



POLITECNICO
MILANO 1863

Master's Degree Thesis in Design for the Fashion System

Integrating Artificial Intelligence in Eyewear Products: Opportunities and Challenges

Supervisor: Paola Bertola

Co-supervisors: Angelica Vandi, Greta Rizzi

Student: Ivana Vorguca

Student ID: 991203

December 2023

Abstract

This thesis examines the integration of Artificial Intelligence (AI) in eyewear products within the fashion industry, focusing on the transformative role of AI in accessory design. It begins by contextualizing AI in the fashion sector, moving towards Augmented Reality (AR), then delves into the evolution of accessory design, particularly eyeglasses, and the emergence of AI-enhanced smart eyewear. The study involves detailed case analyses of pioneering AI-integrated eyewear such as Google Glass, Ray-Ban Meta, and Apple Vision Pro, evaluating their technological features and market impacts.

The thesis also explores future trends in AI-enabled eyewear, addressing user interaction, privacy concerns, aesthetic integration, and adoption challenges. A SWOT analysis further dissects this domain's strengths, weaknesses, opportunities, and threats. This work contributes to understanding the confluence of AI technology with fashion design, particularly in augmenting human-computer interaction through wearable accessories.

Keywords: AI-integrated eyewear, fashion industry, accessory design, smart eyewear, technological features, market dynamics.

Table of Contents

Chapter 1: Introduction.....	4
1.1.What is Artificial Intelligence?.....	4
1.2.Augmented Reality.....	6
1.3.Digital Interaction in the Fashion Industry.....	7
Chapter 2: State of the Art.....	8
2.1. Evolution of Accessory Design.....	8
2.2. Eyewear relevance and anatomy of the Glasses.....	11
2.3. AI-driven Accessory Design.....	14
2.4. Smart AR integrated eyewear.....	16
2.5. Benchmark Analysis.....	19
Chapter 3: Case studies.....	20
3.1. Case Study 1: Google Glass.....	21
3.2. Case Study 2: Ray-Ban Meta.....	22
3.3. Case Study 3: Apple Vision Pro.....	23
Chapter 4: Future Developments.....	25
4.1. Anticipated trends in AI-integrated smart eyewear.....	25
4.2. SWOT of AI-integrated smart eyewear.....	26
4.3. Conclusion.....	28
Bibliography.....	31
Acknowledgments.....	34

1. Introduction

Artificial Intelligence (AI) is becoming the center of attention across every industry, fundamentally altering the way we operate. The convergence of AI with the domains of fashion, encompassing accessory design, and notably, the complex landscape of eyewear design, has grown a broad influence on the industry's different aspects.

“AI is the study of how to build or program computers to enable them to do what minds can do. “(Boden, 1996, as cited in Boden, 1987). AI is a scientific discipline and a field of technology dedicated to building intelligent machines and software that can execute a variety of functions that require human intelligence. (Karthikeyan et al., 2021). AI can simulate human-like cognitive functions and make solutions for the problems thanks to the large amount of data. This type of approach is fundamental to many AI applications, particularly those involving machine learning (ML) and deep learning (DL) algorithms.

Moreover, the influence of AI within the fashion industry transcends the traditional domains of design and manufacturing. It is increasingly evident in the emergence of AI-integrated technologies, where smart accessories and AI-driven wearable innovations take center stage. These developments not only blur the lines between fashion and technology but also unlock fresh opportunities for creative expression and practical utility in the fashion landscape. In the subsequent sections of this thesis, we will delve into a comprehensive exploration of AI's multifaceted impact on the fashion sector.

