuum primarily pertains to visual perceptions. *Figure 10* provides a visual representation of how the different systems are demarcated along the Reality-Virtuality Continuum (Milgram & Kishino, 1994).

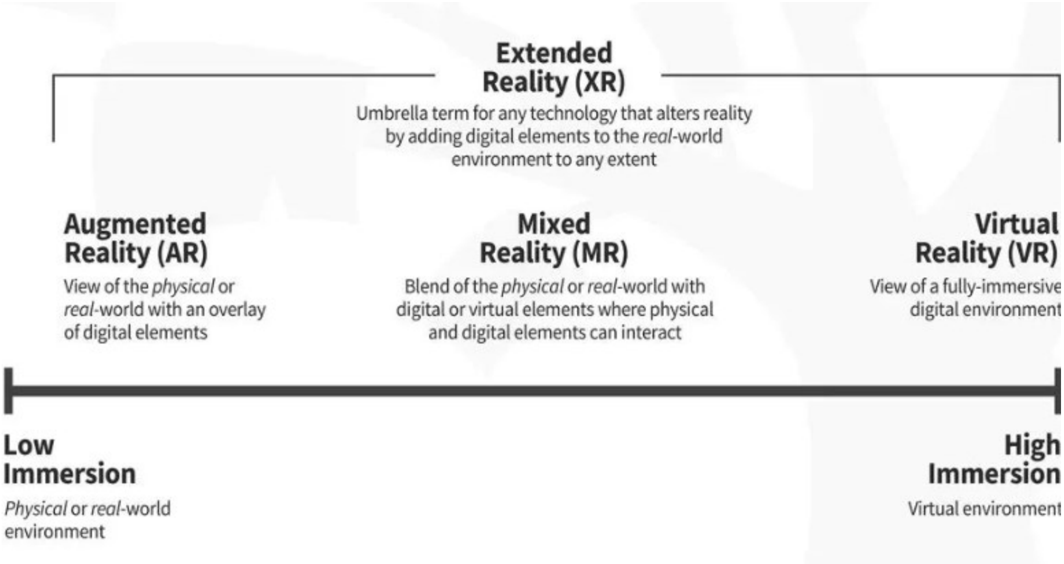

Figure 10. Representation of the virtuality continuum with current XR technologies according to the spectrum of immersion (Source: Interaction Design Foundation).

From a technical point of view, a typical VR system includes three key elements:

- **Tracking system responsible** for constantly transmitting data about position and spatial orientation.
- **Rendering computer** responsible for processing the tracking data, creating the 3D environment accordingly, and transmitting the rendered sensory information.
- **User interface** designed to transmit the sensory information to the user (Blascovich et al., 2002).

In summary, there are two main approaches for creating immersive VR experiences: HMDs and CAVEs (Cave Automatic Virtual Environments)

(Meißner et al., 2020). While CAVE-based systems have not garnered significant public attention due to their high cost and space requirements (Anthes et al., 2016; Mihelj et al., 2014), state-of-the-art HMDs have focused on the consumer market (Anthes et al., 2016). Unlike CAVE setups, which demand a large, room-sized static technical arrangement, HMD-based systems integrate the tracking system and the display into increasingly lightweight, portable HMDs. Regarding display technology, a distinction is drawn between mobile (stand-alone) HMDs like the Oculus Quest and stationary systems like HTC Vive Pro or Oculus Rift (Anthes et al., 2016). Stationary systems are known for their higher computing power, whereas mobile systems offer greater inclusivity owing to increased freedom of movement. Nevertheless, it's important to emphasize that HMD-based systems continue to evolve in various system-specific aspects, including display resolution, field of view, weight, tracking accuracy, and computing power. This constant evolution leads to a continuous enhancement in the level of immersion these systems can provide.

After introducing the fundamentals of VR and its systems, the following section includes a literature review that assesses how VR technology is currently employed in scientific studies within the retail sector.

2.4.2 State of the Art

Morton Heilig pioneered the first virtual system in the early 1960s, combining a pre-recorded colored film with sensory elements like sound and scent, albeit without personal interaction (See *Figure 11*).

Over the years, this technology underwent several enhancements, including interactive graphics, head tracking, and advanced image processing techniques that enabled individual interaction (Radianti et al., 2020). Although the first commercial VR devices entered the market half a century ago, it was only in recent years that companies began harnessing the true potential of this technology (Slater & Sanchez-Vives, 2016).

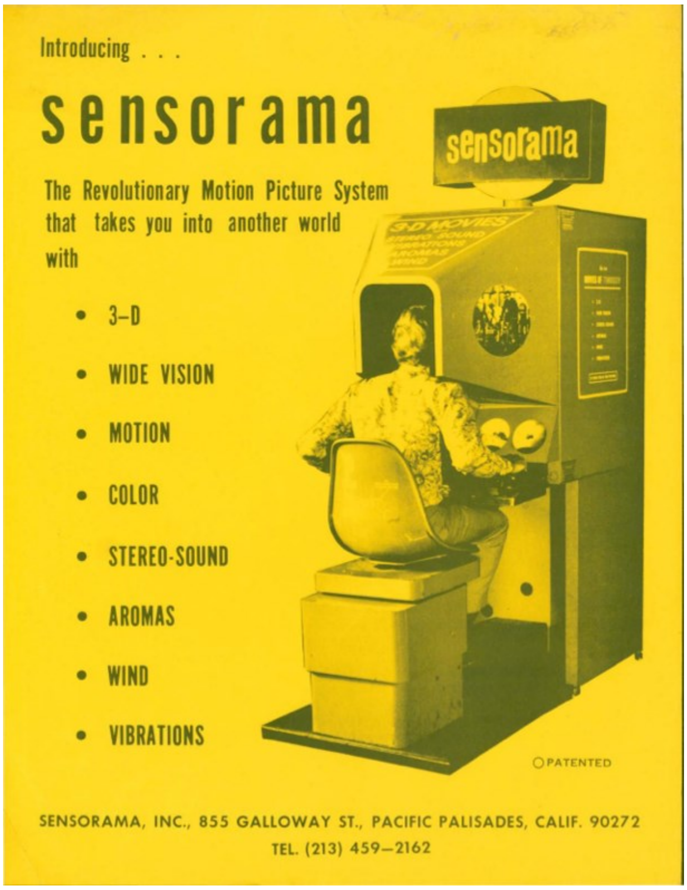

Figure 11. Sensorama was the machine designed for the cinema experience, created by Morton Heilig in 1957.

Presently, VR primarily relies on HMDs, which project images exclusively through their built-in screens (Xu et al., 2015). Coupled with gyroscopes, these headsets bring three-dimensional environments and characters to life, transcending the limitations of conventional television or computer monitors. As technology advanced, lighter virtual prototype gear became accessible to the public, prompting the gaming industry to compete in creating compelling content appealing to marketers and consumers. Nowadays, VR technology empowers consumers to immerse themselves in alternative realities that can sometimes rival real-life experiences in their impact (Farah et al., 2019a).

Companies have recognized the potential of integrating VR technologies into their marketing strategies to enhance the customer experience (Stone & Woodcock, 2014). Technology has long been at the forefront of imaginative thinking to enhance the customer experience, from storytelling to robotics, holograms, and beyond (Chen et al., 2013) In marketing, VR in campaigns is expected to elevate consumers' overall experience and loyalty, ultimately boosting company revenues (Riva et al., 2007). Over the past decade, there have been numerous success stories of brands effectively employing this technology (See *Figure 12*). For example, Mercedes allowed users to virtually explore its SL model by driving on the Pacific Coast Highway in California, offering an interactive introduction to the new design. On the other hand, Oreo used VR to promote its new cupcake-flavored cookies, immersing consumers in a fantastical world with Milk Rivers and chocolate canyons.

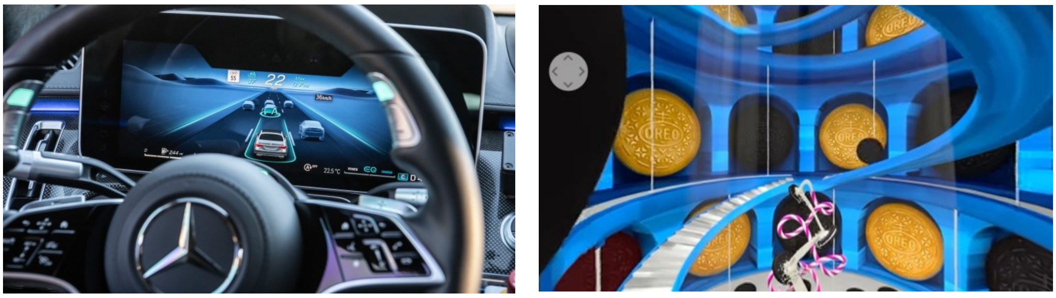

Figure 12. On the left: SL model case study by Mercedes;
On the right: Oreo VR experience case study.

Consumer adaptability to new technologies has increased, with connectivity to various platforms further enticing consumers. Therefore, VR technology is poised to revolutionize the retail landscape, simplifying logistics and business management, and enhancing the customer experience (Pantano & Laria, 2012). VR offers retailers innovative tools to transform the customer experience, engaging consumers with increasingly interactive content (Lau & Lee, 2018).

The literature on retailing demonstrates a growing emphasis on web-based platforms and e-commerce channels for retail shopping, often accompanied by a waning interest in physical stores (Fornari et al., 2018). This increased demand for online stores has compelled traditional retail channels to explore the potential of incorporating VR into the shopping experience. This exploration is crucial for them to maintain their market share and seize new opportunities (Bonetti et al., 2018).

Today, there is a pressing need for point-of-sale environments to leverage VR techniques to disseminate a wider range of valuable information, thus facilitating the decision-making process. VR tools enable the creation of innovative channels rich in interactive three-dimensional images, graphic icons, and hyperlinks (Hilken et al., 2018). These digital channels introduce key features that promote (a) immersion (the sense of being enveloped in a digital environment), (b) presence (the feeling of existing in a virtual world), and (c) interactivity, allowing users to engage with objects and environments in real-time (Oliveira et al., 2023).

Like physical stores, ambience, atmosphere, and store layout play a significant role in virtual contexts (Lyu et al., 2022). Immersing customers in visually appealing environments is a direct effort to stimulate purchases. The unique atmosphere, impossible to replicate elsewhere, is the primary point of attraction, as people crave diverse daily experiences. The goal is to bridge the gap between reality and the digital sphere by accompanying the customer throughout their entire visit, from arrival to payment and even departure (Burke, 2005). For example, a travel agency might offer customers virtual tours of various destinations to facilitate their travel decisions. This not only helps customers make choices but also fosters brand loyalty and trust (Oncioiu & Priescu, 2022). VR can also reduce the patience factor, bridging the gap between consumers and retailers and, in some cases, rendering physical stores unnecessary (Pizzi et al., 2019).

The literature in this field has extensively discussed the most effective e-store modalities for presenting merchandise and related information within an appealing storefront framework (Vrechopoulos, 2004). Numerous studies have emphasized how VR can enhance navigation and, in turn, improve the overall shopping experience (Xi & Hamari, 2021). With the understanding that virtual appeal positively correlates with enhanced consumer perceptions and satisfaction, many retailers now provide innovative and engaging tools to create more efficient online (Pantano & Laria, 2012; Pantano & Servidio, 2012). Notably, there is a growing emphasis on visual and aesthetic appeal over the products themselves.

Considering the literature review on various applications of VR in the retail field, it is important to note that while this technology holds significant potential for retailers to enhance the consumer experience, retailers still need to embrace it fully. Although there are several literature reviews, mostly belonging to the Marketing/Business sector, in contrast there are few user studies in the field. Recognizing this missed opportunity, this research will shed light on the existing applications and how to improve the user shopping experience exploiting digital technologies.

2.4.3 VR Applications in the Retail Field

If we look at the applications that exploit VR to implement retail experiences, we discover that they still need to be implemented and improved. An enlightening vision related to them has been provided by (Xi & Hamari, 2021) that reports on the user studies in the literature, as shown in the *Table 1* below:

Table 1. Product categories analyzed in the VR retail context (Source: Xi & Hamari, 2021).

Type
Food and non-alcoholic beverages/Water/Milk (n = 25)
No specific and mixed products (n = 17)
Clothing (including shoes & accessories) (n = 12)
Alcoholic beverages (wine & beer) (n = 6)
Stationeries (n = 4)
(Luxury) bags (n = 3)
Electronics (n = 3)
Hand-held tools, cleaning products, and toiletries (n = 2)
Devices for car (n = 2)
Brand’s mascot (n = 1)
Flowers (n = 1)
Books (n = 1)
Furniture (n = 1)
Hotel (n = 1)

As we can see from the table, the literature on VR shopping experiences is still limited. Thus, it presents a limited number of user studies in some fields of retail that still need to be improved. Moreover, the existing contributions cannot provide some guidelines on the features/components to be displayed in the VR shopping experience. Therefore, we aim to present a VR user interface that includes more features to communicate the product features more effectively and configure it by developing a user study in a specific retail area.

DO NOT TOUCH!

How often do children hear this imposition repeated.

No one would ever say, don't look, don't listen,

but it seems that touch is different; many think they can do without it.

Munari B.

I laboratori tattili.

Corraini, p. 3, Mantova, 2004

2.5 Haptic Technologies

Haptic technology is the second technological driver analyzed and deployed within this doctoral thesis. "Haptic" originates from the Greek word "haptesthai," which means touch. According to Gibson (1966), haptics is "an individual's ability to perceive the world around their body through the use of their body."

The haptic sensory modality encompasses several types of receptors. These include mechanoreceptors, which detect skin deformations; proprioceptors, which provide information about joint angle, muscle length, and tension; and thermoreceptors, which code for absolute and relative temperature changes. These receptors collaborate with the primary sensory cortex (Marzvanyan & Alhawaj, 2023; Purves et al., 2001). Unlike vision and hearing, which are passive senses that only receive input and cannot interact with the environment, the haptic channel is a bidirectional communication channel. It enables both input and output and allows us to actively explore and gain information about pressure, texture, stretch, motion, vibration, and temperature in our surroundings. Gibson (1966) underscored the intimate connection between haptic perception and body movement, emphasizing that haptic perception involves active exploration.

Haptic perception in human-computer interaction has frequently been proposed to facilitate more natural interactions (Helbig & Ernst, 2008). To address this, researchers have designed and assessed various mechanical haptic devices starting from the 90s (Akamatsu & Sato, 1994; Muench & Dillmann, 1997; Münch & Stangenberg, 1996). Haptic technology encompasses technologies that engage the user through haptic feedback, typically achieved by applying forces, vibrations, or motions to the user via a force-feedback device. These devices allow individuals to perceive a sense of touch while employing hardware devices like joysticks or a mouse to interact with digital displays. They are employed to replicate a wide array of object properties, including mass, stiffness, viscosity, textures, pulses, waveforms, vibrations, and simultaneous compound effects, offering users haptic feedback during interactions with a system.

Nowadays, haptics is frequently employed as an umbrella term encompassing various distinct subcategories, which include **proprioceptive** (about general sensory input concerning body position and the relative positions of adjacent body parts), **vestibular** (related to the perception of head movement), **kinaesthetic** (associated with the sensation of bodily motion), **cutaneous** (about sensory input from the skin), and **tactile** (related to the perception of pressure experienced through the skin) (Cullen & Zobeiri, 2021).

When discussing computers, haptic feedback can encompass a spectrum, ranging from the basic tactile sensation of pressing keys on a keyboard to more advanced forms of force feedback provided by mechanical devices.

2.5.1 Touch in Graphical User Interfaces

Since the introduction of the computer mouse by English, Engelbart, and Berman in 1967 (See *Figure 13*), along with the development of the direct manipulation interface by Shneiderman in 1983, desktop metaphor interfaces centered around windows, icons, menus, and pointing, commonly referred to as windows, icons, menus, and pointing (WIMP) interfaces, have established themselves as the predominant paradigm in human-computer interaction.

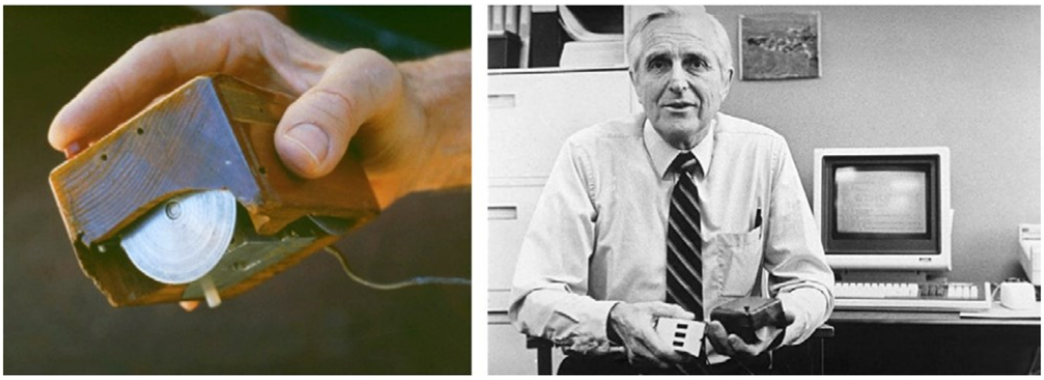

Figure 13. On the left: The first mouse. On the right: Inventor Douglas Engelbart holding his invention in his left hand and an early three-button variation in his right hand.

These interfaces are employed for various activities, including word processing, spreadsheet management, gaming, 3D modeling, social networking, and video streaming on various platforms, including PCs, Macs, Linux systems, desktops, laptops, and more. Millions of individuals dedicate much of their lives to interacting with WIMP interfaces.

Typically, a desktop computer setup comprises a mouse, keyboard, a flat 2D screen, and small speakers. Most contemporary graphical user interfaces involve manipulating on-screen elements with a cursor controlled by a mouse (Myers, 1998).

The mouse is the dominant device for pointing and selecting, making it one of the most frequently used tools in many people's daily routines. It is handled more frequently than cash, a steering wheel, doorknobs, pens, hammers, or screwdrivers (Zhai & MacKenzie, 1998).

There have been some ergonomic improvements to the mouse over the years, such as thumb rests and grips, wireless technology, trackball and vertical mouse, and weight reduction, even if its fundamental design has remained largely unchanged.

2.5.2 Ubiquitous Computing and Tangible Interaction

While some researchers are focused on enhancing visual interfaces by incorporating haptic technology into desktop systems, others are advocating for a more radical shift. Visionaries like Weiser (1991) and Norman (1999) have been advocating for the abandonment of the traditional desktop metaphor.

In line with Mark Weiser's concept of the "invisible computer", ubiquitous computing aims to seamlessly integrate computation into the environment, eliminating the distinction between computers as discrete objects.

This approach is also known as Ambient Intelligence (De Ruyter & Aarts, 2004) or, more recently, Everyware (Greenfield, 2010). Proponents of this concept envision that embedding computation into everyday objects and surroundings will enable people to interact with information-processing devices more naturally and spontaneously, regardless of location or circumstances.

Expanding on ubiquitous computing, Ishii & Ullmer (1997) introduced a framework for tangible interaction. Tangible interaction seeks to bridge the gap between the virtual realm of cyberspace and the physical environment by connecting digital bits with tangible physical objects. Since the inception of tangible user interfaces, numerous studies in the field of tangible computing have been undertaken (Djajadiningrat et al., 2004; Van Den Hoven & Eggen, 2004)

A classic example of this approach is the "Tangible Bits" system, developed at the MIT Media Lab by Hiroshi Ishii and Brygg Ullmer and first described in 1997.

Figure 14. inFORM interface, a revolutionary new interface produced by the MIT Media Lab and the Tangible Media Group, 2013.

"Tangible Bits" are the union of digital information and easily handled common tools or architectural surfaces. The idea is to allow the user to manipulate and grasp the information as a concrete physical object. The purpose is to bridge the gap between cyberspace and real space and foreground and background human activities (See *Figure 14*).

Due to the rapid integration of digital technology into our society, it's becoming increasingly evident that computing activities will no longer be confined to a single device.

Despite the promising developments in force feedback, tangible interactions, and the concept of the disappearing computer, millions of people worldwide continue to conduct their daily work at traditional desktop computers. While computer chips have become smaller, more affordable, more powerful, and widely accessible, innovations in user interfaces appear to lag.

Mobile devices have gained widespread use, but they haven't completely replaced traditional setups. For many of us, a significant portion of our work still thrives within a desktop environment equipped with a large flat screen, ergonomic keyboard, and mouse. Despite its apparent limitations, the desktop computing model has deeply ingrained itself in our society and cannot be expected to vanish overnight, especially considering the emergence of HMDs.

2.5.3 Haptic Feedback

Regarding techniques designed to elicit haptic sensations through optical methods, a variety of terms have been proposed, including "sticky icons" (Worden et al., 1997), "simulated force feedback" (Van Mensvoort, 2002), "pseudo haptic feedback" (Lécuyer et al., 2004), "force fields" (Ahlström et al., 2002), and "gravity" (Park et al., 2006).

To prevent any potential misunderstandings, we can also use the terms "mechanically simulated haptic feedback" or "haptic force feedback" and "optically simulated haptic feedback" or "visual force feedback." (See *Figure 15*)

We add the adjective "simulated" to highlight that these techniques are reproductions, as defined by the Oxford American Dictionary, meaning "to imitate the appearance or character of."

This underscores that while optical and mechanical methods can replicate haptic feedback, they can only recreate a subset of the haptic experiences and lack the sensory richness found in unmediated haptic interactions, such as embracing or kissing. We have chosen this terminology because it accurately describes the approach: haptic feedback is simulated through mechanical or optical means.

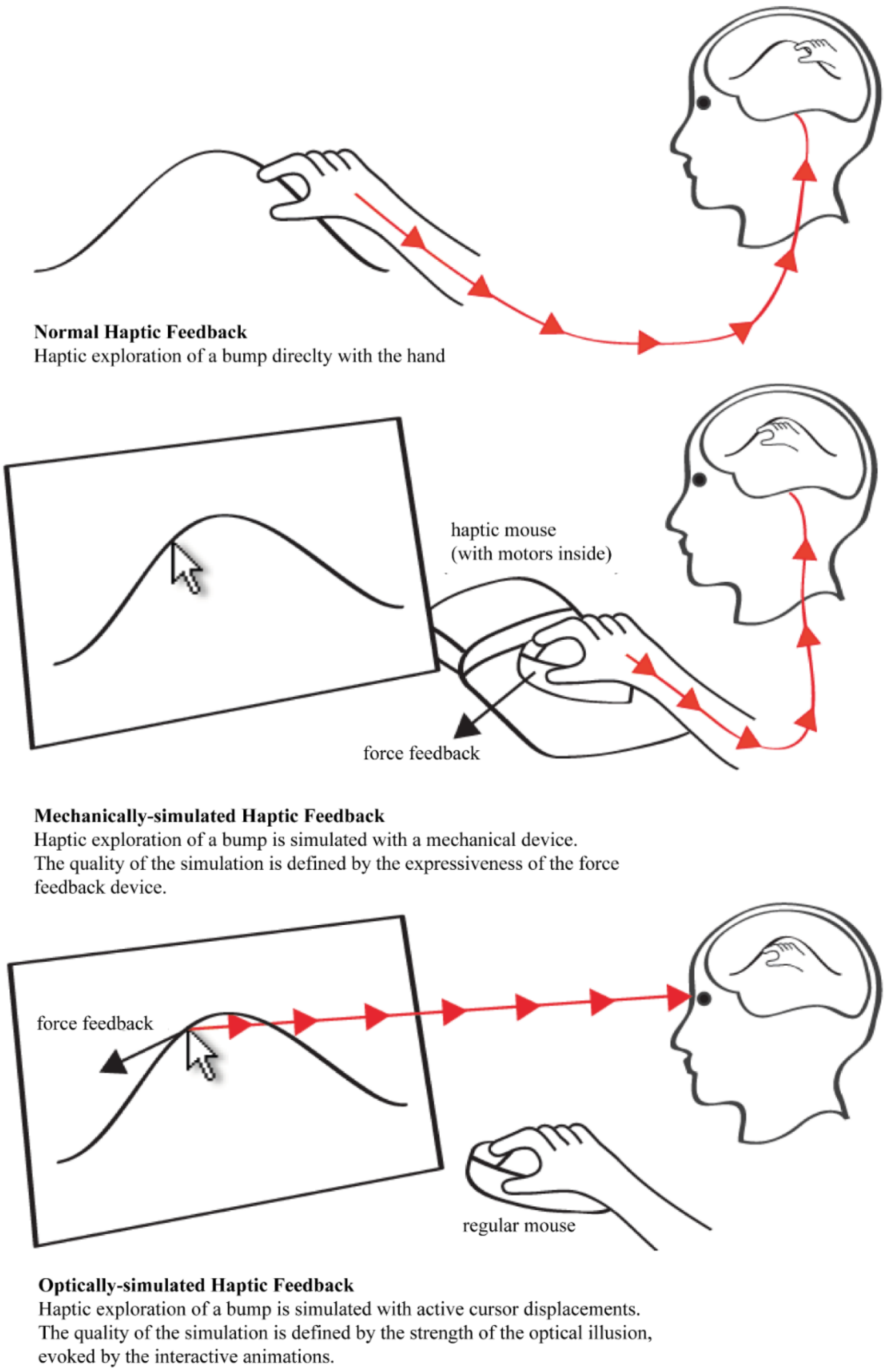

Figure 15. The haptic experience of actively exploring a slope (a) can be simulated both mechanically (b) and optically (c). The mechanical technique simulates the bump shape via force feedback, asserted by a mechanical device, which the user straightforwardly senses and percieves via the haptic sensory modality. The optical technique simulates the haptic feedback via an optical illusion, which is evoked by displacing the cursor on the screen as if there are forces asserted on the mouse.
(Source: I. M. K. Van Mensvoort, 2009).

In summary, the haptic force feedback is experienced by the user via the haptic- or visual sensory modality. Lederman & Klatzky (1987) developed a series of exploratory procedures of the hand with surfaces/objects, as shown in *Figure 16*.

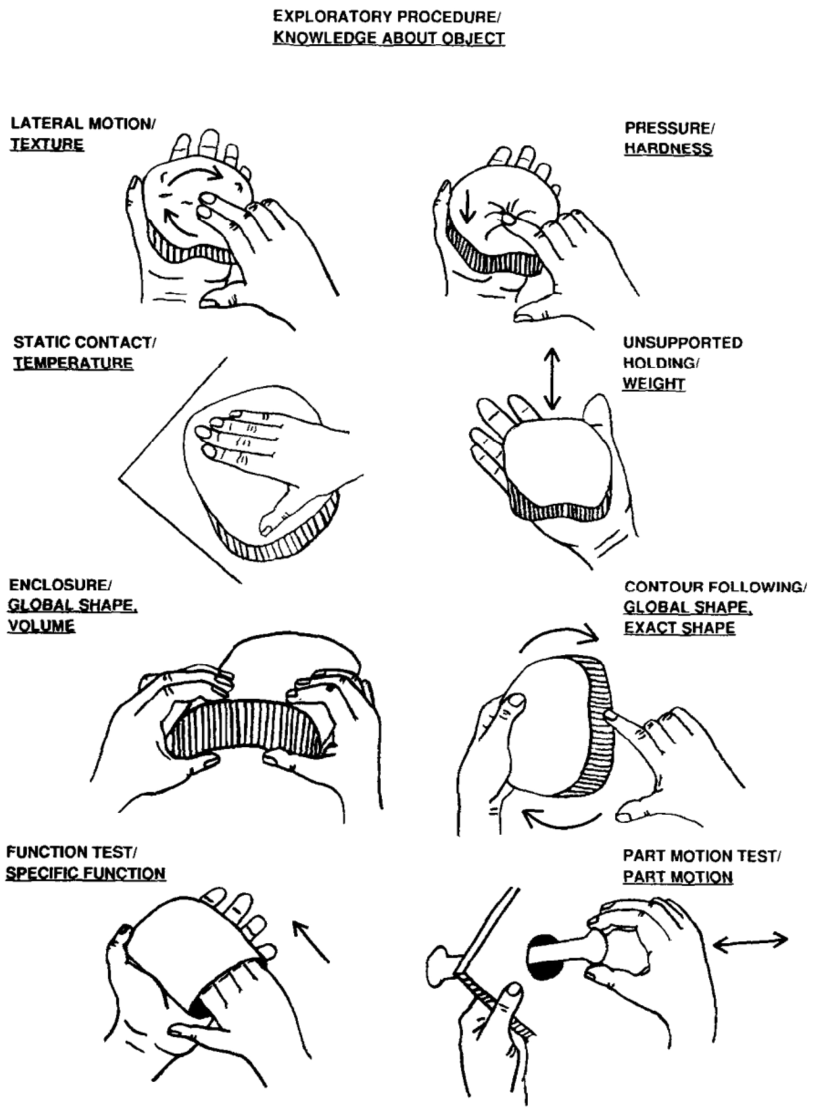

Figure 16. Exploratory procedures. The nature of desired physical information guides strategic touching ("action for perception"). (Source: Lederman & Klatzky, 1987).

In their study, they examined what people do with their hands when asked to make haptic evaluations of various object properties. More specifically, on each trial subjects were initially shown a multidimensional object (the standard stimulus), and asked to examine a specific property, e.g., its hardness. Next, they were presented in sequence with a set of three other multidimensional objects (the comparison stimuli).

Subjects had to select the one comparison object that best matched the standard in terms of the named dimension (hardness). Hand movements were videotaped and subsequently analyzed. One thing was immediately obvious: although subjects were usually unaware of what they did with their hands, the movements themselves were both purposive and systematic. Subjects performed highly stereotypical movement patterns, which possessed both necessary and typical features; these patterns, they call ‘Exploratory Procedures’.

2.5.4 Haptic Imagery

According to MacInnis & Price (1987), 'imagining' can be defined as a cognitive process that involves the presentation of sensory information within working memory. As perception encompasses a multi-modal experience, imagery can serve as a mental reconstruction of an experience, potentially engaging multiple senses. According to the research conducted by Bone & Ellen (1992), imagery may encompass visual, olfactory, gustatory, and tactile sensations. Additionally, scientists have demonstrated a connection between haptic imagery and visual imagery (Lacey et al., 2014) and the ability of mental images to contain tactile elements (Heller et al., 1999). Kaski (2002) defines haptic imagery as the formation of mental representations of tactile information. In human-product interaction, haptic imagery can be understood as mentally constructing a representation of the tactile information one would obtain from interacting with a product. In this regard, providing consumers with the appropriate information to shape their haptic imagery during product interaction may lead to a more immersive experience.

Although limited scientific research has been conducted specifically in haptic imagery, some studies have explored the potential effects of imagining sensory information. For instance, Köster et al. (2014) successfully manipulated olfactory imagination using descriptive words to convey odors. This empirical research revealed that individuals who reported strong olfactory imagery experience odors differently from those with weaker imagery. Another study by Bulsing et al. (2007) employed various descriptive words for odors, resulting in significant differences in participants' attitudes toward these odors based on the words used. Notably, participants did not smell the odors, but the study demonstrated that people associated specific words with odors. Given the ability of these studies to manipulate sensory imagery through words, the current research also utilized words to manipulate haptic imagery. The words chosen for this study were selected based on Fenko et al. (2010) research, which identified words that best describe consumers' tactile experiences. Additionally, a recent study by Cian et al. (2014) demonstrated that pictures can enhance dynamic imagery, which is an image that viewers perceive as having a sense of movement. This research effectively used pictures to influence consumer attitudes and engagement.

Considering the effectiveness of both words and pictures in influencing sensory imagery, as demonstrated in scientific research, the current study examines the effects of both words and pictures in manipulating haptic imagery. In line with the dual coding theory, pictures can enhance the memorization of written information (Paivio, 2014). Therefore, this study explores the relationship between pictures and words and assesses whether this combination can enhance the richness of consumers' product experiences.

Imagery entails a cognitive process where sensory information is stored in working memory, as described by MacInnis & Price (1987). This process involves the mental recreation of experiences using various sensory inputs. Klatzky & Lederman (1992) have proposed two fundamental principles concerning the haptic imagery system. Firstly, haptic imagery is expected to work as actual touch, potentially acting as a cue for retrieving associated information. Secondly, the content of information conveyed through haptic imagery should align with the information obtained through the sense of touch, including attributes such as softness, texture, and weight (Peck et al., 2013).

Additionally, Peck et al. (2013) have discovered that imagining touching an object produces a similar effect on perceived ownership as physical touch, but only when the individual's eyes are closed. This difference is attributed to the variance in the perception of physical control. Touching or imagining touching an object with closed eyes generates a stronger sense of physical control over the object than imagining with open eyes. The degree of vividness in haptic imagery plays a crucial role in determining the perception of physical control and ownership. Essentially, closing one's eyes and engaging in tactile imagery closely resembles actual touch due to the vividness of the imagined tactile experience (Peck et al., 2013). Therefore, the more vivid the haptic imagery, the stronger the perception of physical control and ownership.

Various visual stimuli, including zoomed pictures, product videos, and tactile product descriptions, influence the vividness of the imagined tactile experience in this study. When participants read these descriptions, zoom in on images, or view the product videos, they should experience the sensation of imagining wearing and feeling the product.

2.5.5 Haptic Feedback Simulated via Vision

Using interactive animations allows for the emulation of force-feedback device operation. The significance of movement in interactive applications is still scarcely investigated. During the early stages of graphical user interfaces, incorporating interactive animations was financially impractical due to limited processing capabilities.

Today, interactive animations can be seamlessly integrated without causing substantial performance drawbacks. While the animation of independent objects is well-explored and widely utilized in motion cinema, there has been limited research on animation directly engaging with user interaction. Optically simulated feedback leverages the visual domain's predominance over the haptic domain (See *Figure 17*).

In the early days of computing, interfaces were primarily driven by command lines, necessitating users to learn intricate codes and commands to operate the system. However, the landscape changed with the advent of Graphical User Interfaces (GUIs) and the development of the mouse by English, Engelbart, and

Berman in 1963. This transition from command-based manipulation to direct manipulation marked a pivotal shift.

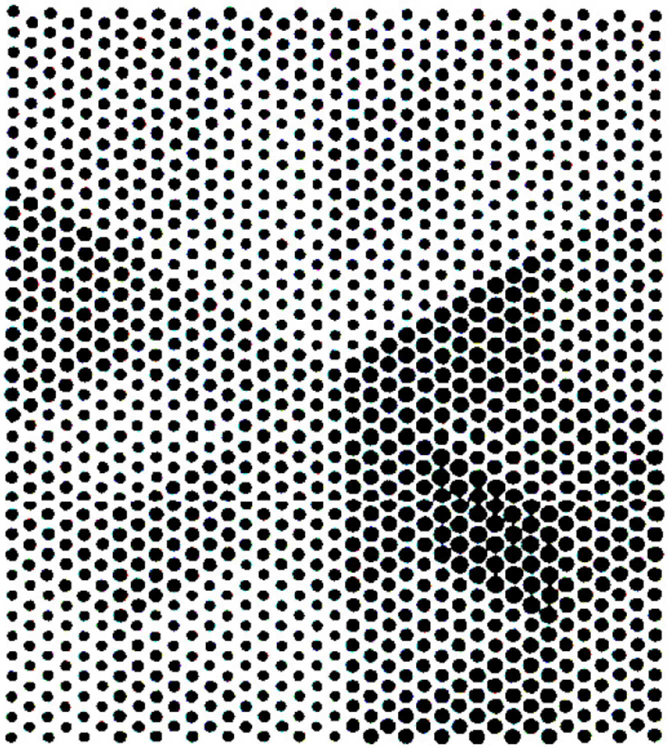

Figure 17. Chicago Tower (1962). Robert Oberdorf. Basic design exercise conducted by William Huff, using half-tone imagery. In this table, point elements of different diameters are used, organized in hexagonal modules, to create the visual effect of a three-dimensional shape perceptible only at a distance.

Direct manipulation enabled novice users to harness powerful features without the burden of mastering complex syntax and extensive command lists.

Direct manipulation encompasses three interconnected techniques, as articulated by Shneiderman (1983):

- It offers a direct, physical means to move a cursor or manipulate the objects of interest.
- It presents a tangible visual representation of the objects of interest and promptly updates the display to reflect operations.
- It eschews reliance on command languages, instead depending on operations applied to a cognitive model displayed on the screen.

In the initial stages of graphical user interfaces, the movement of on-screen objects was abrupt and lacked refinement. The incorporation of animation was cost-prohibitive due to the limited processing power available. However, as animated computer visualizations proved successful and computing power increased, animation techniques gained prominence to enhance the user interface, making it more intuitive and enjoyable to use, as shown in *Figure 18*.

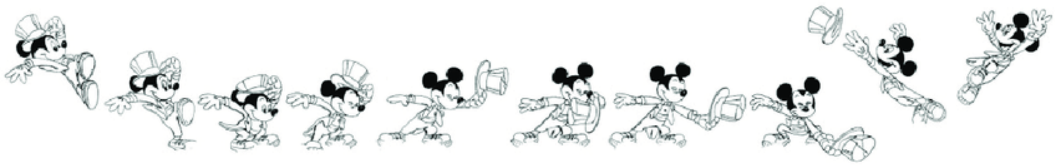

Figure 18. Sequential Animation Drawings of Mickey Mouse.

When thoughtfully applied, the principles of cartoon animation can heighten the perception of direct interaction that many human-computer interfaces strive to provide. Specifically, animation can communicate the physical attributes of the object that users manipulate, reinforcing the feeling of genuine engagement. Numerous individuals have explored interactive animations to imbue graphical user interfaces (GUIs) with a more tactile quality.

Within computer interfaces characterized by WIMP, the cursor assumes a paramount role (See *Figure 19*). It serves as the embodiment of the user's presence within the interface. The act of pointing and clicking represents the primary operation in WIMP interfaces. The cursor channel plays a vital role in the interaction with the system. Within the context of the desktop computing metaphor, the cursor effectively embodies the user (See *Figure 20*). (McLuhan, 1994) noted the tendency of people to extend their identities into inanimate objects when interacting with them. For example, when driving a car, the vehicle becomes an extension of our body, absorbing our sense of identity. In the event of a collision, the driver of the struck vehicle is more likely to exclaim, "Hey! You hit me!" rather than "You hit my car" or "Your car hit my car" for accuracy. Similarly, in desktop computing, we distill our physical presence into the diminutive arrow represented by the computer cursor.

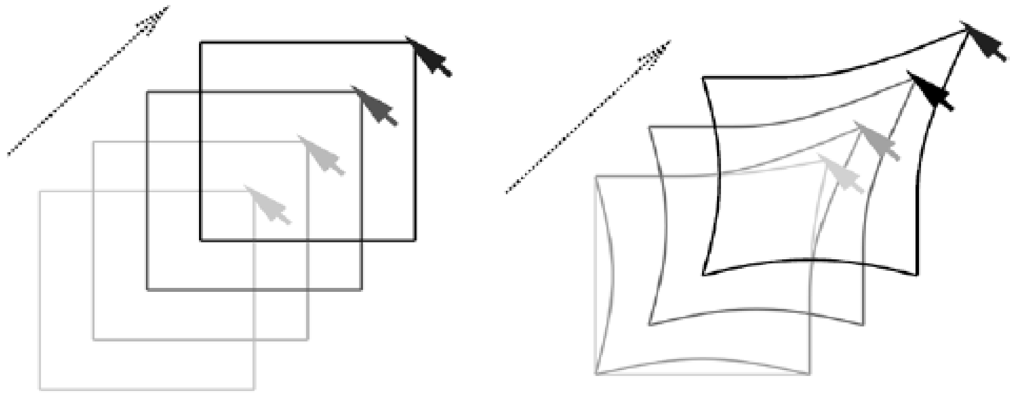

Figure 19. Enhance the illusion of direct manipulation by deforming objects as they are manipulated (Thomas & Calder, 2001).

According to Heidegger (1927), tools should be perceived as bridges or connections between humans and reality. Heidegger elucidated how tools are manifest to human beings when they are in a state of "readiness-to-hand." Tools used for specific tasks often recede from a person's attention; for instance, the focus of a person driving a nail into a wall is on the nail rather than the hammer. A person's engagement with reality occurs through the "ready-to-hand" artifact. It is only when a tool malfunctions or requires attention that it transitions into a state of being "present-at-hand" and can no longer facilitate a connection between the user and their world.

Figure 20. Changing the cursor icon has proven to be an effective and intuitive way to communicate the properties of the system (Muller, 1988).

The haptic does not intend objects but attends to

the flow of experience of which perception is a part.

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2.6 Pseudo-haptics

The sense of touch is an essential part of our daily interactions and experiences (Pramudya & Seo, 2019). Yet the current digital transition makes us participants in an environment that is no longer only physical but integrated and mediated by digital technologies, forcing us to view products on websites and make decisions such as purchasing decisions based on only one sense, vision.

But how is it possible to understand how stretchy is that dress I so badly want to buy? How do we assess whether its surface is as soft as it looks or is not? Will it be lightweight, or perhaps it is too heavy for the summer season? In short, how can I be sure that I understand the properties of the garment I am buying?

Currently, it is difficult for online shopping sites to communicate the tactile qualities of products (Wijntjes et al., 2019). Even the inability to touch a garment emerges as a crucial problem in commerce, especially for products such as garments, affecting hedonic, utilitarian values and perceived realism and generating negative shopping experiences for users (Overmars & Poels, 2015a, 2015b). On the other hand, limited interaction with products online can lead to a distorted perception of the product and sometimes cause a mismatch with the actual product.

Sensory perceptions of materials are primarily visual and tactile (Klatzky & Lederman, 1992; Klatzky & Peck, 2012). Yet, this binomial mode is absent in digital communication, which tends to focus only on the visual mode. What is missing is, in fact, a tactile and, mostly, synesthetic language in terms of how people experience and perceive materials.

Therefore, the designer is entrusted with researching and designing a solution, triggering those symbioses between the "physical environment" and the "digital environment" that characterize not only everyday life but, more specifically, the purchasing activity.

The research, therefore, questions how the digital environment invokes the relationship between the natural experience of perception and digital experience, mediated by new technologies.

The long-term goal, on the other hand, concerns the construction of systems to support the sales experience in the digital environment through an "extended" perception of fruition. How? By exploring touch in the digital environment and designing pseudo-haptic mediated perception through the development of content (such as interactive visualizations), which can communicate tactile information of materials through touch - not active but - visualized.

Pseudo-haptics intervenes in this research scenario, understood as the use of touch-based illusions created by cross-modal perceptual interactions by altering the visual feedback of the hand (or mouse cursor) (Collins & Kapralos, 2019; Ujitoko & Ban, 2021). Through pseudo-haptics, it is possible to stimulate design reflections designed to propose new ways of representing materials and their properties in the digital through interactive models that simulate the behavior of the real material. Pseudo-haptics recalls the concept of "synesthesia" (Riccò, 1999), a cognitive phenomenon in which two or more senses are activated by a stimulus that affects only one of the senses. In cinematography, we also speak of "haptic vision," referring to the possibility for the user to perceive virtual places that are almost real since the haptic sense is the sense related most to the perception of reality.

Numerous studies on human perception indicate that stimuli in one modality can evoke perceptions in another (Marks, 1978). Gibson (1966) describes our senses as active interrelated systems that provide information for our perception of the real world. In contrast, most classical frameworks of the interfaces between perception and action are based on separate encoding (Massaro, 1990). Much evidence from experimental psychology and psychophysics indicates that perception and action share a common computational code (Prinz, 2005).

It is known that vision can actively influence haptic perception (Heller et al., 1999; Klatzky & Lederman, 1992; Lederman et al., 1986; Rock & Victor, 1964).

A classic and robust example of intersensory interaction between vision and haptics is the "size-weight" illusion, documented by Charpentier (1891) and Flournoy (1894) over 100 years ago. When two objects of different volume but equal weight are lifted, the smaller object is considered heavier.

In this example, haptic feedback still plays an important role because the volume of the object is not only seen but also perceived by the hand.

2.6.1 Classifications

The literature analysis allowed the extrapolation of three user inputs (displacement, force, and duration of pressure) and four visual stimuli to present the compliance property (displacement, surface deformation, color, and size). User input can be defined as the action of the user as well as the input information to the system. User input can be classified into:

- Displacement: when users move their bodies (such as fingers or hands) or input tools (such as mice or touch pens), the system detects and uses the displacement as input, and the user input is considered displacement.
- Force: when the user's body or input tools apply a force on something and the system detects and uses the amount of force as input, that specific user input is considered a force.
- Duration of pressure: when the user's body or input tools press something for a certain duration, and the system detects and uses the duration as input, that user input is considered the duration of pressure.

Visual stimuli (See *Figure 21*), on the other hand, are the visual information provided to the user as visual feedback based on the user's action, which can be classified into:

- Displacement: the first approach visualizes the distorted displacement of user input. For example, Dominjon et al., (2005) showed that greater displacement of visual feedback than displacement of user input can make the user perceive that the object is lighter than its actual weight.
- Surface deformation: the second approach presents users with a simulated surface deformation as a visual stimulus. Punpongsanon et al., (2015)

presented a visual simulation of pillow surface deformation through projection mapping when the user presses it with their fingers. The researchers evaluated whether the proposed increased deformation affects the user's perception of softness. The analysis showed that the surface deformation method was effective in the softening direction, but there was no significant effect in the hardening direction.

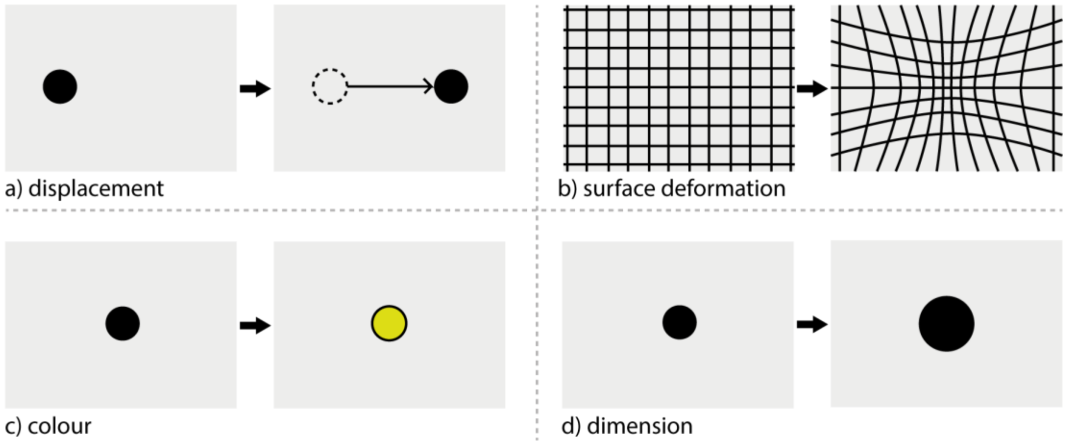


Figure 21. Visual stimuli classification.

- Color: The third approach changes the color of the user's skin or cursor. For example, previous studies have shown that color-temperature correspondence can influence hot and cold sensations (Ho et al., 2014).
- Size: the fourth approach takes place when the change in size of something is presented to users as visual information. Generally, this pseudo-haptic effect is used to convey the perception of the macro-rugosity property through finger size distortion. Lécuyer, (2009) proposed varying the size of the cursor according to the local height of the texture displayed on the screen. Their experimental results confirmed that the "size technique" allowed users to identify bumps and holes successfully.

2.6.2 Control-Display Ratio

When a user holds a computer mouse and moves it to the right, the cursor on the computer screen also moves in the same direction (See *Figure 22*) (Blanch, 2004). This seamless relationship between user actions and on-screen responses is what we expect in human-computer interaction – it feels natural, intuitive, and efficient. These connections between input and output are often referred to as "mappings" because they define how a property of the input device maps to a property of the display. The example of the mouse and cursor illustrates a spatial relationship. There are also dynamic relationships that describe how the input device influences the speed of the response and physical relationships that indicate whether the response is triggered by the movement or force applied to the input device.