1.1. What is Artificial Intelligence?

Prior to delving deeper into the intricate domain of AI, we embarked on an exploration of the concept of intelligence itself. The etymological roots of this term can be traced back to the Latin word 'intelligentia,' which emerges as a synthesis of the roots 'intus' and 'leggere.' In the English language, it is precisely translated as 'inner reading'. Speaking about the term from the standpoint of theology and understanding the thoughts written by Greek philosopher Aristotle in his book “De Anima” (On the Soul) it is noteworthy that St. Thomas expands on Aristotle's theories, incorporating them within a metaphysical framework concerning the conceptions of intellect and existence. In his interpretation of the term intelligence, Thomas Aquinas differentiates two aspects: a universal dimension and a more specific dimension relating to human intelligence. He proposes that the intellect, in its broadest meaning, can be described using the metaphysical theory of act and potency, understanding the existence of potential intellectual activities inside the "passive intellect" and active intellectual operations within the "agent intellect." Aristotle's medieval theory evaluates not just the functional aspects of intelligence, but also its essence, consciousness, which is an essential characteristic of human beings. Another characterization that provides us with a deeper understanding of the multifaceted nature of intelligence as perceived in the historical context is the point of view of the thinker St. Augustine, a prominent intellectual of the Middle Ages who also defined the term “intelligence”. In his concept of intelligence, he argues that human intelligence is more than simple logical reasoning. Instead, it encompasses a rich array of cognitive capacities, including memory, contemplation, judgment, and the ability to make purposeful and meaningful decisions. (Reyes-Cárdenas, 2023).

Returning to the inception of the exploration within this subsection, the question that arises is, "What characterizes the nature of intelligence in the context of AI?"

Moreover, the term "AI" is not new to the world by any chance. Back in 1956, a pivotal moment occurred at Dartmouth University when scholars formally coined the term. This historical event

marked the beginning of an exciting new field of study devoted to investigating how machines mimic human cognitive capacities. (Zhang & Lu, 2021). There are numerous definitions of AI, emphasizing its multidimensional nature. AI, as defined by (Karthikeyan et al. 2021), is a scientific subject and a technology field focused on generating intelligent computers and software capable of undertaking an extensive variety of tasks that typically call for human intelligence. According to this definition, AI has the potential to be utilized across multiple industries and has become omnipresent across many sectors, including the fashion industry.

In general, AI is creating new opportunities for organizations by making major changes in a number of sectors, including fashion. According to recent research, AI could have up to 20% impact on the world economy. This economic shift is mostly due to the benefits that AI-powered services and products have to offer like cost savings, improved customer service, and optimized operational efficiency. (Rathore, 2023).

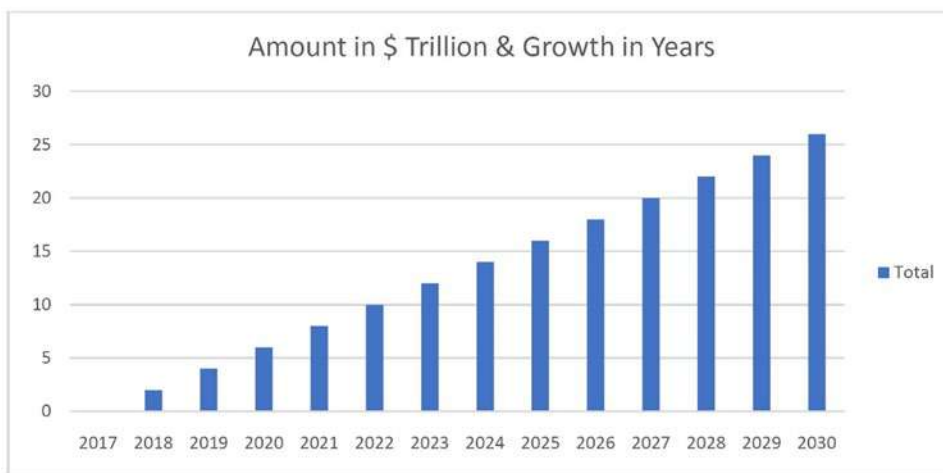


Figure 1. AI in GDP scheme (Rathore, 2023)