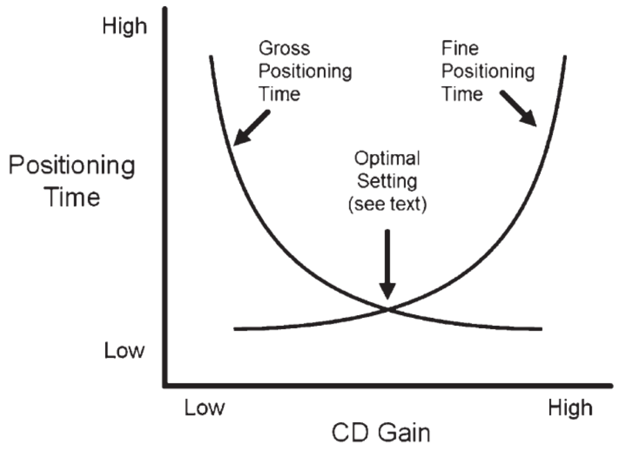


Figure 22. The trade-off between gross positioning time and fine positioning time as a function of CD gain.

Another important concept is "Control-Display (CD) gain," which represents the amount of movement in a displayed object, like a cursor, for a given movement of the input device. For instance, if moving a mouse three centimeters results in the cursor moving three centimeters, the CD gain is 1. If the cursor moves six centimeters for the same three-centimeter mouse movement, the CD gain is 2. CD gain settings for a mouse and cursor are typically adjustable in a control panel. Shifting the slider towards the "slow" end reduces CD gain, meaning more input device movement is needed for each unit of cursor movement. Often, the relationship between input and cursor movement is nonlinear and follows a power function. In such cases, the cursor's movement depends on both the velocity of mouse motion and the input device's movement. When the mouse moves quickly, CD gain increases, and when it moves slowly, CD gain decreases. Reducing CD gain for slow input device movements is useful for enhancing the accuracy of target selection at the end of a point-select operation. Some may use the term "transfer function" for these more complex nonlinear relationships. To ensure the cursor responds promptly to mouse movements without noticeable delay, software implementations of nonlinear relationships usually employ a lookup table to map input device movement to cursor movement.

Research on optimizing CD gain dates back to at least the 1940s when the first electronic joysticks were developed (Jenkins & Connor, 1949). However, finding the optimal setting is more complex than it may seem. Varying CD gain introduces a trade-off between the time it takes to roughly position the cursor near a target and the time it takes for fine adjustments during the final acquisition. In a simplistic sense, the optimal setting would minimize both the combined gross and fine positioning times. Yet, this might conflict with an optimal error rate, as the CD gain setting that minimizes overall positioning time may not necessarily minimize error rates. Other factors like display size or scale, independent of CD gain settings, also complicate the optimization of this common input device parameter (MacKenzie, 1995).

The active cursor technique strives to elicit tactile sensations, even when using a regular mouse that cannot provide any force feedback apart from the resistance encountered while moving the mouse over a surface. Similar methods for simulating the sense of touch by manipulating the graphical representation of the user have been informally employed in video games. An example can be found in the classic racing game **Out Run** (See *Figure 23*), where players must apply force to their input devices when the road curves to keep the car in the center of the road. This effect imparts a feeling of being "pushed" off the road to the players.

Figure 23. Out Run (also stylized as OutRun) is an arcade driving video game released by Sega in September 1986.

Both the **cursor gain technique** and **active cursor technique** aim to disconnect the visual space from the motor space through cursor manipulation. The active cursor technique distinguishes itself from the cursor gain technique in that the adjustment's direction need not necessarily align with the direction of the mouse movement.

While the cursor gain technique is relatively straightforward to implement, it only functions when the user is actively moving the mouse and is constrained to the direction of the user's movements (Baudisch et al., 2005).

2.6.3 Relevant Case Studies

Subsequently, several scientific papers were analyzed, of which we report two relevant case studies, one developed for desktop displays and the other for hand-held displays.

The first one, developed by Argelaguet et al., (2013), presents "elastic images," a new pseudo-haptic feedback technique that allows perceiving the local elasticity of images without the need for any haptic device on desktop displays (See *Figure 24*).

The proposed approach focuses on the ability of visual feedback to induce a feeling of rigidity when the user interacts with an image using a standard mouse.

By clicking on an elastic image, the user can deform it locally according to its elastic properties. To reinforce the effect, they also propose the generation of shadows and folds to simulate the compressibility of the image and different mouse cursor substitutions to enhance the perception of pressure and rigidity.

A psychophysical experiment was conducted to quantify this new pseudo-haptic perception and determine its perceptual threshold. The results showed that users could recognize up to eight different stiffness values with our proposed method and confirmed that it provides a perceivable sensation of elasticity.

Potential applications of the proposed approach range from pressure sensing in product catalogs and games to its use in graphical interfaces to enhance the expressiveness of widgets.

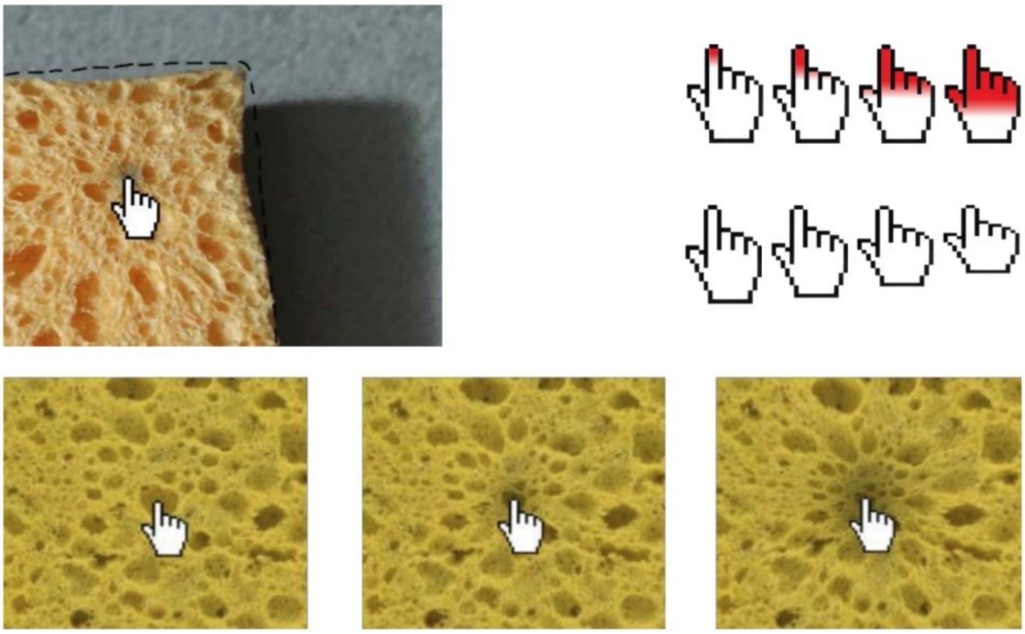


Figure 24. Elastic Images: example for the deformation of the sponge texture used during the experiments.

Costes et al., (2019) argue, however, that haptic enhancement of touchscreens usually involves vibrating motors that produce limited sensations or custom mechanical actuators that are difficult to deploy (See *Figure 25*). The second case study, therefore, proposes an alternative approach called "Touchy," in which a symbolic cursor is introduced under the user's finger to evoke various haptic properties through changes in its shape and motion on hand-held displays. This new metaphor allows four different perceptual dimensions to be addressed, namely hardness, friction, fine roughness, and macro-roughness. Their metaphor has seven visual effects that they compared with real texture samples as part of a study of 14 participants. Overall, the results show that Touchy can elicit clear and distinct haptic properties: stiffness, roughness, relief, stickiness, and slipperiness.

Gestures on hand-held displays include touch mechanics (what your fingers do on the screen) and touch activities (results of specific gestures). A touch mechanic may cause different outcomes, depending on the context in which it is used. For example, a long press may select an element like a list item. The impact of a touch mechanic can vary based on its application context. For instance, in one scenario, performing a prolonged touch could result in selecting an item, such as a list entry.

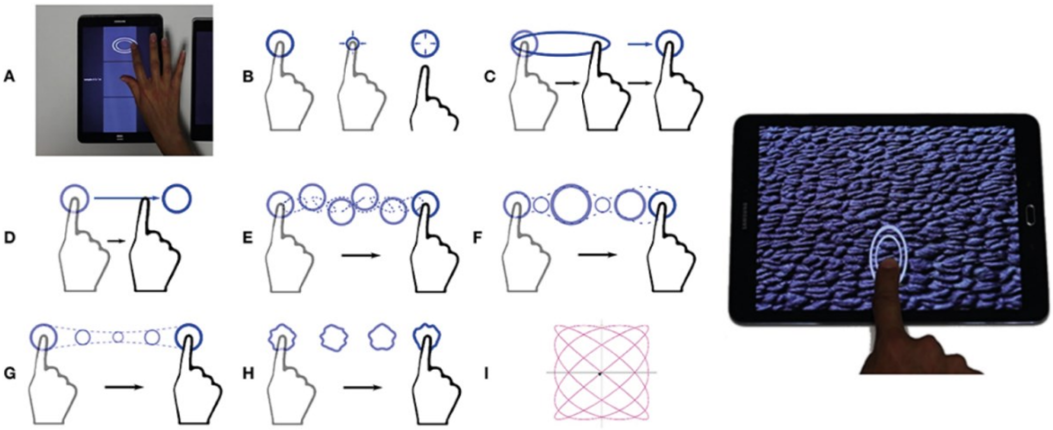


Figure 25. Touchy: The seven visual effects evaluated in the study. (A) A virtual sample with the Stick effect. (B) The Compress effect evokes softness by shrinking over time. (C) The Stick effect evokes stickiness by deforming on small movements. (D) The Slide effect evokes slipperiness through velocity decoupling. (E) The Displace effect evokes fine roughness through motion vibrations. (F) The Dilate effect evokes fine roughness through size vibrations. (G) The Size effect evokes macro roughness through size changes. (H) The Encase effect evokes macro roughness through 3D shape changes. (I) The vibration pattern used for the Displace Effect.

Complex touch interactions can be accomplished by combining multiple touch mechanics. For instance, a user can zoom in on a view by employing touch mechanics like pinch open, double-touch, or double-touch followed by dragging (See *Figure 26*).

Both case studies, although different in terms of the interaction medium, user input, and visual stimuli, demonstrate how, in the testing phase, the properties perceived by the user through pseudo-haptic effects correspond to those designed and manipulated by the researchers in the initial research phase. Therefore, a multimodal correspondence generated by the designed pseudo-haptic effects and the underlying synesthesia in the development of the applications themselves can be traced.

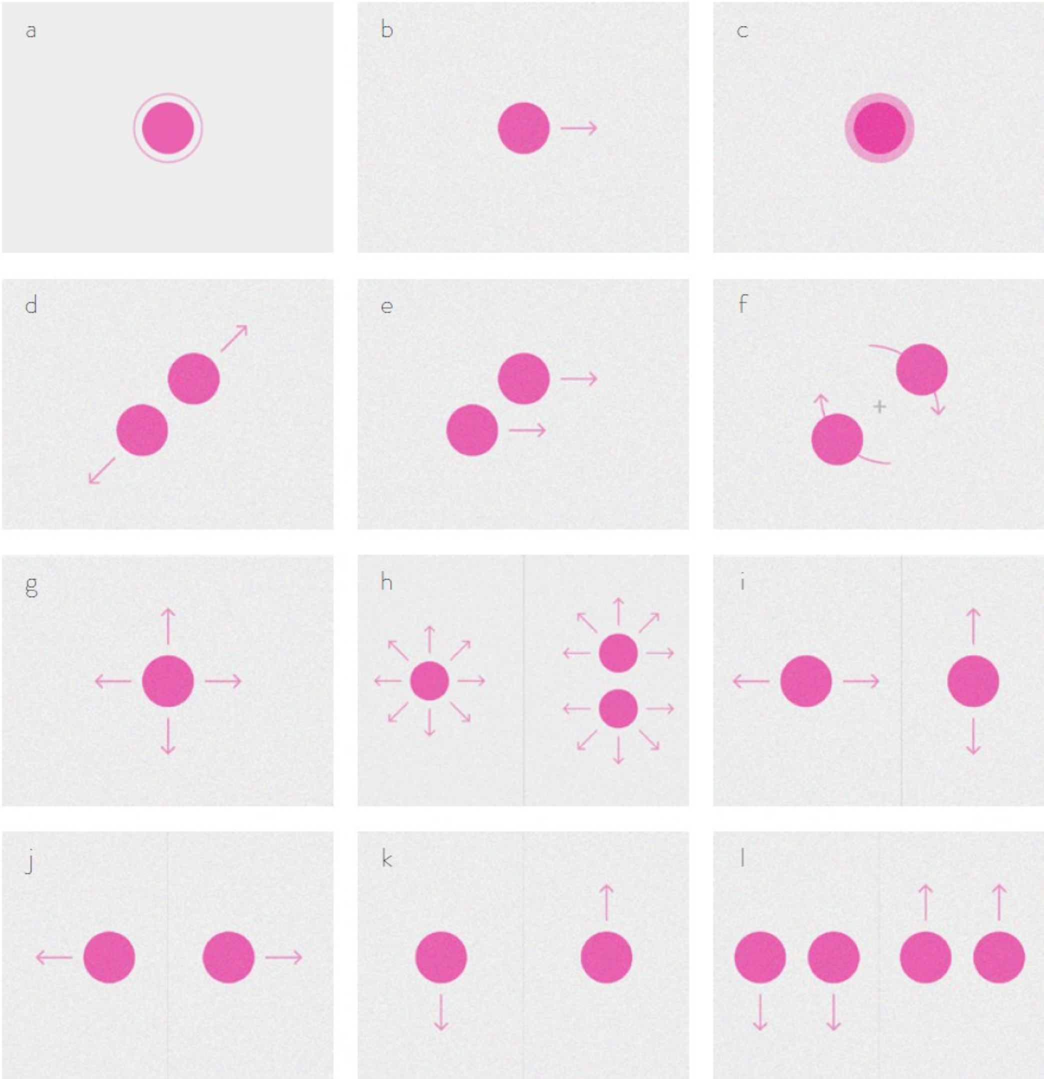


Figure 26. Gestures Patterns (2016) Google, Material Design
Touch mechanics: a) Double touch; b) Swipe; c) Long press; d) Pinch open; e) Two finger swipe; f) Rotate; Touch activities: g) Scroll; h) Pan; i) Dismiss; j) Swipe to refresh; k) Menu open; l) Tilt.

2.6.4 Synesthesia and Haptic Vision

Synesthesias are a cognitive phenomenon related to connotative thinking in general, activated by the human mind to integrate perception and cognition. Synesthetic abilities are due to certain areas of the brain that can unify information from different sensory systems. We speak of synesthesia in the case of involuntary perceptions provoked by a stimulus not usually related to the experience. So, for example, in the case of haptic vision, we perceive sensations that are usually related to touch through vision. A purely visual impression evokes a tactile sensation. Synesthesia is a phenomenon in which two or more senses are activated by a stimulus that affects only one of them.

Etymologically, the word is derived from the Greek syn (with) and aisthesis (sensation or feeling). The concept of synesthesia originated in 1812 when G.T.L. Sachs argued in his medical dissertation that there are chromatic perceptual phenomena that are elicited by the perception of simple elements such as numbers, letters, or notes (Jewanski et al., 2009).

We talk about synaesthesia not only as a perceptual phenomenon related to humans but also related to the properties of a medium or artifact, capable of inducing human synaesthetic processes. To be synaesthetic, a representation can be mono or multimedia; the code must be subjective, it must be connotative, and it must be abstract.

Simpson & Mc Kellar (1955) suggest differentiating Imagery, i.e., the mental construction suggested by a certain sensory stimulus, and Sensory, i.e., the stimulus itself. All the sensations in any sensory system can give rise to visual imagery, and auditory senses produce most imagery.

According to the neurologist Richard Cytowic, we can only speak of synesthesia if it is involuntary, i.e., produced by an objective stimulus; if it is projected, i.e., truly perceived, and not merely imagined; if the synesthetic precepts are enduring and discrete; if the synesthesia is memorable, i.e., easy to remember, and if the synesthesias are emotional. It must be said, however, that most people do not experience synesthesia.

However, it can be said that everyone perceives some synaesthetic sensations: an increase in volume corresponds to an increase in size, the brightness of color corresponds to the height of sound, the height of sound corresponds to the vertical placement of the sign, and a high musical tempo corresponds angular figures.

Another link can be found between the timbre of the sound and color. However, regarding this aspect, it must be noted that it is very subjective, and it is possible to talk about “Chromesthesia.” As an example, Whiteford et al. (2018)

investigated this phenomenon using a wide-ranging selection of 34 musical excerpts encompassing various genres such as Blues, Salsa, and Heavy Metal, among others. They also employed a diverse set of 10 emotion-related rating scales and examined 15 rated music-perceptual features.

Notably, their study revealed consistent connections between the perceptual characteristics of the music and the perceptual attributes of colors deemed most and least harmonious with the music (See *Figure 27*). For instance, music characterized by loud, punchy, and distorted qualities tended to be linked with darker, redder, and more intense colors.

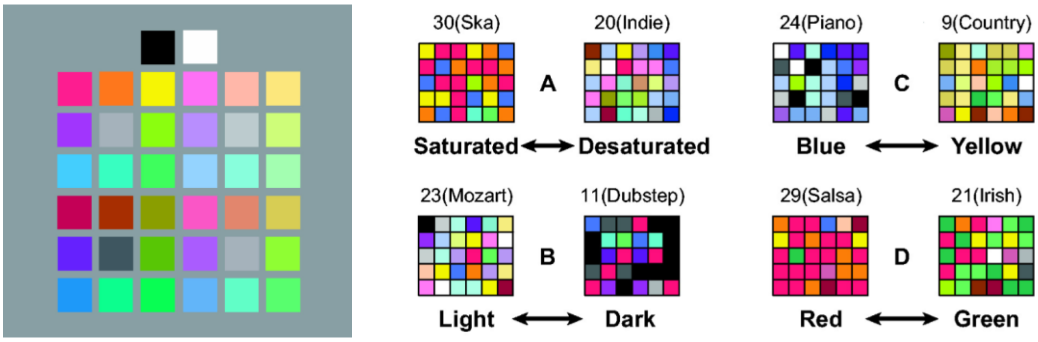


Figure 27. On the left. The 37 colors used in the experiment (from Palmer et al., 2013*). On the Right. Example of the "best fitting" colors from the cross-modal music-to-color association task.*

This also happens in the music field, such as art. Usually, hard objects are associated with dark colors, while soft objects are associated with light colors. Warm is associated with dark gray and cold with white. Excruciating pain is associated with a light metallic color.

As Vasilij Kandinsky argues, some colors *have a rough appearance, while others have a velvety appearance that urges the viewer to touch them, such as ultramarine blue or chrome green*. Vibrations can also be associated with colors (See *Figure 28*). While a low-frequency vibration is associated with a dark color, high frequencies are associated with light colors. The same is true for textures. While rough textures are darker, smooth textures are light.

Figure 28. Study on color: squares with concentric circles by Vasilij Vasil'evič Kandinskij.

Temperature perception is usually related to tactile experience. Each material is related to a precise temperature from our memory: wood is warm, and metal and glass are cold. Both colors and tactile experiences in our memory are linked to certain materials. But even in the visual field, we talk about temperature: color can be warm or cold. While dark colors are perceived as cold, light colors are perceived as warm. Often, changing the color of a material also changes the perception of its temperature. For example, within a dark space, the same temperature is perceived as four degrees cooler than the same temperature within a light space. Again, this is a kind of synesthesia in that a color can convey the sensation of temperature to the eye. Each color can convey tactile characteristics in addition to visual ones.

As we have seen so far, haptic perception is a sense that requires the physical presence of an object or the imitation of tactile features through devices, as happens in VR.

When, however, it is not possible to directly access an object and contact it, it is possible to refer to haptic vision: thus, the ability of the eye to feel surfaces and to access features that are proper to haptic exploration. Haptic vision falls within synaesthesia because the sense of vision can perceive tactile sensations.

Haptic vision allows us to look at and touch the environment simultaneously with only our eyes. You could say that vision is an extension of touch that adds colors to distinguish objects better. Marks (1978) describes haptic vision as a process in which the eyes work as if they were our tactile sense, and a greater involvement of viewers in the process of seeing is created. A haptic image does not invite one to recognize a figure but establishes a bodily relationship between the viewer and the image. These are images that speak to the whole body. Haptics allows us to make contact, and as touch concerns our whole body, it also involves our eyes and feet.

The viewer is inclined to look haptically. Haptic vision is comparable to touching an object: we are not presented with all the features at once but one after another until we have a complete picture of the object "touched." The hand teaches vision to feel and to palpate, so it teaches a mode of perception to vision that does not belong to it. To touch a distant object, we can use another object that serves as our medium. This object can convey all the texture information; however, it cannot make us perceive temperature. Haptic vision, on the other hand, through synesthesia and the use of warm or cool colors, can convey thermal sensations as well, which is advantageous, especially in the world we are living in. Haptic vision could enable us to restore haptic characteristics to objects lost with the virtualization of the world. Everyone knows that in the virtual world, a true haptic sensation is not possible, and as seen above, even different devices cannot replace haptic sensations.

Another situation in which haptic vision is advantageous is when an object is too large to be explored with the hands. In this case, vision can inform us of any haptic features that would otherwise not be accessible. As Berkeley argues, vision, in this case, is an **anticipatory touch**.

2.7 Conclusion

Chapter 2 illustrates the actual research framework related to technology adoption in the retail field. We analyzed the technologies of IIT, VR, and haptics to understand their potential and hypothesize systems to solve the problems identified above. Also, we presented pseudo-haptics, a predominantly new technology in the scientific literature that has great potential for improving perception during the user shopping experience. Starting from Problem 1 and Problem 2 (defined in the *Motivation Section*), the findings we have considered so far are:

- On the one hand, we can exploit VR as a tool to present the storytelling of a product within shopping experiences and allow us to configure it in real-time while discovering the whole shop. As a matter of completeness, however, we need to understand which immersive VR and desktop VR may be more suitable and accepted by users in online shopping (Chapter 3). Also, we can exploit the VR experience by integrating the product configuration in real-time with the manipulation of real product material samples, trying to understand their comfort/discomfort in offline shopping (Chapter 4).
- On the other hand, haptic technologies may be exploited in a novel way: pseudo-haptics. We think of designing digital interfaces that communicate the 'touch and feel' qualities of fabrics with pseudo-haptic effects to compensate for the lack of touch in online shopping (Chapter 5).

Chapter 3. Comparing Immersive and Desktop Virtual Reality Shopping Experiences

At present, we are observing a remarkable rise in the utilization of e-commerce within the retail sector, a trend that has been further accelerated by several years due to the COVID-19 crisis (McKinsey, 2020; Shankar et al., 2021). This phenomenon is also fueling a heightened demand for retail technologies like the Internet of Things (IoT), Artificial Intelligence (AI), VR, and AR, all of which are geared towards enhancing the shopping experience (AWS for Industries, 2021).

Within this context, VR technologies offer a promising avenue for e-commerce (Grewal et al., 2018) to replicate satisfying consumer experiences like those encountered in physical stores (Alcañiz et al., 2019). Moreover, VR can potentially enrich online consumer experiences within the emerging Metaverse (Shen et al., 2021).

VR, by definition, involves "the use of computer simulation that enables interaction with a virtual, three-dimensional, visual environment through digital representation" (Biocca, 1992). Users are typically immersed in this digital environment through an HMD, although they do not physically coexist within the same space as the objects or environment reconstructed through VR (Sheridan, 1992).

Projections suggest that most global Internet users will integrate VR headsets into their daily routines within the next 7-10 years (Rosedale, 2017). Notably, VR applications are evolving rapidly and finding increasing applications within retail environments (Javornik, 2016; McCormick et al., 2014).

In 2021, the global VR market was valued at USD 21.83 billion, with forecasts indicating a compound annual growth rate (CAGR) of 15.0% between 2022 and 2030 (Grand View Research, 2020). These figures underscore consumers' readiness to embrace immersive technologies daily (Rosedale, 2017).

In the contemporary global economy, the fashion sector stands out as one retail segment poised to reap significant benefits from VR. The fashion industry is experiencing rapid growth, with a projected CAGR of 11.45%, culminating in a market volume of US$1.37 trillion by 2025 (Statista Market Forecast, 2022).

The integration of retail technology, notably VR, plays a pivotal role in enhancing the user experience within the fashion industry. VR emerges as a compelling candidate for the next generation of e-commerce, allowing brands to enhance the shopping experience (Morotti et al., 2020; M. Park et al., 2018). Significantly, VR can retain existing web-based services while mitigating the skepticism of discerning online users by offering enhanced digital representations of clothing and accessories through 3D models and interactive features.

However, despite the growth of e-commerce, several issues persist in online fashion retail. For instance, online shopping systems predominantly rely on textual descriptions and static images, failing to deliver an engaging shopping experience to end-users (Wu et al., 2019). These modes of product presentation often fall short of conveying product attributes effectively. Furthermore, unnatural interaction methods, such as scrolling through product lists or navigating product information pages, contribute to heightened cognitive load among consumers, resulting in potential frustrations (Wu et al., 2019) and a negative impact on their shopping experience, including factors like presence, immersion, and attractiveness (Peukert et al., 2019).

In contrast, Immersive VR (IVR) holds the potential to offer numerous advantages, particularly within the realm of fashion retail. IVR enables the comprehensive configuration of products in a 360° environment, enabling users to interact with and understand product features that may be challenging to grasp through flat 2D images displayed on traditional screens. This capability is especially pronounced for high-quality products characterized by unique shapes, materials, and finishes, which demand a high level of consumer confidence due to their cost. For instance, purchasing a costly handbag can be an emotional process that requires an accurate 3D representation of the product.

The "virtual" aspect of the shopping experience can be integrated into e-commerce through immersive and non-immersive means. This study explores how different display and interaction systems within the virtual environment can influence the product's shopping experience. Consequently, we compare the shopping experience on a desktop computer - Desktop Virtual Reality (DVR) - with an experience in IVR, evaluating metrics such as shopping duration, hedonic and utilitarian values, cognitive load, and user experience.

Hedonic shopping value encompasses the value derived from the multi-sensory, imaginative, and emotional facets of the shopping experience. In contrast, utilitarian shopping value focuses on efficiently acquiring products and information, representing a more task-oriented, cognitive, and non-emotional shopping outcome (Babin et al., 1994). Cognitive load, on the one hand, pertains to the perceived mental effort associated with the shopping task (Hart & Staveland, 1988). On the other hand, user experience encompasses aspects such as attractiveness, clarity, efficiency, reliability, stimulation, and novelty within the overall shopping experience (Laugwitz et al., 2008).

Consequently, this study conducts a comparative analysis between IVR and DVR shopping experiences. To the best of our knowledge, there is a shortage of literature that compares immersive and non-immersive shopping experiences within the fashion retail domain. Therefore, this research aims to address the following Research Questions (RQs):

- RQ1 - Is the time duration of the shopping experience longer in IVR than in DVR?
- RQ2 - Can the proposed IVR-based shopping experience deliver higher rates in terms of hedonic and utilitarian values than a DVR-based?
- RQ3 - Can the proposed IVR-based shopping experience present a cognitive load comparable to the DVR-based?
- RQ4 - Can the proposed IVR-based shopping experience improve the user experience compared to DVR-based?

The chapter is organized into five distinct sections. The initial section provides an overview of the current state-of-the-art application of VR technologies to enhance the shopping experience, with a specific emphasis on comparative research within the retail sector. Following this, the second section outlines the methodology employed to conduct the comparative study. The third section delves into the presentation of results, encompassing subjective and objective metrics. Subsequently, the fourth section offers a comprehensive discussion of the obtained findings. Finally, the chapter concludes by summarizing our conclusions and outlining potential directions for future research.

3.1 Comparative Studies in Retail

In the literature, there are few comparative studies related to VR shopping experiences (See *Table 2*). Three distinct scenarios are typically considered for comparison: physical stores, IVR shops, and DVR shops.

Bressoud, (2013) conducted a study in France involving 200 customers to assess the distinctions between real and virtual shopping experiences for a new adult cereal product. The results indicated that attitudinal metrics related to cognition and conation were comparable between the two methodologies. However, affect and behavior could not be directly compared. In conclusion, virtual stores were found suitable for early-stage testing of novel concepts but should not be the sole basis for decisions regarding new product launches.

Waterlander et al. (2015) developed and validated a virtual supermarket by contrasting virtual and actual food shopping behaviors. They employed the Presence Questionnaire Items Stems to collect participant feedback on the perceived sense of presence. Over three consecutive weeks, a sample of 123 primary household shoppers in New Zealand engaged in three shopping occasions within the virtual supermarket. Notably, the four food categories with the highest relative prices were consistent between the virtual and physical supermarkets, signifying similarity in real and virtual grocery shopping patterns. Overall, the virtual supermarket proved to be a dependable method for analyzing consumer food-buying behaviors.

Van Herpen et al. (2016) compared VR to a 2D graphical representation of the same retail environment while maintaining the same store assortment, display, and product information. Their study involved 90 students randomly assigned to one of three groups: a simulated shelf display, a VR shelf display, or a shelf display picture. The shelf contained 16 distinct red wines with brief descriptions and prices. The findings offered preliminary evidence favoring the integration of VR over images in consumer behavior research. Moreover, VR was seen as capable of encouraging more habitual purchasing processes and ensuring consistent responses to display attributes.

Peukert et al. (2019) constructed and experimentally tested a theoretical model exploring how immersion impacts adoption in a shopping environment. To achieve this, they designed a virtual shelf featuring various types of muesli, which participants experienced through either a HMD or 3D product models on a desktop. The study revealed that immersion did not influence consumers' intention to revisit the shopping environment. However, highly immersive retail environments had a positive impact on the hedonic path through telepresence while surprisingly negatively influencing the utilitarian path through product diagnosticity.

Pizzi et al. (2019) introduced a theoretical model to explain consumer in-store reactions based on channel and shopping orientation. They tested this concept in the context of a large European grocery retail chain by replicating the same shelf layout for a target category (industrial confectionery) in both a real and a VR store. Employing a quasi-experimental between-subjects approach, participants interacted with the same shelf in both settings. The findings suggested that VR negatively impacted satisfaction, regulated by perceived assortment size, while simultaneously stimulating utilitarian and hedonic aspects. Following the VR experience, customers reported elevated levels of all tested outcome variables.

Schnack et al. (2019) explored whether VR technology in a virtual simulated store improved perceived telepresence and usability compared to traditional PC technology. Two experiments were conducted, one with a VR group and one with a desktop group, involving 111 participants who completed a simulated shopping trip. The results indicated that participants in the VR group experienced a greater sense of immersion and perceived naturalness in their interactions with the store environment compared to the desktop group.

Lombart et al. (2020) investigated the effects of real shops, non-immersive virtual stores, and immersive virtual stores on consumer perceptions and purchasing behavior concerning Fruits and Vegetables (FaVs). Their between-subject experiment involved 192 business school students. The findings revealed that consumers' perceptions of FaVs in non-immersive and immersive virtual stores were similar to those in real stores. Additionally, people purchased more FaVs in non-immersive and IVR settings compared to real stores. The results also indicated that, when evaluating FaVs in IVR, customers relied more on extrinsic cues, such as prices, and less on intrinsic cues, like appearance, than their behavior in real stores.

While these studies predominantly focused on grocery retail, some authors suggest further exploration in high-involvement categories like fashion products (e.g., clothing and accessories). They anticipate that hedonic and utilitarian values may have a more pronounced and positive impact on such product categories (Peukert et al., 2019; Pizzi et al., 2019; Scarpi, 2006). These findings align with prior research, which suggests that interactive technologies providing hedonic value led to stronger purchase intentions than passive product presentations in traditional web-based shopping practices (Lau & Lee, 2018).

Table 2. Summary of prior literature about comparative studies in retail.

Study	Comparison	Retail Product Category	Dependent Variables
Bressoud (2013)	VR vs. experimental real store	Grocery (Muesli)	Affective attitude (Wahlers et al., 1986), Cognitive Attitude (Filser, 1994), Conative Attitude (Holbrook & Hirschman, 1982); Time of the experience; Purchase rate
Waterlander et al. (2015)	VR vs. experimental real store	Grocery (a: fresh fruit and vegetables, b: bread and bakery, c: dairy, d: meat and fish)	Presence (Witmer & Singer, 1998); % Expenditures; % Items purchased

Van Herpen et al. (2016)	Real vs. VR vs. Picture	Grocery (a: Fruit and vegetables; b: milk, c: biscuits)	Presence (Witmer et al., 2005; Witmer & Singer, 1998), Number of products selected, Level of variety seeking, Purchase of store brands/generics, Purchase of national brand, Amount of money spent, Purchase from top/middle/bottom shelves, Purchase from left/middle / right shelves.
Peukert et al. (2019)	VR vs DVR	Grocery (Muesli)	Hedonic value: Perceived telepresence (Kim & Biocca, 2006; Klein, 2003; Nah et al., 2011), Perceived enjoyment (Ghani et al., 1991; Koufaris, 2002); Utilitarian value: Perceived product diagnosticity (Jiang & Benbasat, 2007), Perceived usefulness (Venkatesh et al., 2017; Vrechopoulos, 2004; Xu et al., 2014), Intention to reuse the shopping environment (Carroll & McKendree, 1987; Venkatesh et al., 2017; J. Xu et al., 2014), Perceived ease of use (Davis, 1989; Koufaris, 2002; Vrechopoulos et al., 2004), NASA task load index (Hart & Staveland, 1988), Simulator Sickness (Kennedy et al., 2009)
Pizzi et al. (2019)	Real vs. VR	Grocery (Industrial bakery)	Overall satisfaction (Bloemer & de Ruyter, 1998), Perceived assortment size (Diehl & Poynor, 2018), Hedonic and utilitarian shopping orientation (Babin et al., 1994), Levels of excitement (Wakefield & Baker, 1998)
Schnack et al. (2019)	VR vs DVR	Grocery (Miscellaneous)	Telepresence (Witmer & Singer, 1998), Usability (Waterlander et al., 2011)
Lombart et al. (2020)	Real vs. VR vs DVR	Grocery (Fruit and vegetables)	Appearance and quality (Aurier & Sirieix, 2009), Price fairness (Bolton et al., 2018), Perceived healthiness and hedonism (Bauer et al., 2013), and Consumer attitude (Lombart & Louis, 2012)

3.2 User Studies in the Fashion Retail Field

While VR has demonstrated its efficacy in fashion retail, the existing scientific literature remains fragmented and predominantly comprises limited studies (Xi &

Hamari, 2021). Additionally, only a handful of these studies employ experimental designs. Therefore, there is a pressing need for further research to elucidate the extent to which VR technology can enhance the overall shopping experience for users.

Lau et al. (2014) explored the design of interactive elements to elevate consumers' shopping experiences. They designed a VR store and conducted interviews with a sample of 61 participants. The virtual environment allowed participants to browse, explore, and interact with products for a 15 minute period. The interviews revealed that participants actively engaged and enjoyed the experience, underscoring how interactive design can enhance consumers' shopping experiences (Wong Lau et al., 2014).

Moes & Vliet (2017) investigated how customers can simulate the experience of shopping in a physical fashion store via visual content. Their study examined the effects of viewing a standard photograph, a 360-degree photograph, and a VR image of a physical store, all online. Two experiments were conducted with between-subjects designs. The independent variable was the communication format. The dependent variables included the perception of a real shop experience, grading, overall experience, visitor intention, purchase intention, opinion of a physical shop, and recall. Notably, consumers who viewed the VR representation of the store reported a more enjoyable shopping experience, a heightened intention to make a purchase, and a greater inclination to visit the shop compared to those who had only viewed the standard photograph or the 360° photograph of the shop.

Dzardanova et al. (2017) investigated the influence of social context on users' perceptions of virtual bodies and their emotional and psychological states. Their study involved immersing a sample of 54 participants in a VR apparel store. These users, alone or accompanied by a virtual salesperson, observed their avatars' naked virtual bodies. The results indicated that the presence of a second character did not impact the extent of the body ownership illusion or presence but did trigger a significant emotional response. This finding underscores the influence of social context and social presence on users.

Donatiello et al. (2018) developed the "Fashion Island" application, a concept featuring a virtual fitting room in VR where users could outfit avatars by selecting clothing and accessories through a basic graphical interface. Thirteen volunteers participated in the experiment, offering feedback on the interface's usability, overall experience, and susceptibility to cybersickness. The results were generally positive, setting the stage for future investigations.

Park et al. (2018) explored user experiences in virtual stores and their impact on shopping outcomes. To this end, they devised a VR store tailored for female customers, recruiting 40 women for the experiment. Participants were given an hour to explore the store freely and were administered a questionnaire assessing elements such as telepresence, perceived realism, pleasure, arousal, attitude, purchase intention, and simulator sickness. Preliminary findings indicated a favorable association between significant purchasing outcomes (pleasure, attitude toward virtual stores, and purchase intention) and the IVR experience, suggesting that VR as a novel shopping tool can enhance customer engagement and satisfaction.

Jang et al. (2019) probed the roles of vividness and interactivity in customers' approach intentions toward an IVR store—a sample of 101 users engaged with the VR store using an HMD. The findings highlighted that participants' perceptions of higher vividness and interactivity were linked to stronger approach intentions. Furthermore, these positive effects were subsequently influenced by participants' perceptions of telepresence and experiential shopping value.

Lau & Lee (2018) concentrated on consumers' shopping experiences in StereoVR, particularly through the design of "FutureShop." They evaluated the potential of this VR setting in enhancing customer engagement compared to online shopping. Fifty-nine participants answered a questionnaire following a 30-minute session in FutureShop to gauge their purchase intentions, interactive shopping experiences, and hedonic user experiences. The results indicated that VR could enhance hedonic value, interactive retail experiences, and purchase intentions.

Morotti et al. (2020) explored the advantages of using vocal communication with a VR assistant as a virtual salesperson in a VR fashion store. They employed the Technology Acceptance Model to design a survey assessing users' perceived ease of use and usefulness of the voice-enabled interface. The experiment involved nine fashion experts. Preliminary findings suggested that VR could offer effective experiences, and integrating a voice assistant could simplify and naturalize the virtual shopping experience.

These contributions span various domains, including computer science, marketing, and management, highlighting the interdisciplinary nature of academic research on VR in fashion retail (Bonetti et al., 2017). Nevertheless, a common thread among all these contributions is the shared intention to enhance the shopping experience by exploiting VR technologies.

3.3 Bag Shopping Experiences

In our experimental study, we opted to focus on bags as the product for our case study. This choice was motivated by the fact that bags, unlike generic clothing items, offer greater potential for achieving realistic textures and involve materials with less complex physical characteristics. Within the existing literature, only three contributions have explored the shopping experience for bags (Altarteer et al., 2016; Altarteer & Charissis, 2019; Wu et al., 2019).

Altarteer et al. (2016) conducted a comparative study to investigate customer preferences between a VR system and a 2D system for customizing products from a luxury brand online. The results revealed that the VR system provided a high level of product visualization, real-time interaction, and enhanced hedonic values, elevating the overall customer shopping experience.

Altarteer & Charissis (2019) introduced a VR prototype that allowed customers of luxury brands to view, interact with, and customize life-sized and photorealistic VR models of bags before making a purchase. The study findings indicated that perceived experiential value, sense of presence, ease of use, and perceived usefulness significantly influenced attitudes toward the VR system.

Wu et al. (2019) devised a series of typical VR shopping tasks centered around the bag shopping experience. Participants completed identical shopping tasks as quickly as possible using three distinct interactive techniques: virtual handle controller, raycasting, and user-defined gestures. The results indicated that the freehand gesture-based interaction technique received the highest ratings in terms of task load, user experience, and sense of presence, all without sacrificing performance in terms of speed and error count.

3.4 Methodology

Considering the previous scientific literature and in response to the research questions, we conducted a comparative study and established the following hypotheses:

- H1 - The time duration of the shopping experience in IVR is longer than in DVR.
- H2 - The proposed IVR-based shopping experience delivers higher hedonic and utilitarian values than DVR.
- H3 - Users' cognitive load in IVR does not differ from that in DVR.
- H4 - The proposed IVR-based shopping experience gives a better user experience than the DVR-based one.

To assess these hypotheses, we conducted a within-subjects experiment comprising two conditions: IVR mode and DVR mode. Both conditions featured the same shopping environment but varied in terms of display systems and interaction methods. We used a Latin square design to ensure the random allocation of participants to different treatment orders.

3.4.1 Participants

For this study, we recruited 60 participants, comprising 36 men and 24 women, ranging in age from 22 to 58 years (Mean: 30.5 years, SD: 10.23). The participant pool included individuals with an academic background and university students from the Polytechnic University of Bari. Most participants (n=53) reported having one to three years of experience with online shopping. Furthermore, most participants (n=41) had previous exposure to VR technology, with a familiarity level rated at 4 on a 7-point Likert scale (from 1 = "not familiar at all" to 7 = "totally familiar").

3.4.2 Task

We designed a virtual fashion store that featured gender-fluid clothing and accessories constructed using virtual assets purchased online.

Within the experiment, the assigned task involved navigating the virtual shop, searching for and selecting a specific bag (which was presented to participants before the experiment), and engaging with the bag and its various attributes.

- The bag's features encompassed several layers of actions (See *Figure 29*).
- Resizing the bag, allowing users to enlarge or shrink it.
- Accessing detailed information about the bag, such as its brand, history, production process, size, washing instructions, and reviews.
- Initiating an attribute window to modify the bag's color and finishes (See *Figure 29*).
- Placing the selected bag into a shopping cart by clicking on it.

Participants were initially briefed on the experiment's objectives and requirements, followed by obtaining informed consent.

Subsequently, they underwent training exercises in both DVR and IVR settings, which replicated tasks similar to those encountered in the actual experiment. This training phase involved interacting with cubes within a training scene (See *Figure 29*) and included the following tasks:

- Navigating within the virtual environment.
- Selecting the red cube.
- Engaging with the menu options, such as invoking an attribute window to modify color and finishes or accessing a window displaying two cube images.

- Completing the experience by clicking on the shopping cart.

Figure 29. On the left: IVR shopping task of the experiment: color and finishes configuration; On the right: IVR training scenario with sphere and cube.

Therefore, both our DVR and IVR applications present a user interface located around the handbag, as shown in *Figure 30*. When the user interacts with each component, a panel appears on the left side of the handbag.

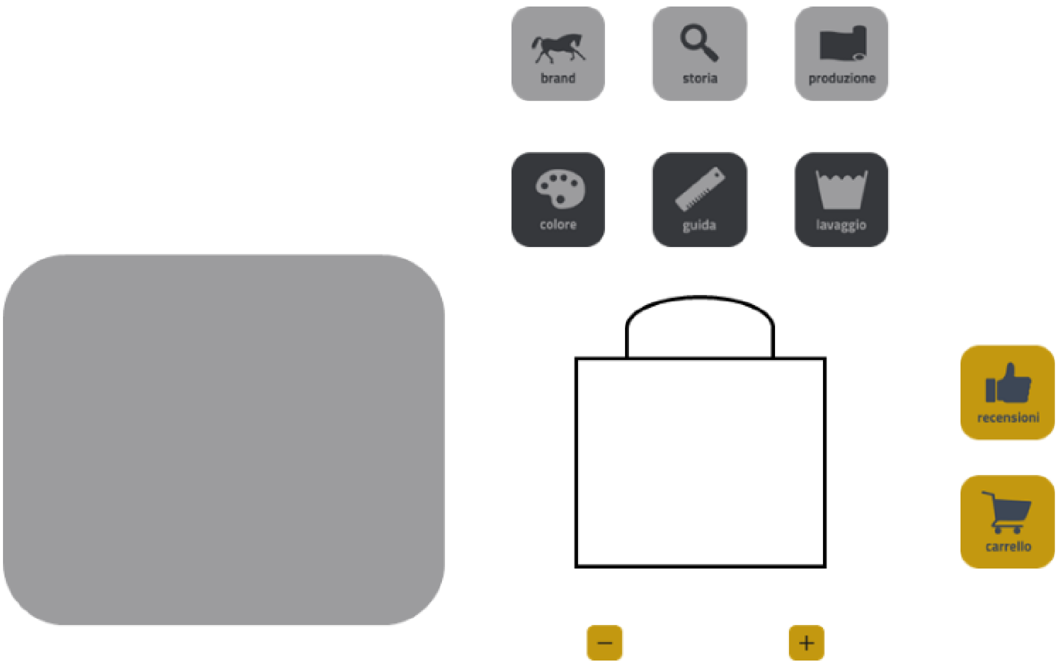


Figure 30. The proposed VR user interface for a luxury handbag. The interface surrounds the product, and a panel appears on the left when the user clicks on the various components.

From a structural point of view (See *Figure 31*), the user interface presents six narrative components:

1. Brand. It presents the history of the brand and its evolution over time.

2. History. It illustrates the history of the product, how it was conceived, and by whom it was worn.
3. Production process. It shows the process by which the product was made. This is a very valuable aspect of the shopping experience because it allows you to emphasize the craftsmanship with which it was made.
4. Size guide. It illustrates the size of the product through dimensioning.
5. Washing mode. It shows the process of washing the product.
6. Reviews. Like online websites, it shows the reviews left on the product to train the user who intends to purchase it.

Also, the user interface is characterized by three call-to-action components, as shown in *Figure 31*:

1. Color configuration. It allows changing the product color in real-time and evaluating its appearance before purchasing it.
2. Shopping cart. It allows the user to add the product to the cart to place the purchase.
3. Zoom in/out. It allows the user to enlarge or reduce the size of the product.

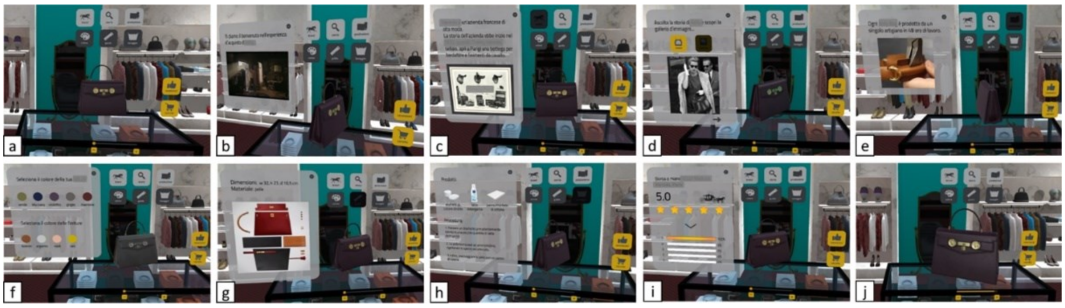


Figure 31. The virtual handbag features within the shopping experience: (a) user interface; (b) presentation trailer; (c) brand; (d) history; (e) production process; (f) color and finishes configuration; (g) size; (h) washing mode; (i) reviews; (j) zoom in.

3.4.3 Experimental Setup

We conducted this experiment within the university laboratory setting. The computer setup for the experiment included a desktop workstation featuring an Intel Core i7-10400 processor, 32GB of RAM, and a GeForce RTX 3070 graphics card. The HMD utilized for the experiment was the Oculus Quest 2 HMD, which came equipped with two handheld controllers.

To compare various measures, we developed two application versions using the Unity engine (Refer to *Figure 32*). The initial version was crafted as a conventional desktop application, while the second version was tailored for use with the Oculus Quest 2. Both iterations offered the same functionalities but diverged in terms of interaction and display devices. In the DVR application, interaction was accomplished via the keyboard and mouse, and the visual output was presented on the computer monitor. In contrast, the IVR application relied on controllers for interaction, and users experienced the virtual environment through the HMD. To prevent any discomfort related to motion sickness, participants remained seated during both experiences despite the expansive shop environment presented in the virtual world. For IVR locomotion, we implemented the point-and-teleport technique (Bozgeyikli et al., 2016), while in the DVR scenario, locomotion was achieved by using the arrow keys on the keyboard, as shown in *Figure 32*.