Nowadays, AI is made up of various branches and subdomains, each of which contributes to the growth of AI in its own unique way. However, in the context of this discussion, the focus is primarily on DL due to its pivotal role in contemporary AI research and development. DL has emerged as an important and evolving part of AI since it is at the heart of intensive experimentation and research activities focused on improving the accuracy and capabilities of AI technologies. Because of its extraordinary capacity to model complicated data, discover patterns, and drive innovation across a wide range of applications, this area of study has drawn significant interest and investment. While other AI branches are important, DL's present dominance highlights its potential for revolutionary discoveries and its current position as a driving force in the ever-evolving AI ecosystem. (Yongjun Xu et al., 2021).

In discussions surrounding AI, common terms like ML, DL, and AI are often used interchangeably, yet they hold distinct meanings. To mitigate any potential confusion, in the following part, it will be possible to find concise definitions of these terms, further illustrated in Figure 2. for clarity.

CHAPTER 1 BASICS OF ARTIFICIAL INTELLIGENCE

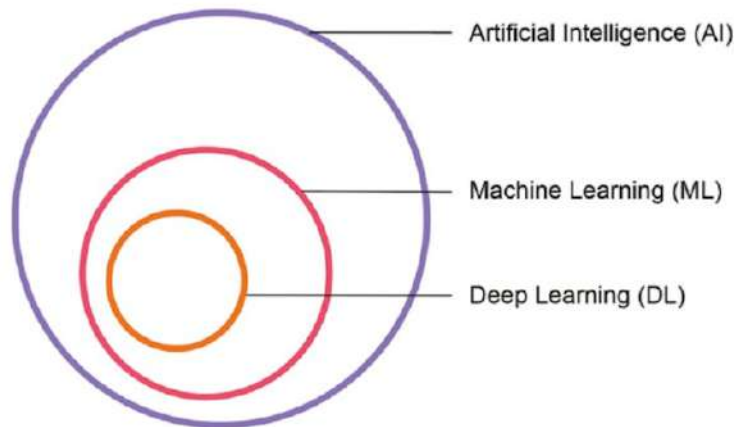


Figure 2. (AI), (ML), (DL). (Luce, 2019).

The inserted above Figure 2, depicts the differences between AI, ML, and DL, fostering a better understanding of their intertwined yet diverse tasks. At the highest level, AI comprises the overarching objective of developing computers with human-like cognitive capacities. ML entails teaching machines to learn and anticipate without explicit programming. DL makes use of complex neural networks. To give an example, think of a sewing machine: ML, akin to a sewing machine, enhances precision and expedites tasks, like how sewing machines improve stitching precision. This figure provides a valuable visual aid, showing the hierarchical relationships among these concepts and highlighting their pivotal roles in the realm of AI. (Luce, 2019).

With a foundational understanding of how AI can simulate human-like cognitive functions and store data for solutions, the focus is shifting toward the role of AI in the fashion industry.

1.2. Augmented Reality

Augmented Reality (AR) stands at the forefront of technological innovation, seamlessly integrating digital elements into a user's real-world perspective. To add to this, from another definition, AR can be explained as the immediate or indirect observation of a physical, real-world environment in real-time, enriched by the incorporation of virtual computer-generated information (Carmigniani et al., 2011). Here the evolution of AR, from its historical roots to its anticipated market expansion, mentioning its impact on diverse fields.

AR origins date back to the 1960s, with a pivotal breakthrough in the early 1990s. 1997 definition by Azuma, identified three key characteristics: the fusion of real and virtual worlds, real-time interaction, and three-dimensional registration. These principles underscore the necessity of real-time control and spatial registration for navigating the AR scene and optimizing user experiences (Asiminidis, 2023). At the core of any AR system lie three essential components: tracking, registration, and visualization. Complemented by a spatial information database, these components collectively enable a seamless integration of digital and physical environments, contributing to the immersive and interactive nature of AR experiences. (Mendoza-Ramirez et al., 2023).