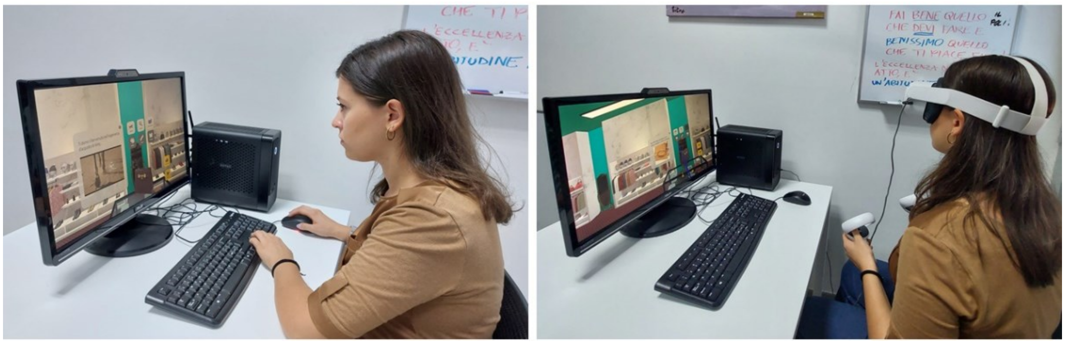


Figure 32: User testing both DVR and IVR versions of the application.

3.4.4 Procedure

Upon arrival, participants were warmly welcomed by the experimenter and directed to their designated seating positions. We commenced by acquainting the participants with the experiment's objectives and tasks, utilizing a concise 5-slide presentation, and subsequently sought their informed consent. Subsequently, we provided participants with instructions on (1) how to interact within DVR and IVR modes and (2) how to navigate within these modes.

The pre-experience questionnaire was administered by the experimenter once the participants were prepared to commence. After completing the pre-experience questionnaire, participants engaged in training exercises for both DVR and IVR. Upon their readiness, participants proceeded to undertake the actual shopping scenario to fulfill the assigned task. In the last phase, participants were kindly invited to complete a post-experience questionnaire, which encompassed assessments for both DVR and IVR modes.

3.4.5 Measures

We evaluated both objective and subjective measures to test our hypotheses.

Objective Measures

About hypothesis H1, we conducted a comparative analysis of the time duration encompassing users' shopping experiences in both IVR and DVR modes. This time duration was calculated from the event's initial timestamp, which marked the commencement of the shopping experience within the virtual shop environment, to the point at which the user completed the experience by clicking on the shopping cart.

Subjective Measures

We administered three sets of questionnaires to participants: one before the experiment and two following the conclusion of each session. These questionnaires were formulated and distributed to participants via the Google Forms platform.

The pre-experience questionnaire was structured into three distinct sections. The initial section comprised inquiries about demographic information, encompassing age, gender, nationality, and occupation. The second section featured questions designed to gauge participants' familiarity with VR, employing a 7-point Likert scale (Albaum, 1997). Lastly, the third section delved into participants' online shopping habits, including an open-ended query that encouraged users to suggest potential enhancements for online shopping.

The post-experience questionnaires were similarly divided into three sections. The initial section aimed to measure hedonic and utilitarian values, aligning with hypothesis H2. These questionnaires were adapted from the model introduced by Peukert et al. (2019), with select questions modified to align with the specific objectives of this study, as shown in *Table 3*. The model identified key dimensions for the hedonic perspective of the shopping experience, encompassing perceived telepresence and enjoyment, as well as dimensions pertinent to the utilitarian perspective, encompassing perceived product diagnosticity and perceived usefulness. All items within the questionnaire employed a 7-point Likert scale.

The second section of the questionnaire pertained to hypothesis H3, wherein we administered the unaltered NASA-TLX (RTLX) questionnaire to evaluate mental workload (Hart, 2016; Hart & Staveland, 1988). Participants were requested to complete this section following each mode. The choice of the unweighted version of the NASA-TLX was motivated by its ease of administration, with prior literature establishing high correlations between weighted and unweighted scores (Byers et al., 1989; Moroney et al., 1992).

Table 3: Peukert et. al. (2019) model of hedonic and utilitarian values measurement: revised table for the experiment.

Hedonic Value	
Perceived telepresence	I forgot about my immediate surroundings when I was doing the shopping.
	When the shopping task ended, I felt like I had returned to the “real world” after a journey.
	During the shopping tasks, I forgot that I was in the middle of an experiment.
	The shopping environment displayed on the screen (or on the HMD) seemed to be “somewhere I visited” rather than “something I saw.”
Perceived enjoyment	I found my shopping experience interesting.
	I found my shopping experience enjoyable.
	I found my shopping experience exciting.
	I found my shopping experience fun.
Utilitarian Value	
Perceived product diagnosticity	The shopping environment was helpful for me to evaluate the cloth.
	The shopping environment was helpful for me to understand the characteristics of the clothes.
	The shopping environment helped familiarize me with the clothes.
Perceived usefulness	The shopping environment is useful for doing the shopping.
	The shopping environment improves my shopping performance.
	The shopping environment enhances my effectiveness when doing the shopping.
	The shopping environment increases my shopping productivity.

The third section of the questionnaire was employed to assess the user experience. To examine hypothesis H4, participants were tasked with completing the User Experience Questionnaire (UEQ). This comprehensive tool encompassed both conventional usability aspects (such as efficiency, perspicuity, and dependability) and aspects related to the user experience (including novelty, stimulation, and attractiveness) (Schrepp et al., 2017a).

3.5 Results

3.5.1 Objective Measures

Time Duration of the Shopping Experience

We compared the time duration associated with the shopping experience in both IVR and DVR modalities using the paired sample T-test. To ensure the validity of this test, we assessed its underlying assumption by subjecting the paired measurements to the Shapiro-Wilk normality test. The outcomes of this assessment revealed that the samples from both DVR and IVR did not adhere to a normal distribution. Consequently, we opted to perform a log transformation (as depicted in *Table 4*). This transformation effectively satisfied the T-test assumptions for the IVR and DVR samples.

With the confirmed assumptions of independent observations and normality, we evaluated the null hypothesis, which posited the equality of means. The T-test enabled us to reject this null hypothesis conclusively. On average, the IVR mode exhibited superior performance, with an average time duration of 247.11 seconds, compared to the DVR mode, which had an average time duration of 179.43 seconds. Notably, this observed improvement was statistically significant, as evidenced by the results of the test ($t(59) = -3.811$, $p < 0.05$).

Table 4: Normality test scores before and after log transformation.

	Shapiro-Wilk			Shapiro-Wilk (after log-10 transformation)		
	statistics	df	sig.	statistics	df	sig.
DVR	,914	60	,000	,988	60	,834
VR	,952	60	,019	,984	60	,619

3.5.2 Subjective Measures

Hedonic and Utilitarian Values

To assess the normality of the data distributions for both the hedonic and utilitarian value constructs, we conducted the Shapiro-Wilk test. As a result of this analysis, it became evident that the samples from both the DVR and IVR modalities did not adhere to a normal distribution for all constructs (as illustrated in *Table 5, 6*). Consequently, considering the non-normal distribution, we employed the Mann-Whitney U test. This statistical technique compares differences between two independent groups when the dependent variable is ordinal or continuous but does not conform to a normal distribution.

Table 5: M, mean; SD, standard deviation. Sig., normality based on the Shapiro-Wilk test for the Hedonic Value dimensions.

	Hedonic Value					
	Telepresence			Enjoyment		
	M	SD	sig.	M	SD	sig.
DVR	3,62	1,54	,139	5,35	1,31	,001
VR	5,55	1,24	,000	6,41	0,87	,000

Table 6: M, mean; SD, standard deviation. Sig., normality based on the Shapiro-Wilk test for the Utilitarian Value constructs.

	Utilitarian Value					
	Product Diagnosticity			Usefullness		
	M	SD	sig.	M	SD	sig.
DVR	5,28	1,37	,001	5,29	1,44	,000
VR	5,95	1,21	,000	6,08	1,07	,000

In the context of the telepresence dimension, the p-value registers as less than 0.001, leading to the rejection of the null hypothesis. This outcome highlights that the mean rank for telepresence scores in the DVR group is 40.49, whereas in the IVR group, it is notably higher at 80.51. Consequently, participants in the IVR group achieved higher telepresence scores than their counterparts in the DVR group. A similar pattern emerges when examining the enjoyment dimension. The Mann-Whitney U test yields a p-value of less than 0.001, rejecting the null hypothesis. In this case, the mean rank for enjoyment scores is 44.39 for the DVR group and 76.61 for the IVR group, underscoring that IVR participants report higher enjoyment scores than those in the DVR group.

For both dimensions related to utilitarian values, namely product diagnosticity, and usefulness, the p-value is less than 0.001, signifying the rejection of the null hypothesis through the Mann-Whitney U test. In product diagnosticity, the mean rank for DVR scores is 50.55, while for IVR, it stands at 70.45. This pattern indicates that scores in the IVR group tend to be higher than those in the DVR group. A similar trend is observed for the usefulness dimension, where the mean rank score for DVR is 49.67, contrasting with the IVR group's mean rank of 71.33. Further insights regarding the means and standard deviations for both modes can be found in *Figure 33*.

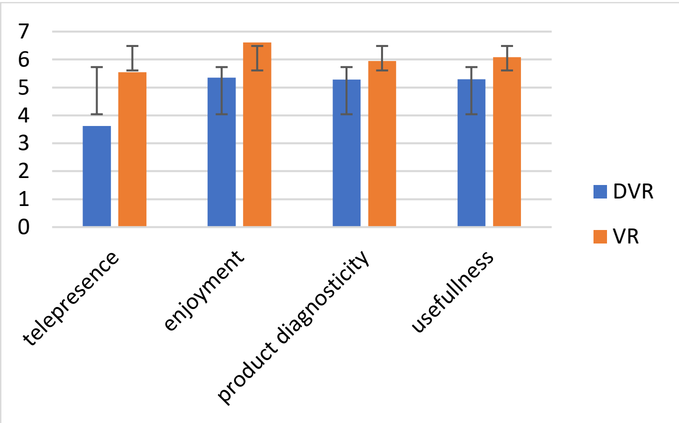


Figure 33: Hedonic and utilitarian dimensions mean and standard deviations in IVR and DVR.

Cognitive Load

We conducted the Shapiro-Wilk test to assess the normality of the cognitive load data. The results revealed that both the DVR and IVR samples did not follow a normal distribution (refer to *Table 7*). To address this deviation from normality, we applied a log transformation to the data for both DVR and IVR samples to achieve a normal distribution (as depicted in *Table 7*).

Table 7: Normality test scores before and after log transformation.

	Shapiro-Wilk			Shapiro-Wilk (after log-10 transformation)		
	statistics	df	sig.	statistics	df	sig.
DVR	,883	60	,000	,988	56	,066
VR	,943	60	,008	,984	56	,095

Since the T-student assumptions were met, we employed the paired-sample T-test to assess the RTLX results. The mean overall RTLX score for the IVR mode was similar to that of the DVR mode. Consequently, the T-test did not provide enough evidence to reject the null hypothesis, indicating that the observed difference was not statistically significant (17 vs. 14, t (55) = -1.854, p > 0.069, as illustrated in *Figure 34*).

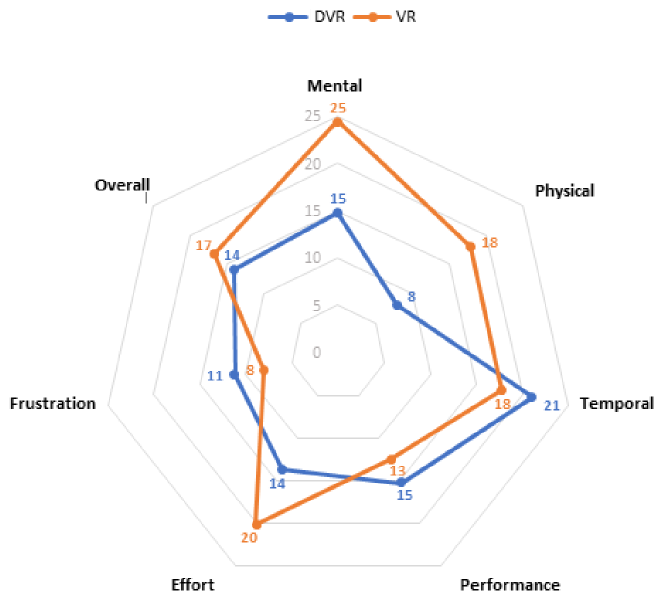


Figure 34. Comparison of the overall and the Nasa-RTLX subscales of IVR and DVR modes.

User Experience

The User Experience Questionnaire (UEQ) is a widely used tool designed to gather users' subjective opinions regarding the user experience of various products (Laugwitz et al., 2008). The UEQ employs a semantic differential format comprising 26 items represented by adjectives. Its primary purpose is to assess users' perceptions of a system across six dimensions: attractiveness, perspicuity, efficiency, dependency, stimulation, and novelty. The UEQ scores for these six scales, along with their corresponding Cronbach's Alpha coefficients, are presented in *Table 8*. Cronbach's Alpha coefficient (Cronbach, 1951) measures the internal consistency of a scale. While there is no universally accepted threshold for the Alpha coefficient, it is generally considered satisfactory when exceeding 0.7 (Schrepp, 2019). This criterion is met for five scales, except for dependability, which exhibits an Alpha value below 0.7(*) in both IVR and DVR modes. This suggests that the items related to dependability may be interpreted inconsistently by different participants.

Table 8: UEQ Scores with dependability inconsistencies.

	VR mode		DVR mode	
	Mean	Cronbachs Alpha	Mean	Cronbachs Alpha
Attractiveness	2,35	0,88	1,84	0,91
Perspicuity	2,42	0,75	2,05	0,84
Efficiency	2,26	0,75	1,87	0,80
Dependability	1,56	0,37*	1,62	0,46*
Stimulation	2,38	0,83	1,79	0,89
Novelty	2,47	0,76	1,79	0,86

This discrepancy likely arises from inconsistent responses on the scale. Specifically, in the IVR mode, there are 25 items with a Critical Indicator (CI) equal to 2 for dependability, while in the DVR mode, there are 18 items with CI=2. Such variations can stem from random response errors or a misunderstanding of certain items. However, it's important to note that this issue appears to be specific to the dependability scale and is not indicative of a broader problem (Schrepp, 2019).

To assess this, we utilized the UEQ analysis tool developed by Schrepp and colleagues (Schrepp et al., 2017b) to compare the two UEQ datasets. Our analysis included a comprehensive dataset comprising responses from 21,175 individuals across 468 studies involving various items, serving as a reference point. *Figure 35* illustrates the comparison of scores obtained in both modes.

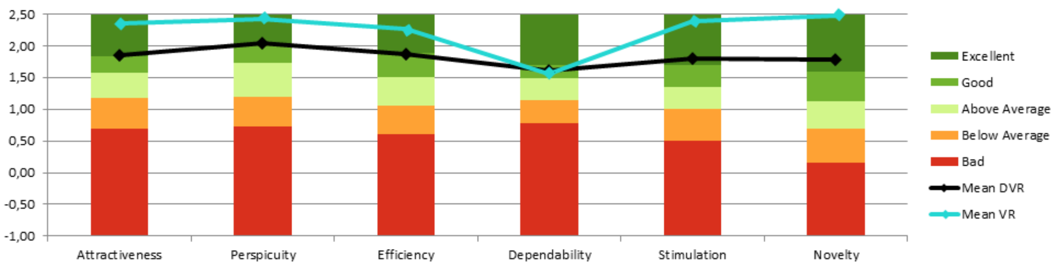


Figure 35. The UEQ benchmark histogram comparison of IVR mode against DVR mode.

3.6 Discussion

The results of our study confirm several hypotheses and provide insights into the differences between IVR and DVR shopping experiences. Here is a summary of our findings:

Hypothesis H1: Time Duration

The longer duration of the shopping experience in IVR compared to DVR supports H1. This can be attributed to the heightened sense of immersion and engagement in VR, leading to increased user involvement and a desire to explore the virtual environment further (Huang et al., 2021). Some participants even expressed a reluctance to complete the experience in IVR, indicating a strong preference for the immersive environment.

Hypothesis H2: Hedonic and Utilitarian Values

The results support H2, indicating that IVR delivers higher hedonic and utilitarian values than DVR. Shopping experiences, such as DVR, are found to be inadequate for delivering a rich, hedonic shopping experience (Goldsmith & Flynn, 2005). The positive emotional aspects of the IVR experience align with previous research that associates hedonic experiences with greater time spent in the store (Babin et al., 1994; Jones et al., 2006). IVR emerges as a valuable technology for enhancing the hedonic and utilitarian aspects of shopping.

Hypothesis H3: Cognitive Load

H3 is confirmed based on the cognitive load assessment. Although preliminary results show comparable cognitive load in both versions, further research is needed to assess factors like frustration and temporal demand. It is expected that frustration would be higher in the DVR version due to unnatural interaction techniques (Wu et al., 2019), while users might perceive the IVR shopping experience as faster, possibly due to the higher degree of immersion.

Hypothesis H4: User Experience

H4 is confirmed as IVR outperforms DVR in terms of attractiveness, perspicuity, efficiency, stimulation, and novelty, as indicated by the UEQ. The inconsistency in dependability scores is attributed to the dependability scale's items being interpreted differently by participants.

Our study suggests that the differences in perceived hedonism and utilitarianism between IVR and DVR shopping experiences are influenced by several factors. These include the display and interaction systems, the degree of immersiveness, and the quality of technology, such as the high-resolution Oculus Quest 2 HMD used in our study.

The correlation between immersiveness and shopping experience aligns with prior research, highlighting the importance of technology's degree of immersiveness in influencing hedonic and utilitarian values (Childers et al. 2001).

Furthermore, our findings suggest that using controllers and techniques like virtual hands and raycasting-based virtual pointers in IVR can enhance the user experience compared to mouse-based interactions in DVR.

We acknowledge some limitations of our study, such as focusing only on bags and not exploring other fashion products. Future research could investigate various fashion items. Additionally, considering participants' feedback, conducting experiments in a standing position and incorporating virtual mirrors for users to visualize themselves with purchased products could be beneficial. Lastly, conducting experiments in real retail scenarios and evaluating additional metrics like purchase intention, item purchase percentage, and customer engagement could provide further insights.

To aid future researchers, we have compiled *Table 9* summarizing the interaction, visualization, locomotion systems, product types, and results related to hedonic and utilitarian values in previous comparative studies and our research.

In conclusion, our study sheds light on the differences between IVR and DVR shopping experiences, emphasizing immersiveness and technology quality in shaping user perceptions. Future research in this area can explore a wider range of fashion products and real-world scenarios to gain a comprehensive understanding of the impact of VR on the retail industry.

Table 9: General framework of DVR-IVR studies related to hedonism and utilitarianism.

Shopping experience modes	Display	Interaction	Locomotion	Hedonism	Utilitarianism
DVR (high involvement product)	Desktop computer screen	Mouse cursor	Keyboard arrow keys	Low	Low
IVR (high involvement product)	IVR headset (Oculus Quest 2)	Raycasting laser pointer interaction	Teleport metaphor	High	High
DVR (low involvement product)	Desktop computer screen	Keyboard and a mouse (Lombart et al., 2020) Mouse cursor (Peukert et al., 2019)	Keyboard arrow keys and mouse (Lombart et al., 2020) Keyboard arrow keys (Peukert et al., 2019)	Low (Peukert et al., 2019) High (Lombart et al., 2020)	High (Peukert et al., 2019)
IVR (low involvement product)	Oculus Rift DK2 (Lombart et al., 2020) HTC Vive; (Peukert et al., 2019)	Raycasting gaze pointer interaction (Lombart et al., 2020) Virtual handle controller (Peukert et al., 2019)	Game controller with two thumbsticks (Lombart et al., 2020) Natural walking (Peukert et al., 2019)	High (Lombart et al., 2020; Peukert et al., 2019)	Low (Peukert et al., 2019)

3.7 Conclusion

Nowadays, the potential of VR as a transformative tool for enhancing shopping experiences, especially in retail industries such as fashion, cannot be overstated. This part of the doctoral research contributes to this evolving landscape by presenting the first comparative study between IVR and DVR within the fashion industry, specifically focusing on the shopping experience for bags.

The task of the experiment consisted of the real-time product configuration in the virtual environment and the exploration of all the bag's features (storytelling).

The findings of this study highlight the advantages of IVR, showcasing superior hedonic and utilitarian values, a more favorable user experience, and comparable cognitive load, although with longer experience duration times.

While this research focuses on the first and single implementation of the shopping experience-related bags, it paves the way for further exploration and innovation in the fashion industry and the retail industry in general.

Chapter 4. A Multi-Sensory In-Store Virtual Reality Customer Journey for Retailing

The retail industry is undergoing significant transformations concerning products, customers, and sales channels. Regarding the first aspect, there has been notable progress in product evolution (Pantano, 2014). Advances in engineering and processes have enabled a higher level of features and the customization of configurations, materials, and finishes. Consequently, customers find it much more challenging today than before to make choices, leading to reduced confidence in their purchases. On the retail side, the wide array of products makes it impossible to maintain the entire catalog in local warehouses. Furthermore, customers are evolving due to digital connectivity, making them better informed about products and empowering them to participate in the purchasing process actively. However, most customers struggle to envision the final product, including ergonomics and aesthetics (Oh et al., 2008), and how it fits within their space (spatial visualization). Additionally, the decision-making process is intricate and influenced by budget, available space, aesthetics, ergonomics, time investment, environmental impact, and lifestyle (Oh et al., 2004). Customers now demand a novel (Kozinets et al., 2002; Oh et al., 2008), multisensory (Suraj Manojkumar et al., 2021), entertaining (Jones, 1999), and social (Borges et al., 2010) shopping experience. Consequently, the shopping experience has become crucial, serving as a sensory and emotional journey for discovering products and instilling confidence in the purchase (Oh et al., 2008).

Customer Journey (CJ) refers to examining customers' interactions with a service provider to achieve a specific goal, encompassing multiple touchpoints (Lemon & Verhoef, 2016). CJ has gained increasing importance in understanding and influencing complex customer behaviors and experiences. This term has been utilized across various disciplines since the 1990s and its literature has expanded more than sevenfold in the past eight years (Tueanrat et al., 2021).

The final aspect is connected to the recent expansion of digital sales channels, including e-commerce and other opportunities arising from the digital landscape (Pantano et al., 2017; Willems et al., 2017). Although physical stores can offer a more immersive experience than their online counterparts, they are currently grappling with a significant challenge: delivering added value that justifies their expenses, including real estate, management, personnel, and warehousing costs (Berman, 2019).

We introduce an innovative approach to enhance the in-store retail experience by harnessing VR technology. VR seamlessly integrates into the customer journey, providing a multisensory experience that combines virtual stimuli, such as audio and video, with tactile sensations from real object samples. Our approach, named the Multi-Sensory In-Store Virtual Reality Customer Journey (MSISVRCJ) (See *Figure 36*), strives to render the in-store experience competitive when compared to other channels by engaging customers, assisting them in making informed decisions and fortifying customer-brand relationships (Hollebeek et al., 2020; van Kerrebroeck, Brengman, et al., 2017).

Figure 36. Our novel MSISVRCJ: starting from a safer seated position, once confident, the customer can stand up and explore product configuration.

4.1 State of the Art

The inaugural venture into VR within the retail sector dates to 1993, with the inception of a simulated shopping environment (Gold, 1993). The primary objective was to replicate a shopping environment and experience closely resembling real-life circumstances. Subsequently, researchers delved into the immersive aspects of VR and its interactive capabilities (Slater & Wilbur, 1997).

Others explored how the virtual store influenced customer behavior compared to traditional brick-and-mortar stores (Vrechopoulos, 2004). The latest research focuses on gauging the impact of VR on customer satisfaction, enjoyment, engagement, and overall acceptance.

Fox et al. (2009) contended that VR serves a utilitarian purpose by meeting the needs and expectations of certain consumers. Building on this, Farah et al., (2019) posited that retailers adopting VR can enhance the overall consumer experience by placing greater emphasis on the human senses (Biocca & Delaney, 1995). Indeed, as the literature discusses, VR serves as a medium to cater to users' sensorimotor channels (Biocca & Delaney, 1995). Through the adoption of this technology, users can become fully immersed in a virtual world, engaging various senses such as touch, sight, and even smell (Gutierrez et al., 2008).

Van Kerrebroeck et al. (2017) explored the potential of a relaxing in-store VR experience within a shopping mall to address the issue of overcrowding during shopping excursions. This research provides a solution for retailers facing perceived overcrowding issues by offering shoppers a VR experience as a mitigating option to alleviate the adverse effects of crowding on consumers and, subsequently, reduce the negative repercussions for retailers.

Zenner et al. (2020) introduced a VR-based application designed to support consultations in furniture stores. This system enables customers to explore various configurations of sofas with the guidance of a sales expert and experience them through immersive VR in a range of virtual environments. While the sales expert can modify the sofa's layout and fabric, the customer remains immersed and can physically sense the configured sofa's texture through passive haptic feedback provided by a sample piece upon which the customer can sit.

The metrics being assessed are largely subjective, including factors such as the duration of the experience (as estimated by users themselves), users' attitudes and behaviors regarding new technologies, and the level of immersion and practicality of the system. An initial field study conducted in a furniture store indicates that the system effectively immerses users, providing them with a realistic sense of sofa configurations. Furthermore, customers perceive the VR configurator as a valuable tool that simplifies their decision-making process regarding purchasing.

Lately, the concept of Virtual Reality Customer Journey (VRCJ) has emerged, encompassing the utilization of interactive computer-mediated environments by businesses. VRCJ has the potential to offer sensory feedback that can engage consumers, bolster consumer-brand relationships, and influence consumers' desired behaviors at various stages of their journey (Hollebeek et al., 2020). The VRCJ framework posits that sensory feedback plays a pivotal role in all dimensions of VR engagement. Nevertheless, a comprehensive and systematic understanding of VR's drivers and effects within the Customer Journey (CJ) context remains limited (Hollebeek et al., 2020).

These aspects are the driving force behind our research, aiming to provide deeper insights into user behavior within a novel journey, specifically the MSISVRCJ, which represents an in-store implementation of a multisensory experience.

4.2 Methodology

The design of the journey is aimed at facilitating the shopping experience in collaboration with our industrial partners. The MSISVRCJ involves several key participants:

- Customers: MSISVRCJ seamlessly accompanies customers through each touchpoint in a natural manner to cater to their individual needs and expectations.
- Sales Assistants: These individuals are well-trained in the usage and objectives of MSISVRCJ. They introduce the VR experience to customers based on their preferences and the specific context.
- Technical Helpers: Their role is to support the hardware and software associated with MSISVRCJ, such as assisting with the setup by wearing of the HMD and addressing safety concerns. They aim to be as unobtrusive as possible, and in the long run, their responsibilities can potentially be taken over by the sales assistants.

MSISVRCJ necessitates a dedicated area within the store, measuring 3 x 3 meters, which should not be a thoroughfare and should provide a quiet environment. This is important because users may feel uncomfortable being observed or distracted while in VR (Billinghurst et al., 2014; Mai & Khamis, 2018). The experimental setup, including room dimensions and placement, was adapted to the flagship store where the experiment was conducted and agreed upon with the industrial partner. Additionally, the space should feature comfortable seating options (e.g., chairs or sofas) around the perimeter, as the seated position is safer and more comfortable for first-time VR users.

The central area of the space must be kept free of obstructions (e.g., tables, hard chairs, cables, etc.) to prevent potential collisions and tripping hazards during standing VR sessions (See *Figure 37*). A graphics PC is responsible for running dedicated VR software and driving the HMD. This graphics PC is connected to a tablet used by the sales assistant through a wireless network. The tablet assists the customer in the setup process before and after the VR session to conceal the technology and maintain an experience akin to traditional shopping.

One distinctive feature of MSISVRCJ, setting it apart from other methods in the literature, is its inclusion of multisensory feedback. This feature aims to compensate for the absence of tactile sensations in cost-effective VR experiences by incorporating real material samples as non-virtual haptic support. In the context of the composite continuum (Jeon & Choi, 2009), known as visual virtuality–haptic reality (vV-hR), MSISVRCJ combines conventional visual virtual environments (VEs) with real tactile interactions. This is achieved using tangible material samples to interact with virtual objects configured according to the customer's material choices.

The introduction of these real-world sensory elements can vary depending on the specific product. For instance, in a car configurator, a real seat might be used to demonstrate ergonomics, and a sample piece of leather from a catalog can be presented for users to experience the material. Concurrently, users can visualize various color combinations within the virtual environment. The timing of these tangible experiences can also be adjusted to be included or excluded from the VR session, providing flexibility. This approach necessitates well-designed in-store samples to offer an extensive catalog of tactile options.

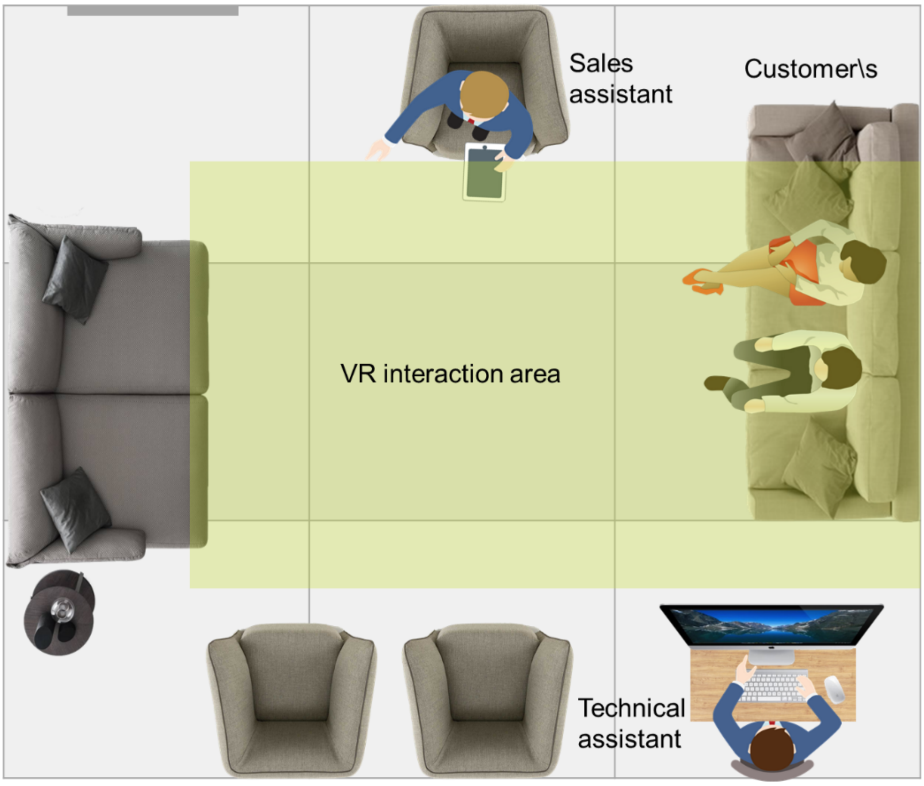


Figure 37. An example of layout (3x3m) for the dedicated store area to the MSISVRCJ.

The MSISVRCJ is a well-structured process comprising four distinct touchpoints, as depicted in *Figure 38*. This process is characterized by the active engagement of store management and staff, who are equipped with the necessary tools, motivation, and training to support its implementation.

Customers initially enter the store (Touchpoint 1). Söderlund (2016) revealed that the presence of a shop assistant in the store, as opposed to their absence, leads to significantly higher levels of customer satisfaction. This increase in satisfaction is attributed to the heightened sense of pleasure experienced by customers, which serves as a mediating factor.

Sales assistants invite customers, proposing that they explore the store's current catalog using VR (Touchpoint 2). Upon agreeing, customers put on the HMD and begin acquainting themselves with MSISVRCJ's predefined scenes, referred to as "moods." To facilitate their initial interaction with the VR interface, customers start in a seated position. Subsequently, if they feel comfortable, they can transition to a standing position and navigate within the designated area to alter their point of view (PoV).

A Multi-Sensory In-Store Virtual Reality Customer Journey (MSISVRCJ)			
	touchpoints	**actors**	
		assistants	customer
1	Customer enters in the physical store and the sales assistant proposes the journey		
2	Customer familiarizes with the VR-interface and discovers the products		
3	Sales assistant configures the product for the customer who experiences the multi-sensory journey		
4	Customers are more confident about the purchase choice		

Figure 38. The MSISVRCJ touchpoints and the actors involved.

The virtual scenes within MSISVRCJ are thoughtfully crafted to convey products with a strong emotional impact, effectively utilizing traditional multimedia elements (such as color schemes, product arrangements, and combinations) and virtual multimedia components (including 3D animations and sound). During this phase, customers begin to explore the capabilities of MSISVRCJ in altering their PoV by seeking guidance from the sales assistant. Typically, at this juncture, most customers desire to view the product they have in mind or the one that has piqued their interest the most. This transition marks Touchpoint 3, where customers become actively involved in configuring the virtual space. The sales assistant's software configurator, accessible on a tablet, incorporates several essential features (refer to *Figure 39*) designed to accommodate and implement customer suggestions:

- Projects: This feature enables the loading and saving of scenes from the virtual catalog, encompassing both preset scenes (referred to as "moods") and those created by customers.
- Scene and Product Navigation: Users can manipulate 3D models, including the entire scene, by rotating, moving, and scaling them as desired.
- Product and Material Selection: This feature facilitates the loading of products, materials, and finishes for customization.
- Teleport: Customers can employ this feature to swiftly reposition the virtual camera or themselves within the scene, avoiding the need for physical walking.
- Walls and Ceiling Control: This feature allows users to toggle occlusion elements on or off, enhancing visibility within the virtual environment.
- Scene Scaling: Customers can adjust the size of the virtual scene, either enlarging it for an overall view or reducing it to focus on intricate details (e.g., examining the stitching on a virtual sofa).
- Resetting the Scene: This feature completely restores customer changes, reverting the scene to its default settings.
- Camera Switch: Users can quickly transition their PoV to different preset positions within the scene (e.g., taking a seat on the virtual sofa) for convenient navigation.
- Scene Transfer: This feature facilitates the scene transfer to the customer's HMD.

Notably, the software was meticulously designed to minimize any technical interactions required from the customer's end, thereby mitigating any potential digital discomfort or embarrassment (referred to as "digital shame") (Lavoie et al., 2020). The sales assistant adeptly customizes furniture based on the customer's verbal instructions, ensuring that the customer only sees the result without engaging in technical intricacies.

Figure 39. On the left: the sales assistant interface with its features. On the right: what the customer sees, including a realistic rendering of the product inserted in an evocative background.

4.3 Field Study: Flagship Furniture Store

The choice of a furniture flagship store as the setting for our study was deliberate, given that the furniture industry is a high-value sector with a market worth $247,836 million in 2021 and a steady annual growth rate of 2.17% (Furniture - United States | Statista Market Forecast). Furniture purchases are significant investments that require careful consideration due to their long-term nature (Oh et al., 2004). They involve intricate configurations, attention to materials, considerations of space constraints, texture, and surface touch (Oh et al., 2008). Consequently, we conducted our field study in collaboration with a renowned furniture design manufacturer, operating globally and offering an extensive catalog of furniture products bearing the "Made in Italy" hallmark. This manufacturer provides customers with the ability to customize product dimensions, choose from a wide palette of materials (comprising over 500 options), and select features such as recliners, automatic headrests, and even embedded speakers.

The manufacturer played an active role in the development and validation of MSISVRCJ within the context of the field study, although certain conditions were imposed:

- Non-Interference with Sales: Our investigation into customer behavior needed not to disrupt the sales process. In-store researchers conducted discreet observations of user behavior and engaged in brief customer interviews with a minimal number of concise questions.

- Informed Customer Consent: Customers were required to be fully aware of and agree to the experimental conditions, encompassing data collection, photography, and feedback collection. These activities were solely for scientific research purposes.
- Sales Assistant Discretion: Sales assistants had the autonomy to decide whether to propose the MSISVRCJ experience to customers, considering factors such as the customer's available time and the situational context.

These constraints precluded using certain well-established questionnaires commonly employed in the literature. Consequently, we opted for a qualitative analysis approach, combining user observation with a survey (Oh et al., 2008).

The primary objective of the field study was to assess, in a real store environment with actual customers, several key questions:

- Customer Appreciation: Did customers value the MSISVRCJ experience?
- Realism of Virtual Scenes: Were the virtual scenes perceived as realistic by customers?
- Perceived Usefulness: Did customers view MSISVRCJ as a useful and helpful tool in their decision-making process?

These questions aimed to provide valuable insights into the reception and effectiveness of the MSISVRCJ system in a practical retail setting.

4.3.1 Procedure

Once customers agreed to participate, they wore the HMD and started their MSISVRCJ experience by exploring the virtual catalog, which featured a range of preset "moods" or scenarios. Within these moods, customers were free to personalize their experience by requesting specific models, materials, colors, and finishes. Notably, this represented a departure from the traditional shopping journey. Additionally, we introduced the role of the shadowing researcher, an unobtrusive observer who discreetly observed and recorded user behavior. After the VR experience, the shadowing researcher formally surveyed customers (McDonald, 2005).

The implementation of the VR system within the furniture store was carried out in a dedicated area strategically surrounded by sofas to minimize the risk of collisions with other customers. The tangible element of MSISVRCJ was carefully curated to include a selection of sofas in the VR area, each offering different seat firmness levels. This allowed users to assess and find their preferred comfort level on a real sofa while simultaneously visualizing their chosen materials in the virtual environment. Additionally, a book containing material samples for textures and finishes was made available (See *Figure 40*). After customers select the model, materials, colors, and finishes, they can remove the HMD and purchase. Regardless of the purchase outcome, the researcher surveyed the customer to gather valuable feedback.

Figure 40. During the proposed MSISVRCJ, customers can experience the textures of the materials using real samples and the ergonomics by sitting on a real sofa with similar specifications to the virtual one.

4.3.2 Materials

The field study was conducted within a flagship store in London, a trend store that has gained popularity in major cities, to establish brand identity, showcase the latest trends, and exhibit product collections (Kozinets et al., 2002). To ensure an immersive and secure virtual experience, we carefully selected a dedicated in-store area in the corner of the ground floor.

For the experiment, we utilized the Samsung Odyssey HMD. Interestingly, we chose not to provide users with the two wireless controllers since they were not intended to interact directly with virtual elements. Instead, the shop assistant assumed responsibility for configuring the elements within the virtual environment based on the user's requests. Furthermore, users were required to keep their hands free to touch real material samples while immersed in the virtual environment, thus enabling them to experience realistic tactile feedback.

The only user activity permitted was the adjustment of the point of PoV, achieved by naturally moving the head. The graphics PC used in the setup was a mobile workstation with an Intel Core i7-7700HQ processor, 16 GB of RAM, and an NVIDIA GeForce GTX 1070.

To enhance the immersive quality of the experience, the company implemented several "moods" within the virtual environment. These environments were meticulously crafted by skilled 3D artists and aimed to replicate realistic scenarios, including countryside settings. Realism was achieved through sound effects and animations, such as the wind rustling through the vegetation and sky. Additionally, the experience incorporated aroma emitters (Manghisi et al., 2017) that diffused local fragrances, adding an olfactory dimension to convey the sensation of "being there." The collection of sofas was faithfully reproduced in every detail, including aspects like stitching, cushion wrinkles, and even animations for reclining.

4.3.3 Participants

Customers participated in the experiment during two distinct sessions. As part of the experimental protocol, customers were required to consent and accept the specified privacy conditions before commencing their participation.

4.3.4 Measures

The researchers meticulously observed the customers and recorded data from the following indicators on the rendering PC:

- Time Duration: This metric encompassed the VR time duration, from when customers donned the HMD until they either concluded the session or removed the HMD.
- Level of Familiarity with VR: Users were informally queried to rate their familiarity with VR on a scale ranging from 1 to 7.
- User Behavior: This category encompassed the primary actions undertaken by users within the VR experience, such as attempts to touch objects, alterations in the PoV, or passive observation.
- User Targets: Researchers noted the specific objects or elements that captured the user's attention or elicited interaction, such as furniture details or an overview of the virtual catalog.

In addition to these observations, a survey was administered to customers, with only four questions permitted by the furniture manufacturer. These questions were meticulously designed to evaluate the customer's experience (Kranzbühler et al., 2018) and were rated on a 7-point Likert Scale. The third question was accompanied by an open-ended query to gain deeper insights into user motivations. The survey questions were as follows:

- How do customers rate the MSISVRCJ? - This question aimed to gauge general satisfaction.
- How do customers perceive the realism of the virtual scenes? - This query focused on the cognitive and sensory evaluation of the virtual experience.
- Does MSISVRCJ help customers with shopping? Why? - This question aimed to assess the affective evaluation of the system's impact on the shopping process (refer to Appendix B for further details).

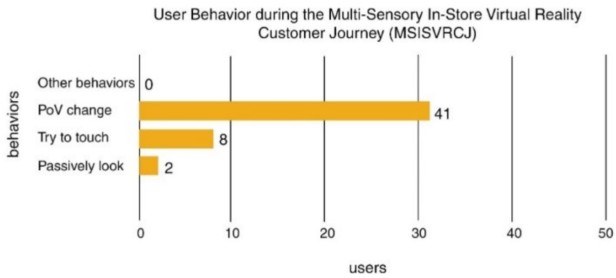
4.4 Results

During the session days, a total of 65 customers entered the store. However, only n = 50 agreed to participate in the experiment. These 50 participants included 32 males and 18 females, with varying age distributions: n = 18 were between 18 and 30 years old, n = 22 were aged between 30 and 45, and n = 10 fell within the 45 to 70 age range. The average duration of time spent in the virtual environment was generally below 10 minutes, with an average of 7.03 minutes and a standard deviation of 1.63 minutes.

Participants had limited to no prior experience with VR. Specifically, 30 participants had never experienced VR before, while 20 participants had some previous exposure to VR. To assess their level of familiarity with VR, users were asked to rate their familiarity on a 7-point Likert scale, ranging from 1 (indicating "not very familiar") to 7 (indicating "very familiar"). The results indicated that the overall level of familiarity with VR was not particularly high, with an average score of 3.45 and a variance of 0.94.

Interestingly, it was observed that all participants changed their position while immersed in the virtual environment, transitioning from a sitting to a standing posture. Furthermore, the most prevalent user behavior observed in 82% of participants (n = 41) was the act of changing the PoV (refer to *Table 10*). This behavior carries significant implications for the immersive nature of the experience. Using the HMD allowed users to achieve complete immersion in the virtual environment, offering them a fundamentally different way to explore the furniture collection compared to traditional printed catalogs.

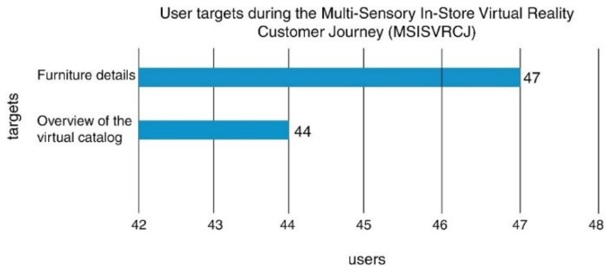
Table 10. User behavior during the MSISVRCJ.



A noteworthy and intriguing observation was made regarding eight participants who attempted to touch the virtual objects to validate the realism of the experience. This behavior highlights the extent to which the virtual environment could elicit a sense of immersion and tangibility.

Further examination of user targets (as depicted in *Table 11*) revealed that nearly all participants could gain an overview of the virtual catalog, with 88% (n = 44) of users achieving this perspective. Additionally, a substantial portion of participants, totaling 94% (n = 47), focused their attention on specific details of the furniture, including aspects such as hand rests, legs, and stitching. Some customers even tried to inspect the bottom of the sofas, presumably to assess the "quality of construction." These findings underscore the effectiveness of the virtual experience in engaging users and encouraging them to closely examine the virtual objects, further enhancing the perception of realism and immersion.

Table 11. User targets during the MSISVRCJ.



The observations made during the experiment frequently revealed expressions of surprise and excitement among the users. These expressions were often accompanied by comments such as:

- "I feel well in here!"
- "It's crazy. I can look around the sofa!"
- "Amazing, I want to touch it!"
- "It's fun!"
- "Very helpful; I want to see my home with this technology."
- "My wife is very happy, so I'm the happiest man in the world."
- "When I buy my sofa and furniture, I want to use this technology."
- "It's a good overview of the product, and I should make a decision."
- "Technology is amazing; I never saw it so clearly!"

These comments underscore the positive emotional reactions and engagement of the users with the MSISVRCJ.

The survey results align with these observations, revealing a high level of customer satisfaction (average score of 6.12, variance of 0.71) among those who engaged with the MSISVRCJ (Kranzbühler et al., 2018). This level of satisfaction was consistent with what was observed during the experiment.

Furthermore, the perception of realism in the virtual scenes was also positively received by users (average score of 5.98, variance of 0.59). The results suggest that users felt genuinely immersed in the virtual environment. The positive outcomes of the third survey question (average score of 6.54, variance of 0.73) were supported by several reasons provided by users:

They could see products and configurations not physically available in the shop. They observed models displayed in pleasant environments or settings reminiscent of their homes. They gained increased confidence through a clearer visualization of spatial configurations and material combinations.

These findings emphasize the effectiveness of the MSISVRCJ in enhancing the customer's shopping experience and decision-making process by providing a realistic and immersive virtual environment.

4.5 Discussion

The primary outcome of the field study on the MSISVRCJ is the overwhelmingly positive feedback received from participants. However, it is worth noting that the average duration of the VR experience was lower than initially expected despite the diverse range of moods available in the 3D catalog. Several factors could explain this result:

- Customer Preselection: Many customers already had a specific model in mind from other sources, such as advertisements or recommendations from friends. As a result, they often requested to skip the mood selection process and proceed directly to configuring their chosen model. The software accommodated this request by allowing users to jump to configuration and shopping activities.
- Discomfort with New Technology: The relatively short time spent in VR could be attributed to discomfort or apprehension associated with using unfamiliar technology or being immersed in an unfamiliar virtual world, especially in a public place.

- Isolation from Physical Reality: Wearing an HMD means losing visual awareness of the physical environment. Users may have felt uncomfortable about not being able to see their surroundings, potentially making them more cautious about their personal belongings or interactions with others (Mai & Khamis, 2018).

Another interesting observation was the natural and spontaneous change in the PoV by users. This behavior appeared to enhance the sense of immersion and the feeling of "being there" in a real shop (Bartlem, 2005). Many customers expressed curiosity about details such as the area under the sofa and the stitching between cushions, which were present in the well-modeled virtual scenes. Surprisingly, customers reported feeling more confident and private while examining these details in VR compared to their discomfort in attempting the same in a physical store.

Another indicator of the quality of the experience was the instinctive attempt by some participants to reach out and touch the virtual objects, demonstrating a natural desire for tactile engagement (Biocca et al., 2001). This behavior supported the realism and immersion achieved by the MSISVRCJ.

The open-ended question in the survey helped validate customer acceptance, a crucial parameter in VR experiences, particularly in public settings. Furthermore, the responses supported the third research question about the perceived value of MSISVRCJ, highlighting its ability to offer a broader catalog, create pleasant virtual environments, enable product visualization before purchase, and potentially strengthen consumer-brand relationships, as previously demonstrated in the literature (Goh & Ping, 2014; Hollebeek et al., 2020; Homburg et al., 2015). These findings underscore the potential of VR in enhancing the shopping experience and fostering positive interactions between customers and brands.

4.6 Conclusion

In this Chapter, we propose an MSISVRCJ that integrates IVR, an optimal warehouse, material samples, and a dedicated in-store area to provide a comprehensive product catalog with sensory and ergonomic feedback. In this study, we focused on a different retail industry, such as the furniture industry. The technology is hidden from the customer by the sales assistant's dedicated interface to control the scenes, the PoV, and the customization process.

This application shows a different approach to exploiting IVR in shopping experiences while configuring the product in real-time. Users, while immersed in an IVR environment, could have the possibility to manipulate fabric samples of the product they were considering buying to evaluate which one fits best in their houses and for their tastes. Also, they could try a product sample physically present in the store and evaluate the comfort before buying it.

This different approach shows a "mixed" experience that combines the IVR component with the real and physical interaction of users with products. In summary, only the vision sense is altered thanks to the HMD; the touch sense, instead, was happening with an actual touch of real products/samples.

Chapter 5. Designing Pseudo-Haptics Shopping Experiences

People prefer direct interaction with the product to evaluate experience attributes. Besides this utilitarian aspect, physically touching the product also entails a hedonic aspect. Need for touch (NFT) is the preference for extracting and utilizing information obtained through touch. Peck & Childers (2003) identified individual differences in NFT, which comprises two dimensions, each with six variables. One dimension is instrumental NFT, where consumers seek relevant information about a product's physical attributes and gain confidence and security through touch, including geometric properties like size or shape and material attributes such as texture, hardness, weight, or temperature (Klatzky & Lederman, 1992).