AR technology has overcome initial challenges, progressing towards a phase of sustained growth. This evolution reflects not only historical development but also underscores that AR has the potential for substantial returns and widespread user acceptance. As AR continues to integrate into everyday life, its transformative impact becomes increasingly evident across various industries, including the fashion sector which will be the focus of this research.

Economists anticipate a significant expansion in the AR market, recognizing it as a transformative force across diverse sectors. According to a 2021 Grand View Research report, the global AR market is projected to reach USD 340.16 billion by 2028, boasting a remarkable Compound Annual Growth Rate (CAGR) of 43.8% from 2021 to 2028. This market projection highlights the increasing integration and acceptance of AR technologies. (Mendoza-Ramirez et. al, 2023).

1.3.Digital Interaction in the Fashion Industry

In the last ten years, the globalization of markets has altered economic, social, and cultural dynamics in the fashion industry, unveiling a system with both constraints and potential opportunities. The Fourth Industrial Revolution (4.0) and digital technologies are instigating significant changes within the traditional industrial framework. (Denaro, 2023) Industry 4.0 is a framework that integrates specific technologies for automation. This concept was unveiled at the Hannover Fair in 2011 and swiftly gained widespread attention in Germany and around the world. The 4.0 paradigm is intricately linked to manufacturing, where technological advancements such as digitization, robotics, and AI are redefining production processes. The term 4.0 is sometimes denoted by related expressions like "smart manufacturing," "industrial internet," or "integrated industry." It is often considered a critical part of the ongoing "great transformation." The business world is closely associated with other social and organizational megatrends such as digitization, cloud computing, AI, and the Internet of Things (IoT). (Nääs et al., 2022) The focal point lies in harnessing these technologies to enhance operational efficiency, advance sustainability, and shape a future characterized by environmental awareness and resource efficiency, particularly in the realm of the fashion industry. (Kopeinig et al., 2023) Industry 4.0 is guided by two main drivers. Firstly, it responds to the escalating demands of an expanding consumer base marked by extensive connectivity, hyper-customized preferences, and a penchant for immediate consumption, with a notable inclination towards services rather than products. Secondly, it is fueled by the substantial progress in digital technologies that permeate different aspects of today's society. This new industrial paradigm aims to seamlessly blend the physical and virtual domains, creating environments where data and information play a central role in shaping business models. Human involvement in the manufacturing process is deemed pivotal in this transformative framework. (Lucizano et al., 2022)

AI is expected to significantly impact the fashion business by revolutionizing multiple areas of the process. AI's data-driven insights and automation capabilities will facilitate operations, improve customer experiences, promote innovation, and ultimately revolutionize the fashion industry—from designing and customizing apparel to optimizing supply chains and prediction trends.

The transformative engagement between individuals, designers, and the fashion industry fostered by the incorporation of technology into the creative process may be referred to as digital interaction in fashion. Digital fashion is a paradigm change that effortlessly merges the digital and physical worlds. This implies that digital connection requires innovative approaches to fashion production that go beyond traditional limits. This relationship extends the runway, serving as an inspiration for modifying how customers interact with fashion. The digital fashion landscape encourages innovative design concepts, sustainable methods, and personalized fashion experiences. It provides a platform for expressing an individual in a world where self-identity and style have no separation.

As technology and creativity meet to build a new era in fashion, a bright and unlimited future for the industry takes shape. (Singh, 2023)

In the rest of the paragraphs in this section, the main topic will be how AI is currently being used in the fashion value chain.

AI and fashion design have a strong and evolving relationship in contemporary times. The fashion business is increasingly incorporating AI technologies to improve several aspects of the design process, including fashion identification, creation, and suggestions. AI can support fashion designers, as well as all the people involved in the process from the starting, and creation to the final output, by giving them the resources and knowledge that simplify design, stimulate creativity, and respond to the changing preferences of customers. AI in the fashion industry can be seen as a beneficial partner that accelerates operations, increases efficacy, drives innovation, and promotes sustainability.