In contrast, autotelic NFT, the other dimension, is related to the hedonic aspects of touch (Overmars & Poels, 2015b). It encompasses elements related to the pleasure and enjoyment consumers experience through direct contact with products (Manzano & Gavilan, 2016). Observations suggest that materials that appear soft or smooth or products with sleek designs invite a hedonic touch (Klatzky & Peck, 2012). Consequently, touch not only conveys structural information about a product but also elicits a significant affective response toward the product (Peck & Wiggins, 2006).

Consumers with a high level of NFT exhibit differences in their use of touch to gather information. They possess a superior ability to access haptic information, exhibit quicker memory recall of tactile details, and employ touch early in their product evaluation process (Balaji et al., 2011). Additionally, the level of NFT influences their product perception, leading to increased confidence and reduced frustration when they have direct access to the product. The NFT also impacts factors like the speed of accessing tactile information, motivation and skill in processing written messages, consumer assessment and trust, and product quality evaluation (Manzano et al., 2016).

Recent studies have focused on understanding the role of touch in shaping consumer attitudes within interactive online environments, primarily involving widely available haptic interfaces like laptops, tablets, mobile phones, and peripheral accessories, which offer regular feedback such as vibrations or pulses (Ornati & Kalbaska, 2022). A comprehensive overview of the literature in this area is provided by Racat et al. (2021). In the same article, the authors emphasize the significance of interface touch in inferring product information and the pleasure of interacting with a product, thereby reinforcing the link between knowledge, mental representation, sensory-motor actions, and online shopping contexts.

In an earlier exploratory study, Van Kerrebroeck et al. (2017) established that touch-enabled technologies can deliver utilitarian and hedonic value to consumers, primarily during the pre-purchase stages of the path to purchase. (de Vries et al., 2018) later proposed that the ability to interact with objects, such as images, using a touch interface is a predictor of online shopping enjoyment, regardless of the product category. Mulcahy & Riedel (2020) also affirmed that haptic feedback enhances the experience of advertisements, consequently strengthening purchase intentions. Also, scientific literature demonstrated that offering richer perceptual cues, including tactile and visual elements with interactive surface haptic effects, adds value to online fashion shopping, particularly during the information-gathering stage of the customer's e-commerce journey (Ornati & Cantoni, 2020).

Apart from consumer research, a significant body of literature delves into the importance of touch for various actors in the fabric and fashion value chain, such as designers. Petreca et al. explore the sensory experience of materials for designers, highlighting the need for digital fashion tools to provide adequate sensory feedback to design experts (Petreca, 2017). They propose innovative, embodied design methods involving material "sensing" technology (Petreca, 2017). Bridging fabric sensory research with interactive design, Atkinson et al. (2011) investigate how to convey fabric properties through digital media effectively. In a subsequent study, they developed a framework that facilitates the systematic analysis and comparison of tactile experiences, making it a valuable communication tool for designers (Atkinson et al., 2011).

Lastly, research in the sensory evaluation of apparel and fabrics has a history dating back to the early 21st century (Binns, 1926). Various methodologies have been developed over the years, using both human-centered and mechanical approaches, as reviewed by Ornati (2021).

5.1 Visual Perception of Materials

In physical retail stores, individuals naturally tend to touch products, whether to assess product qualities or simply for emotional engagement. However, in situations where physical touch isn't feasible, can this sensory experience be recreated through visual perception?

Everyday experiences demonstrate that people can visually discern the characteristics of materials because material perception typically engages multiple senses. When people physically interact with certain materials, they can not only feel them through touch but also observe their deformation, hear the sounds they produce, or even detect their distinct scents. Since material properties are accessible through various sensory channels, primarily vision, and touch, it becomes feasible to convey them visually.

Extensive research has delved into exploring visual and tactile perceptions of materials. Studies have shown that the combined sensory input from both touch and vision tends to dominate over single sensory modalities like touch or vision alone (Wesslein et al., 2014). In visual perception, research indicates that our perception of materials may heavily depend on our past experiences and memories regarding the visual distinctions among objects (Hutmacher, 2019).

Furthermore, evidence suggests that motion can significantly influence our perception of surface materials (Doerschner et al., 2011a). For instance, in a study examining matte and shiny surfaces, it was observed that the brain can rely on specific "motion cues" to discern differences and that these motion-based cues can override static visual cues in shaping our perception of material properties, resulting in substantial changes in how we perceive them (Doerschner et al., 2011b). This observation aligns with our everyday experiences, as movies often provide richer information than still images.

5.2 The Sense of Touch

Touch is profoundly influenced by visual and tactile stimuli, especially in specific contexts like shopping. Despite significant technological advancements in online websites over the past few decades, they currently fall short in replicating the tactile feel of materials such as fabrics accurately. Existing literature predominantly relies on computer-generated graphics, stop-motion animations, and static images. In contrast, our study introduces an innovative approach utilizing interactive visualizations incorporating shoogles and pseudo-haptic effects. To assess and validate our approach, we conducted user studies focused on elasticity and weight properties. Experiment 1 aimed to establish a correlation between the displayed fabric properties and user ratings. In contrast, Experiment 2 sought to determine the correlation between the actual fabric properties and those represented through interactive visualizations. Our findings demonstrate a consistent correlation between visual and tactile cues in both experiments, laying the groundwork for future research in online shopping to surmount the limitations of conventional platforms and provide a more authentic tactile experience.

Touch is an integral part of our daily lives, allowing us to explore, interact with our surroundings, gather information, make judgments, and form emotional connections (Mattens, 2016). The haptic system provides information that links sensory, motor, and cognitive functions within the nervous system, connecting the hand to the brain (Rodrigues et al., 2017). The hand's motor skills, referred to as "exploratory procedures" or "movement patterns," are utilized to extract specific object properties like surface texture and hardness (Klatzky & Lederman, 1992). While touch has long been recognized for its role in fundamental survival functions and social interactions, its significance in specific aspects of human life, such as shopping, has only recently garnered substantial attention (Pino et al., 2020).

When assessing fabrics and clothing, consumers engage multiple senses, including sight, touch, sound, and even smell, as suggested by Fiore (1993). However, visual and tactile sensations exert the most significant influence, with consumers "viewing" and "feeling" fabrics, as articulated by Burns et al. (1995).

Nevertheless, traditional online retail has struggled to provide consumers the opportunity to physically touch, handle, or feel the products they are interested in. Consequently, consumers have hesitated to purchase clothing online, underscoring the necessity to address the absence of tactile involvement in e-commerce (Silva et al., 2021b).

While this issue has been acknowledged in scientific literature, practical solutions have been scarce (Wilfling et al., 2022). Particularly for products involving complex materials like fabrics, online shopping faces challenges in conveying tactile qualities.

Although haptic interface technology has made significant strides, it cannot faithfully replicate the haptic experience of fabrics. Thus, vision is employed as a sensory substitute to convey material properties.

Our research builds upon recent studies demonstrating the potential of using visual stimuli to simulate tactile experiences (Bouman et al., 2013). We discovered considerable room for application and improvement by exploring the concept of pseudo-haptics, which entails a haptic perception different from what the actual haptic sensory input would suggest, achieved by manipulating the primarily visual feedback of a system (Pusch & Lécuyer, 2011).

Previous efforts to convey fabric properties through pseudo-haptic effects have primarily relied on static images, stop-motion animations, or computer-generated graphics.

In contrast, our approach introduces an innovative concept termed "interactive visualizations", centered on fabric perception, achieved through the integration of:

- Pseudo-haptic effects through mouse-based manipulation of visual feedback.

- Shoogles, an interactive photo sequence.

Through these visualizations, we can effectively convey the psychophysical dimensions of fabrics, enabling users to experience a "visualized touch." In this part of this research, we conducted user studies limited to elasticity and weight properties to test and validate our approach. Hence, we aim to address the following RQs:

- RQ1: Is there a relationship between the displayed degrees of elasticity and weight and the actual ones, as mediated by visual cues? (Experiment 1).
- RQ2: Does a correspondence exist between the actual weight and elasticity of fabrics and their digital representation, as mediated by visual cues? (Experiment 2).

5.3 State of the Art

Approximately two decades ago, user interface researchers ventured into an alternative approach - pseudo-haptics (Lecuyer et al., 2000) - to simplify system and device intricacies while delivering a substantial haptic experience. Lécuyer (2009) defined pseudo-haptic feedback, describing it as "a technique aimed at replicating haptic sensations by utilizing visual feedback and exploiting the characteristics of human visual-haptic perception."

In situations where minimal haptic stimuli are available, pseudo-haptic feedback can augment haptic sensations to a certain degree. For instance, by altering the CD ratio of the mouse cursor during the exploration of a 2D image, it becomes feasible to mimic negative or positive slopes, enabling users to perceive the "physics" of the image.

Nonetheless, previous research has primarily concentrated on assessing static attributes of materials, including properties such as surface reflectance, material category, roughness, and surface gloss.

Additionally, past literature has conducted experimental studies exclusively on static images, computer-generated images, or videos. In contrast, we intend to conduct user studies by harnessing our innovative concept of 'interactive visualizations' to validate our approach.

For our initial studies, we have focused on material properties related to elasticity and weight since both attributes have been relatively underexplored within previous pseudo-haptic literature concerning desktop displays.

5.3.1 Elasticity

In pseudo-haptics literature, we initially delved into studies concerning the perception of elasticity. The haptics community has extensively investigated the perception of stiffness and elasticity in real and virtual objects, typically focusing on measuring humans' ability to discern varying stiffness levels through dedicated haptic devices.

Our particular interest, however, centered on mouse-based input (utilized on a desktop display) to create a pseudo-haptic sensation of stiffness, devoid of the necessity for specialized hardware. In our exploration, we identified only one pertinent paper.

Argelaguet et al. (2013) introduced the concept of "elastic images," a pseudo-haptic feedback technique enabling users to perceive the local elasticity of images without the requirement for any dedicated haptic equipment on desktop displays. Their proposed approach emphasizes the capacity of visual feedback to induce a sense of rigidity when users interact with an image using a standard mouse.

Through a simple click on an elastic image, users can locally deform it according to its elastic properties. To heighten this effect, they also suggested the generation of shadows and folds to mimic the image's compressibility, as well as employing various mouse cursor replacements to enhance the perception of pressure and rigidity.

Their study demonstrated that users could distinguish between up to eight different stiffness values and confirmed that the approach imparts a tangible sense of elasticity. Potential applications of this innovative approach span a wide range, including pressure sensing in product catalogs and games or its integration into graphical interfaces to amplify the expressiveness of widgets.

5.3.2 Weight

A similar situation applies when considering the weight property. Although numerous papers address weight perception using pseudo-haptics, the primary focus of these works has been within VR environments, predominantly utilizing controllers [21]–[25]. These studies have concentrated on investigating how weight can be effectively conveyed by manipulating the CD ratio.

Our study diverges from the existing literature, as our objective is to delve into weight perception specifically within the context of desktop displays. Only one paper, authored by Kawagishi et al. (2023), introduced a method that combines pseudo-haptics and a tensile illusion with asymmetric vibration to amplify the pseudo-force sensation. Importantly, this sensation can be generated without requiring a force feedback device, simulating interactions with objects of varying masses and weights.

5.3.3 Our approach

Here, we introduce our innovative concept known as interactive visualizations, which combines pseudo-haptic effects with shoogles to replicate and simulate the authentic behavior of fabrics closely.

To enable interaction similar to a virtual, rendered model, we captured sequences of images, referred to as shoogles, that mimic these interactions. To achieve this, we obtained approximately 25 images using professional photography equipment to depict the progression of material movement (Refer to *Figure 41*). These images formed the foundation for two psychophysical experiments that explored material perception solely from a visual perspective, influencing haptic perception through visual cues.

Figure 41. A photographic setup consisting of 2 LS-1200 LED Panels, Canon EOS 5D Mark II on a tripod, a white paper backdrop, and a blue velvet fabric (32 x 46 cm).

From a pseudo-haptic viewpoint, we harnessed the cursor gain technique, as our goal was to ensure a parallel adjustment direction aligned with the mouse movement direction.

Although the cursor gain technique is relatively straightforward to implement, it exclusively functions while the user is actively moving the mouse and is confined to the direction of the user's movement. The formula used for the gain calculation was as follows:

$$\text{Virtual position} = \text{actual position} / \text{gain}$$

The previously captured images were integrated into the code using p5, a JavaScript library for creating the shoogles (Refer to *Figure 42*). By leveraging the virtual position formula, we could generate pseudo-haptic effects and enable the interactive visualizations to function.

Interaction occurs on a desktop display using the mouse (and cursor). As users interact with the fabric through the mouse, the interactive visualizations produce pseudo-haptic effects aligned with the movement.

During the experimental phase, we deliberately designed interactive visualizations featuring only one material sample. This decision was made to prevent any influence on the perception of fabric properties.

Consequently, users could only discern the distinct material properties after engaging with each interactive visualization, as each presented a unique gain value.

For our user studies, we focused on the properties/stimuli of elasticity and weight, reenacting various fabric interactions:

- Performing lifting/lowering motions to replicate weight perception.
- Executing stretching/distretching movements to emulate elasticity perception.

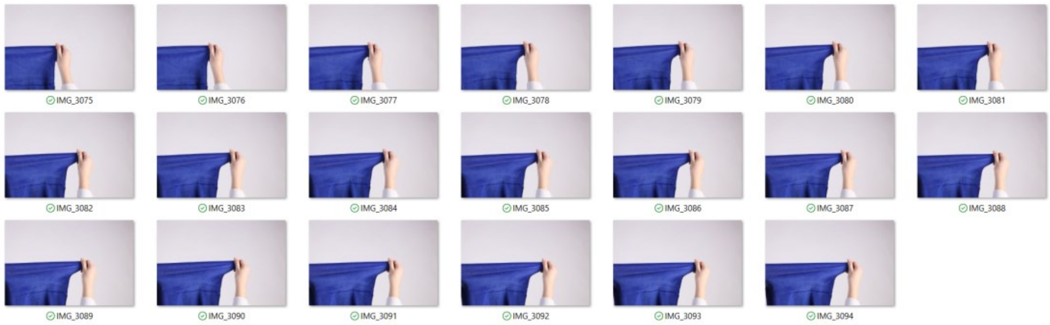


Figure 42. Elasticity interactive visualization design: Sequence of pictures taken in sequence (i.e., shoogles) to capture hand motion and fabric movement before being embedded in code on JavaScript's p5 library.

Additionally, we incorporated a "signifier" within the interactive visualization, represented by a transparent white circle. It automatically suggested to users the direction to click and move the cursor to experience the stimulus (left-right for elasticity; down-up for weight). We also included clear instructions, prompting users for weight perception to "Hold the mouse and drag the cursor to the top" and for elasticity perception to "Hold the mouse and drag the cursor to the right.

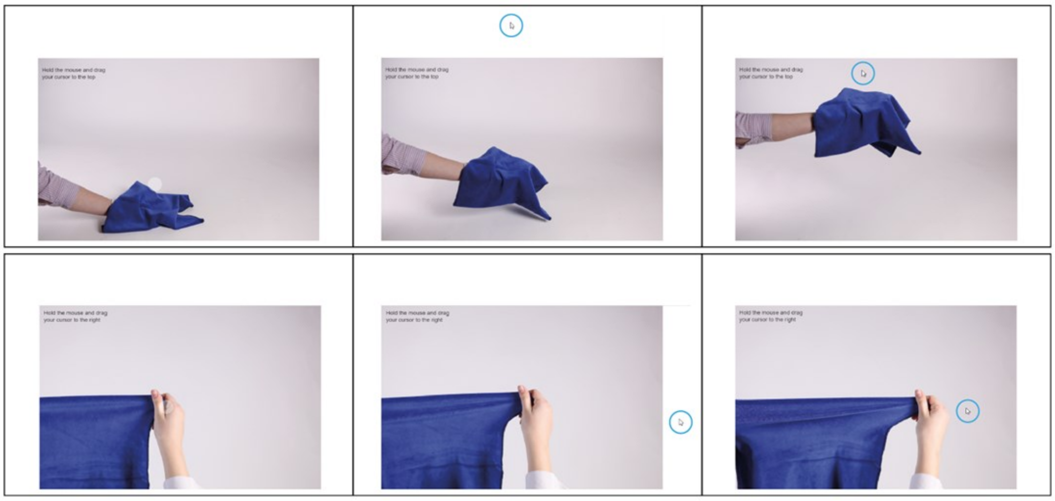


Figure 43. Overview of the interactive visualizations. Top. On the left. The weight visualization is in the first frame, In the middle. The weight visualization after user manipulation (heavier weight; gain = 2) is on the right. The weight visualization after user manipulation (lighter weight; gain = 0,5). Down. On the left. The elasticity visualization is in the first frame, In the middle. The elasticity visualization after user manipulation (minor elasticity; gain = 4); On the right. The elasticity visualization after user manipulation (major elasticity; gain = 0,25).

5.4 Experiment 1

In the first experiment, we employed a rating task to evaluate observers' ability to perceive various degrees of displayed elasticity and weight. Our primary hypothesis was centered on the existence of a relationship between the fabric properties displayed using the logarithmic variable "gain" during the coding phase and the user ratings (RQ1).

5.4.1 Stimuli

In the initial study, participants were tasked with rating their perceived elasticity and weight on a 7-point Likert Scale while interacting with five interactive visualizations (Refer to *Figure 43*). To assess perceived elasticity, the scale ranged from "1," denoting "rigid," to "7," indicating "elastic." For perceived weight, the scale spanned from "1," signifying "light," to "7," representing "heavy." Each stimulus was associated with an incremental gain, ranging from 0.25 to 4 for elasticity and from 0.5 to 2 for weight.

5.4.2 Procedure

Participants were provided with written instructions, along with a consent form, followed by a brief video demonstration outlining the general procedure. Participants were then required to rate the tactile perception of the fabrics using bipolar semantic differential (SD) scales, encompassing dimensions such as heavy-light and elastic-stiff. To account for the potential effects of different gain levels on ratings, we established five conditions per stimulus, ranging from lightest to heaviest and from most elastic to stiffest. Randomization of the five interactive visualizations ensured unbiased distribution among participants. Participants used their mouse to interact with the visualized fabrics and provide ratings, as shown in *Figure 44*:

Figure 44. On the left: The elasticity interactive visualization at the first frame. On the right: The weight interactive visualization at the first frame.

5.4.3 Participants

Forty-one participants voluntarily took part in the study at TU Delft, receiving compensation for their involvement and providing informed consent. The experiment adhered to a within-subject study design and was conducted in a university laboratory (See *Figures 45, 46*). Ethical approval was obtained from the TU Delft ethics committee, and the Declaration of Helsinki conducted the study. The participants consisted of 15 males and 26 females, with age distribution as follows: 14 participants aged 18-24, 24 participants aged 25-34, 1 participant aged 35-44, and 2 participants aged 45-54. Furthermore, 35 participants had over three years of experience using online shops for clothing purchases. In comparison, 3 participants had 1-2 years of experience, 1 participant had less than one year of experience, and 2 participants exclusively bought clothing from physical stores.

Figure 45. Experimental setup for both Experiment 1 and Experiment 2 consisting of a workstation with a laptop, mouse, and three real fabrics (useful only for Experiment 2).

Figure 46. User interacting with the elasticity interactive visualizations during Experiment 1.

5.4.4 Results

Figure 47 illustrates that perceived elasticity consistently decreases as gain levels increase, while perceived weight decreases similarly with higher gain levels. Error bars represent standard deviations, indicating that the entire Likert scale range was utilized.

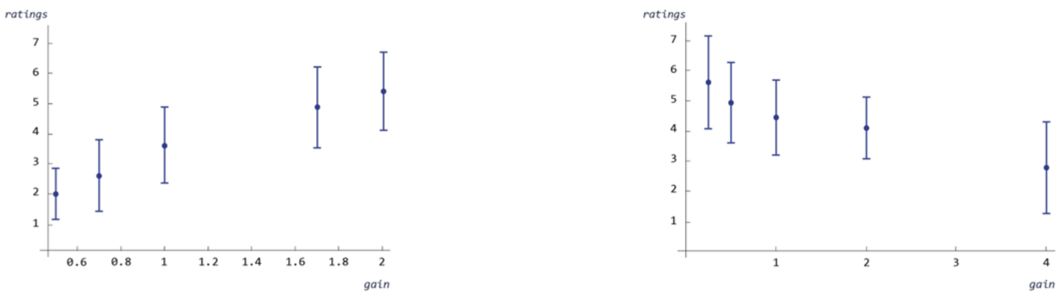


Figure 47. On the left. The elasticity interactive visualization variables distribution. On the right. The weight interactive visualization variables distribution.

To precisely understand the relationship between gain and perception, we applied linear and quadratic models to the data. Linear regression was utilized to examine the influence of one or more independent variables on a single dependent variable.

Elasticity.

The "Sig." column in the "Coefficients" section reflects the significance of the predictor variables. In our case, the gain variable is significant due to a p-value < 0.05 (=0.00). The negative "Beta" coefficient suggests that gain levels have a negative impact on ratings. The Variance Inflation Factor (VIF) value is < 10, indicating the absence of multicollinearity or internal correlations among the predictor variable gain. The fitted regression model is as follows:

Ratings = 5.430 - 0.671 (gain levels) [fitted regression equation]

The comprehensive regression analysis yielded a statistically meaningful outcome ($R2 = 0.318$, $F(1, 203) = 94.822$, $p < .000$). This analysis revealed a significant relationship, indicating that the levels of gain were effective predictors of user ratings ($\beta = -0.564$, $p < .000$).

The results observed in the predicted probability (P-P) plot displayed minor deviations from the normality line, all of which remained within the acceptable range. Consequently, we possess compelling statistical evidence that empowers us to reject the null hypothesis and conclude that these variables do not conform to a normal distribution.

Furthermore, the scatterplot offers insight into the data distribution, revealing homoscedasticity as the residuals are evenly and consistently dispersed.

Weight

In the context of weight analysis, the significance of predictor variables is discerned from the "Sig." column of the "Coefficients" table. In our case, the gain variable proves to be statistically significant, as indicated by its p-value being less than 0.05 (=0.00). The positive "Beta" coefficient suggests that higher gain levels exert a positive influence on user ratings. Furthermore, the Variance Inflation Factor (VIF) value falls below 10, signifying the absence of multicollinearity or internal correlations within the predictor variable gain. The formulated regression model is expressed as follows:

Ratings = 1.137 + 2.220 (gain levels) [fitted regression equation]

The overall regression analysis was statistically significant ($R2 = 0.528$, $F(1, 203) = 227.353$, $p < .000$), reinforcing the conclusion that gain levels significantly predict user ratings ($\beta = 0.727$, $p < .000$). Similar to the elasticity analysis, the predicted probability (P-P) plot displayed minor deviations from the normality line, all of which remained within acceptable boundaries. Thus, we possess robust statistical evidence that allows us to reject the null hypothesis and infer that these variables do not adhere to a normal distribution.

5.4.5 Discussion

This study represents a groundbreaking endeavor to convey the physical characteristics of fabrics through the innovative combination of shoogles and pseudo-haptic effects. Experiment 1 demonstrates the effectiveness of manipulating gain values within interactive displays in predicting user evaluations and perceptions. This holds for both elasticity and weight, where gain levels emerged as significant predictors of user ratings (elasticity: $\beta = -0.564$; weight: $\beta = -0.727$) as shown in *Figure 47*.

Consequently, there appears to exist a direct and linear correlation between the displayed fabric properties and their actual degrees of elasticity and weight, all mediated by visual cues (RQ1). Specifically, the perceived elasticity consistently diminishes as gain levels increase, while the perceived weight follows a similar downward trend with higher gain levels. This intriguing "opposite" trend can be attributed to our formula: virtual position = actual position / gain.

5.5 Experiment 2

In the second experiment, the task relates to adjusting the displayed elasticity/weight to match the actual visual and tactile stimuli. The main hypothesis is that there is a correspondence between the real fabric properties and those simulated by interactive visualizations.

5.5.1 Stimuli

To further assess whether varying levels of actual elasticity and weight could impact the perceived elasticity and weight, we established three conditions for each stimulus.

The fabrics, each measuring 32 x 46 cm, exhibited distinct weight values, as indicated in *Table 12*: fabric "1" weighed 38.4 g, fabric "2" weighed 22.0 g, and fabric "3" weighed 49.6 g. In terms of elasticity, fabric "1" boasted a modulus of elasticity ε equal to 3 cm, fabric "2" had a modulus of 1 cm, and fabric "3" featured a modulus of 8 cm. These fabrics could be characterized as follows: fabric "1" was composed of denim containing elastane, fabric "2" was made of linen, and fabric "3" was crafted from jersey material.

Table 12. Fabrics real properties.

Fabric		Weight (grams)	Elasticity (ε)
1	denim+ elastane (woven)	38,4 g	3 cm
2	linen (knitted)	22,0 g	1 cm
3	jersey (woven)	49,6 g	8 cm

5.5.2 Procedure

In Experiment 2, we conducted a match-to-sample task involving three distinct fabrics, each differing in terms of elasticity and weight. Participants were required to interact with these fabrics and then adjust the displayed elasticity and weight within the shoogles interface. To make these adjustments, users utilized the "W" keys to increase elasticity and weight, and the "S" key to decrease them. During the task, participants were able to interact with real fabrics simultaneously while adjusting the interactive display. They adjusted the virtual display until it closely matched their perception of the real fabric properties. After each interaction with the interactive visualization, the experimenter recorded the gain value, which remained concealed from the participant.

5.5.3 Participants and Results

Following Experiment 1, forty-one participants engaged in Experiment 2. We employed linear regression to analyze the influence of one or more independent variables on a single dependent variable. Simple linear regression was utilized to assess whether user ratings (expressed as gain inputs) significantly predicted the actual mechanical properties (expressed as gain levels) of fabrics, both in terms of elasticity and weight stimuli. In these models, we hypothesized that the independent variable 'real properties' would predict the dependent variable 'perceived properties.'

Elasticity

The "Sig." column in the "Coefficients" table indicated the significance of the predictor variables. In this context, the gain variable proved significant, with a p-value less than 0.05 (=0.00). The negative "Beta" coefficient suggested that real elasticity had a negative impact on perceived elasticity. The VIF value, less than 10, indicated the absence of multicollinearity or internal correlations within the predictor variable real elasticity. The fitted regression model took the form of:

Perceived gain = 25.714 – 8.198 (real properties) [fitted regression equation]

The overall regression analysis yielded statistically significant results ($R2 = 0.465$, $F (1, 121) = 105.122$, $p < .000$), indicating that real properties significantly predicted perceived gain ($\beta = -0.682$, $p < .000$). The predicted probability (P-P) plot demonstrated minor deviations from the normality line that remained within acceptable limits.

Weight

In the context of weight analysis, the "Sig." column in the "Coefficients" table again revealed the significance of the predictor variables. Here, the gain variable exhibited significance, with a p-value less than 0.05 (=0.00). The positive "Beta" coefficient suggested that real weight negatively impacted perceived weight. The VIF value, less than 10, indicated the absence of multicollinearity or internal correlations within the predictor variable real weight. The regression model was expressed as follows:

Perceived weight = -0.303 + 0.036 (real weight) [fitted regression equation]

The overall regression analysis yielded statistically significant results ($R2 = 0.256$, $F (1, 121) = 41.585$, $p < .000$). It was found that real weight significantly predicted perceived weight (β = 0.506, $p < .000$). As with elasticity, the predicted probability (P-P) plot showed minor deviations from the normality line, remaining within acceptable boundaries.

5.5.4 Discussion

Experiment 2, employing actual fabric samples, demonstrated a correlation between these samples and the perceived properties of elasticity and weight within interactive visualizations guided by visual cues.

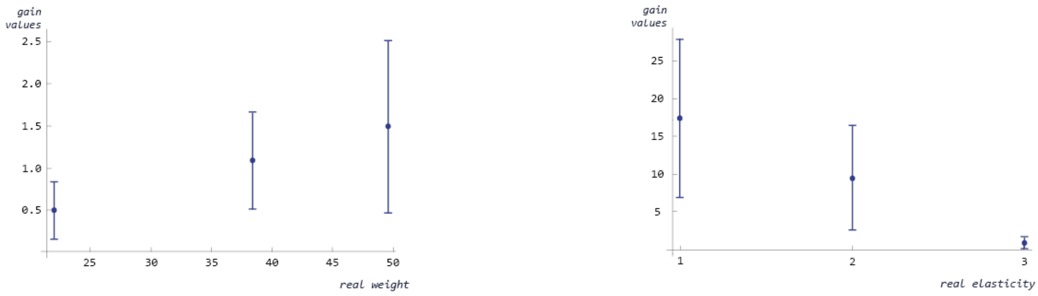


Figure 48. On the left: The weight interactive visualization variables distribution. On the right: The elasticity interactive visualization variables distribution.

Our hypothesis that actual properties predict perceived properties was substantiated. Specifically, we observed that both elasticity and weight properties significantly predicted perceived gain in user evaluations (elasticity: β = -0.682; weight: β = 0.506). Thus, a linear correlation exists between the actual weight and elasticity of fabrics and their digital representation, as mediated by visual cues (RQ 2) as shown in *Figure 48*.

5.6 General Discussion

This study delves into the relationship between the visual perception of fabric texture and its actual tactile qualities. To address the challenge of replicating the tactile aspects of fabrics in online shopping environments, we introduced the concept of binomial fabric perception, which integrates visual and tactile sensations. Recognizing the substantial role of touch in fabric and garment evaluation, our objective is to bridge the gap between the physical and digital realms by using visual stimuli to emulate the tactile experience.

Through our interactive visualizations, we conducted experiments to investigate whether there is a connection between the visual channel and real fabric properties (Experiment 1) and, conversely, between the actual tactile experience and visualized fabric properties (Experiment 2). Our hypothesis involved using samples of the same color but simulating different materials to evaluate the perception of "touch" based solely on their visual representation through movement.

The results are intriguing and reveal direct and linear correlations between these two sensory channels. In Experiment 1, we confirmed a correspondence between the displayed fabric properties and user ratings, both for elasticity and weight. Notably, the results exhibited a consistent and similar distribution across all five conditions. However, in the case of Experiment 2, user input for fabric 3 (jersey, the most elastic fabric) displayed very similar values, resulting in a minimal distribution bar. This differs from fabrics 1 and 2, where variations were more noticeable.

5.7 Conclusion

Instead, in this Chapter, we present a new approach that explores haptic technology, particularly pseudo-haptics, through interactive visualizations that can convey the haptic qualities of materials (in the specific case study, fabrics) to enrich consumers' online shopping experience. These interactive visualizations aim to mimic the actual interaction of the hand with the fabric, achieved by changing the movement of the fabric as the mouse clicks, controlled by a variable CD ratio (or gain value), to solve Problem 2, identified in the *Motivation section*.

Chapter 6: General Discussion and Conclusions

This doctoral thesis paves the way for the design of next-generation shopping experiences. To do so, a multidisciplinary approach was used, drawing on the areas of Design (Interaction Design and User Experience Design), Cognitive Psychology, Computer Science, and Marketing.

The technologies involved are VR (IVR and DVR) and pseudo-haptic interfaces. Certainly, the research shows that VR and haptic technologies can revolutionize the user shopping experience in the retail field by providing a dynamic and immersive environment that seeks to overcome the limitations of traditional stores or two-dimensional online shopping. These technologies bridge the physical and digital worlds, allowing consumers to explore products in a realistic virtual space. The significance of these new experiences lies in the increased sensory engagement they offer, allowing users not only to be completely immersed in these environments but also to interact with products and feel their properties.

6.1 Contributions to Theory

There is no doubt that this research may have several contributions related to academia. This is mainly because the literature regarding the design of virtual retail experiences is predominantly fragmented. The only papers about it mostly belong to the Marketing-Business area, and, in most cases, they are literature reviews and do not present user studies. Therefore, we report a list of academic contributions:

- Structure a thesis that presents a multidisciplinary approach ranging from Design to Computer Science, Marketing to Cognitive Psychology, with all the complexity of aspects to be considered for its development.
- Development of a framework related to adopting technologies (i.e., VR, haptics, and pseudo-haptics) to design shopping experiences. This represents a tool that may be useful for academics and practitioners interested in the design and development of these types of experiences by exploiting one of these techniques.

- Design and development of user studies **(Study 1 and Study 2)** that provide useful insights for the researchers in fashion and furniture retail, even if the results may be generalized and extendable to a broader range of retail fields (such as automotive).
- Identification of measures that can be considered for the validation phase of the applications, such as user experience, cognitive load, time of the experience, hedonic/utilitarian values **(Study 1)**; time duration, level of familiarity with VR, behavior, user targets **(Study 2)**; perceived weight and perceived elasticity by exploiting semantic-differential scales **(Study 3).**
- **Study 1.** Within this comparative study, IVR performs better regarding all the metrics considered in the methodology. These results may mostly depend on the higher degree of immersiveness and the consequent sense of presence of each participant. This result may also depend on the implementation modality of the DVR and IVR versions: both presented the same functionalities but differed in terms of interaction and display devices. The keyboard and mouse were used to interact within the DVR application, and the display was on the computer monitor. However, interaction occurred with the controllers in the IVR application, and the scene was seen through the HMD. In this case, we implemented the standard metaphor of raycasting (Lee et al., 2003), a group of interactive techniques used in IVR for selecting distant targets. We implemented a raycasting-based virtual pointer as a laser pointer that, when intersecting a target object, selects it. Furthermore, the locomotion technique also differed between the two versions. Whereas in DVR, locomotion took place using arrows on the keyboard, in IVR we implemented a natural navigation metaphor, i.e., teleportation (Bozgeyikli et al., 2016). Specifically, point & teleport is a locomotion technique that overcomes the problem of limited tracking areas by allowing users to teleport to selected target positions using either controller. Furthermore, teleportation was the

most suitable technique for our application, as the designed virtual shop was very large in terms of spatial extension.

Also, users were highly involved in exploring the fashion product for which we exploited the storytelling technique of showing and recounting all the relevant features (such as production process, history, size, etc.). We, therefore, designed *Table 9* to provide future researchers with an overview of the DVR and IVR shopping experiences in previous comparative studies and our study. We focused on the interaction, visualization, and locomotion systems implemented, the related products compared (low-high involvement), and the results concerning hedonic and utilitarian value. We aim to provide a comprehensive framework of shopping experiences that could be useful for researchers who want to undertake similar comparative studies in other retail areas. Additionally, we provide some guidelines on the features/components to be displayed in a VR shopping experience on the user interface presenting *six narrative components*:

- Brand. It presents the history of the brand and its evolution over time.
- History. It illustrates the history of the product, how it was conceived, and by whom it was worn.
- Production process. It shows the process by which the product was made. This is a very valuable aspect of the shopping experience because it allows you to emphasize the craftsmanship with which it was made.
- Size guide. It illustrates the size of the product through dimensioning.
- Washing mode. It shows the process of washing the product.
- Reviews. Like online websites, it shows the reviews left on the product to train the user who intends to purchase it.

Also, the user interface is characterized by *three call-to-action components*:

- Color configuration. It allows changing the product color in real-time and evaluating its appearance before purchasing it.
- Shopping cart. It allows the user to add the product to the cart to place the purchase.
- Zoom in/out. It allows the user to enlarge or reduce the size of the product.

- **Study 2.** The MSISVRCJ journey exploits an innovative approach to enhance the in-store retail experience by integrating IVR with real feedback from physical samples of materials and objects. In this way, it is possible to design a "mixed" experience that combines the immersivity of VR with real tactile sensations. The journey also provides for the collaboration and training of shop assistants. Finally, the novelty of the journey is also represented by the fact that it is one of the few field studies developed: i.e., not carried out in controlled environments and with generic users, but in a real shop, witnessing real sales processes.
- **Study 3.** The design and development of the interactive visualizations show, both in Experiment 1 and Experiment 2, that there is a strong correlation between the gain value and the user ratings, and vice versa. This study, therefore, shows that it is possible to predict users' perception of material properties. Although perception is usually subjective, it is possible to trace patterns of perception in the task of discriminating and evaluating a property when the extremes of the same property are indicated to the user. Also, we provided the first user study on interactive visualizations, which exploit pseudo-haptic effects based on a progression of pictures and not on computer-generated images.

6.2 Contribution to Practice

The doctoral research, given its strong connection to the retail industry, entails implications for the practice and purely academic research. The development of experiences that can improve the issues present in current online shopping platforms allows retailers to be given tools to improve their processes and services. As the retail landscape evolves, integrating VR and haptic technologies is a key step in revitalizing the industry, fostering customer loyalty, and staying ahead of the curve in a highly competitive market. Therefore, we report a list of academic contributions:

- **Study 1.** The IVR, due to its degree of user acceptance and satisfaction, could have an impact on industry (such as fashion) sustainability in the long run. Indeed, by configuring and viewing products in IVR before purchase, companies can adopt a more environmentally friendly approach. For example, this would involve producing clothing and accessories only at purchase confirmation, thereby avoiding the need for pre-production and extensive warehousing. These practices, with conscious use of technology, can significantly reduce the environmental impact associated with fashion production and be extended to other industries as well.
- **Study 2.** The journey is implemented for a furniture design manufacturer and tested in a flagship store with real customers, providing the following advantages to the user:
  - Improve the product customization and configuration process in IVR.
  - Help to evaluate the spatiality with the support of the shop assistant.
  - Keep the in-store feeling and enhance it with a broader catalog and experiences.
  - Provide the touch of real material samples and try the product's comfort.
  - Induce better confidence in customers and reduce the risks of an afterthought.
  - Deliver an engaging and new experience, strengthening brand awareness and driving innovation and technology.
- **Study 3.** Pseudo-haptic interfaces may represent a key component of online shopping experiences since they can simulate haptic feedback, enhancing the realism of the shopping experience itself. Shoppers can

touch, manipulate, and evaluate items before purchasing, increasing confidence and reducing the uncertainty associated with online shopping. This not only enriches the entire customer's path to purchase but also enables retailers to offer highly personalized and memorable experiences.

6.3 Limitations and Future Research

In this section, we first delve into the limitations and drawbacks of the studies conducted within the doctoral thesis, shedding light on areas where the research may benefit from further refinement and exploration, as follows:

- **Study 1.** This study, however, has some drawbacks. First, it involves only one task related to the shopping experience of a bag. Therefore, we did not investigate the effectiveness and contribution of other fashion products (e.g., clothes). In addition, some users stated that the shopping experience would probably be more convenient if performed while standing rather than sitting. Therefore, future studies could use smaller shop environments to avoid cybersickness through room-scale experiments. In addition, future research may also include the development of virtual mirrors within which users can mirror themselves with the purchased product to increase their presence. Finally, we tested the application in IVR and DVR but not in a real scenario, as in other comparative studies (in the grocery sector). In this way, we will also be able to evaluate other interesting aspects in addition to the metrics already used, such as purchase intention, % of items purchased, and customer engagement.
- **Study 2.** We encounter major limitations in the design of the case study because of the constraints imposed by the furniture manufacturer. Also, the self-selected sample for the field study should be considered the main limitation since consumers who volunteered for VR experience could already be inclined to review the technology positively.
  An important aspect that we want to report is the initial resistance from sales assistants to adopt the novel approach alongside their well-known sales techniques. This provoked that many customers entering the store

were not offered the MSISVRCJ. Therefore, we want to pinpoint the importance of the involvement, motivation, and training of the store management and staff to properly and successfully implement the MSISVRCJ.

- **Study 3.** The study presents the implementation of pseudo-haptic effects within interactive visualizations only related to two properties: elasticity and weight. This limitation is because the findings are related only to two tactile properties. However, we recognize this drawback; we consider this to be, rather, a starting point for similar studies concerning other tactile properties as well. The same applies to the three fabric samples used in Experiment 2, which could be extended to a larger sample in the future to obtain a complete framework regarding the perception of individuals.

Also, we present the future research of this thesis, which concerns the further implementation of retail experiences that exploit both IVR and pseudo-haptics in other areas, measuring other aspects and exploiting other technologies in combination with them. Each of the studies conducted led to hypothesizing and formulating follow-up research that could represent the next step of those conducted, as follows:

- **Study 1.** In the future, we intend to extend our research by evaluating the effectiveness of IVR to improve the online shopping experience by contributing to a more sustainable fashion industry since IVR could help reduce the environmental impact of apparel production. We also plan to conduct a user study in a real shopping scenario to enrich the three-axis comparative study (IVR, DVR, real) and collect users' feedback regarding the three shopping modes.
- **Study 2.** We are planning to use MSISVRCJ as a framework for further research in this growing area, introducing well-supported evaluation standards (i.e., System Usability Scale, NASA-TLX, UeQ), and compare the results in other fields and store locations and dimensions (e.g., mall and shopping centers).

- **Study 3.** The research concerns the development of a synesthetic design approach or *perception-driven design* that exploits pseudo-haptics to develop new ways of communicating and using materials in the digital context. Although the focus of the research is on fabrics, it can generally be extended to other materials to be used in design. The most spontaneous - and logical - field of application is the online shopping sector, which could provide significant benefits to industries such as fashion, furniture, automotive, and many other sectors that make material communication a pillar for their success in the market. Furthermore, future developments of this research concern the possibility of perpetrating synesthetic stimuli using immersive digital technologies such as VR and AR. In the long term, the aim is to systematize the development of different modes of interactions concerning the range of tactile properties and different types of materials and exploit VR and AR technologies.

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I would like to conclude with my Mantra:

« Volli, e volli sempre, e fortissimamente volli »

Appendix

List of Figures

List of Tables

Supplementary Materials

A. Supplemental Tables

Survey questions	**Related metrics**
How do you rate the MSISVRCJ on a scale of 1 to 7? 7-point Likert Scale; from 1 (= very bad) to 7 (= very good)	general satisfaction
How do you perceive the realism of virtual scenes on a scale of 1 to 7? 7-point Likert Scale; from 1 (= very bad) to 7 (= very good)	cognitive and sensory evaluation
Does MSISVRCJ help you while shopping on a scale of 1 to 7? 7-point Likert Scale; from 1 (= strongly disagree) to 7 (= strongly agree)	affective evaluation
If yes/no, why? open-ended question	affective evaluation

Figure A1. Survey questions designed to evaluate the MSISVRCJ.

Answers to the open-ended question
Positive answers
Yes, it is useful since I can see a model not physically present in the store.
Yes, because in this way I can see the old models I already purchased next to the ones I would like to buy
Very nice if you need to see a specific model
Indeed, because you can go beyond your imagination and see it clearly with this technology
I can see products and configurations not physically available in the shop.
Yes, because I can observe the models arranged in a pleasant environment
Indeed, I can see this sofa in this virtual environment, which reminds me of my home!
Yes, I feel more confident in purchasing the armchair because I can better visualize spatial configurations and material combinations.
It seems to be a more immersive version of The Sims! Great!
Indeed, I felt well there!
It was crazy, I could look around the sofa! Better than a paper-based catalog.
Yes, my wife is very happy, so I'm the happiest man in the world!
Of course, when I buy my dining room table and chairs, I want to use this technology again!
It was fun!
It provides a good product overview and helps me decide to purchase it.

The technology is amazing; I saw it so clearly!
Very helpful; I want to see my whole home with this technology.
Negative answers
Not so convincing. In my opinion, textures are not so well-represented, but you do a very good job!
I liked it a lot, but I was sad because I wanted to touch everything in the scene.
I felt a little dizzy in VR.

Figure A2. Most relevant answers to the open-ended question of the survey.

B. Human Research Ethics Checklist

Delft University of Technology
HUMAN RESEARCH ETHICS
CHECKLIST FOR HUMAN RESEARCH
(Version January 2022)

IMPORTANT NOTES ON PREPARING THIS CHECKLIST

1. An HREC application should be submitted for every research study that involves human participants (as Research Subjects) carried out by TU Delft researchers
2. Your HREC application should be submitted and approved **before** potential participants are approached to take part in your study
3. All submissions from Master's Students for their research thesis need approval from the relevant Responsible Researcher
4. The Responsible Researcher must indicate their approval of the completeness and quality of the submission by signing and dating this form OR by providing approval to the corresponding researcher via email (included as a PDF with the full HREC submission)
5. There are various aspects of human research compliance which fall outside of the remit of the HREC, but which must be in place to obtain HREC approval. These often require input from internal or external experts such as Faculty Data Stewards, Faculty HSE advisors, the TU Delft Privacy Team or external Medical research partners.
6. You can find detailed guidance on completing your HREC application here
7. Please note that incomplete submissions (whether in terms of documentation or the information provided therein) will be returned for completion **prior to any assessment**
8. If you have any feedback on any aspect of the HREC approval tools and/or process you can leave your comments here

I. Applicant Information

PROJECT TITLE:	**Pseudo-haptics for fabrics perception**
Research period: *Over what period of time will this specific part of the research take place*	**1-1-2023 until 1-6-2024**
Faculty:	**Industrial Design Engineering**
Department:	**Human-Centered Design (HCD)**
Type of the research project: *(Bachelor's, Master's, DreamTeam, PhD, PostDoc, Senior Researcher, Organisational etc.)*	**Guest Ph.D. Project**
Funder of research: *(EU, NWO, TUD, other – in which case please elaborate)*	**TUD – Polytechnic University of Bari**
Name of Corresponding Researcher: *(If different from the Responsible Researcher)*	**Marina Ricci**
E-mail Corresponding Researcher: *(If different from the Responsible Researcher)*	**m.r.ricci@tudelft.nl**
Position of Corresponding Researcher: *(Masters, DreamTeam, PhD, PostDoc, Assistant/ Associate/ Full Professor)*	**Guest Ph.D. Student**
Name of Responsible Researcher: ***Note**: all student work must have a named Responsible Researcher to approve, sign and submit this application*	**Sylvia Pont, Maarten Wijntjes, Gijs Huisman**
E-mail of Responsible Researcher: *Please ensure that an institutional email address (**no Gmail, Yahoo, etc.**) is used for all project documentation/ communications including Informed Consent materials*	**s.c.pont@tudelft.nl** **m.w.a.wijntjes@tudelft.nl** **g.huisman@tudelft.nl**
Position of Responsible Researcher : *(PhD, PostDoc, Associate/ Assistant/ Full Professor)*	**Professor, Associate professor, Assistant professor**

II. Research Overview

***NOTE**: You can find more guidance on completing this checklist here*

a) Please summarise your research very briefly (100-200 words)

What are you looking into, who is involved, how many participants there will be, how they will be recruited and what are they expected to do?

Add your text here – (please avoid jargon and abbrevations)
In online stores, the lack of actual contact with products can sometimes make it difficult for customers to evaluate the product. The lack of touch is a crucial issue in retail, especially in those product areas such as clothing. Therefore it provokes the lack of hedonic and utilitarian values and realism within the virtual experience and generates negative user shopping experiences. Without direct contact, people may be unsure of their purchase activity because there is not enough information about the material, texture, and finishes. *The main goal of this work is to propose a "visualized touch", a new way to interact with online products, and examine how users perceive the fabric's properties without physically touching them, but only interacting with them via the cursor. In this project, we will work with about 30/50 participants in person, and about 300/500 online participants. In-person participants will be recruited in the IDE building, and online we will use Prolific. Participants are expected to respond to quantitative and qualitative questions about the interaction with the fabric samples.*

C. QUESTIONNAIRES FOR COMPARATIVE STUDY

- Pre-experiment questionnaire: https://docs.google.com/forms/d/e/1FAIpQLSex6ggJqtsI_o5d-bqwIaDoojMbzrBhocTXQJSHSXmzPmccQA/viewform?usp=sf_link
- Post VR experience: https://docs.google.com/forms/d/e/1FAIpQLScZZc8Skg3AadDo3uZdwHbsAbOom_grDzbYm_kdA2Do6u7zSg/viewform?usp=sf_link
- Post DVR experience: https://docs.google.com/forms/d/e/1FAIpQLSdwPVZZ50ygMPrdJLOZ4pEU7lYVrVOk1WeCiv59eBicL6bm5g/viewform?usp=sf_link

D. VIDEOS

Videos of the DVR and VR experiences in the section **Supplementary Information** at this link **https://link.springer.com/article/10.1007/s10055-023-00806-y.**