As per Forbes data (2021), smart factory adoption rates in the fashion industry stand at 67% in industrial manufacturing, 50% in automotive transportation production, and 40% in consumer goods production. Smart Factories Will Deliver \$500B in Value by 2022. (Lee et al., 2021).

To give an example, the results from the empirical study named *AI Assisted Fashion Design*, showed how important AI technologies were integrated into the clothes production processes of the fashion sector. These tools include diffusion models with denoising priors for producing realistic samples, Generative Adversarial Networks (GAN)-based models for fashion creation, fashion suggestion engines for improved selection, and the use of multifaceted inputs for improved design processes. Computer vision algorithms are also used for fashion detection and trend analysis. Together, these AI instruments elevate fashion design, customization, and user experiences in the fashion sector. (Ziyue Guo et al., 2023).

This structuring approach is aimed at emulating the creative process of a fashion designer, facilitating a comprehensive understanding of how AI is transforming the fashion landscape. As the transition goes towards the next subsection, "AI-driven Accessory Design," the center of attention is on AI's potential to revolutionize fashion accessories, further expanding the possibilities of innovation and transformation.

2. State of the Art

In this chapter, we will have a look at the development of accessory design throughout history which is shown with a graphic chronology. In addition to exploring the development of accessory design, this historical journey provides the cultural and historical background necessary to comprehend the importance and transforming power of fashion accessories. The complex internal anatomy of eyeglasses is next explored, providing a thorough visual illustration that establishes a foundation for an in-depth understanding of their structural nuances. After exploring this, the focus will be on presenting the study results related to smart eyewear with AI integration. That subsection provides an overview of the current state of these innovative accessories by explaining their purpose, design, and importance in the domains of technology and fashion. The final section of this chapter includes a benchmark study that presents a systematic and structured analysis of the strengths and weaknesses inherent in these products. This is essential for providing guidance for upcoming improvements and developments in the area.

2.1. Evolution of Accessory Design

This subsection traces the historical evolution of accessories in the Western world from ancient Egypt to the twentieth century. Examining unique characteristics across different periods enhances the understanding of how accessory design contributes to individual style. Fashion, integral to societal constructs, shapes collective identities, with accessories holding a rich historical tapestry

woven into the ebb and flow of social movements. This contextual understanding is crucial for appreciating the historical and cultural significance of accessory design.

Accessories, with historical significance, have evolved over time, serving both utilitarian and symbolic purposes. From handbags to hats, gloves, and footwear, they complement the attire and were initially designed for practicality, offering protection against weather conditions or providing support and shaping. Accessories also historically signaled group affiliations through uniforms, insignia, or tribal tattoos. This exploration of accessory design highlights its multifaceted role in shaping fashion and identity, building upon the earlier discussion of its significance in enhancing individual style. (Genova, 2012).

Beginning with a historical lens, the roots of accessory design in the Western world can be traced back to the ancient civilizations of Egypt, Greece, and Rome.

Ancient Egyptian accessories, blending quality and utility, reflected a society that valued aesthetics and function. Artifacts from pyramids and tombs spanning 30 centuries (3100 B.C. to 332 B.C.) reveal insights into Egyptian adornment. Common Egyptians preferred headbands and wigs, while elites wore regal crowns and symbolic nemes. Gemstone-adorned belts added vibrancy, and thong sandals symbolized privilege. Tutankhamun's tomb included 93 pieces, featuring sandals with symbolic images. Gold sandals, representing prosperity, emphasized the dual practical and symbolic importance of shoes, reserved for the nobility, priests, and warriors (Genova, 2012).



Figure 3. Ancient Egyptian Papyrus - King Tutankhamun Hunting with Bow with His Wife

Ancient Greece, spanning from (1200 B.C. to 323 B.C.), made lasting contributions to various fields. The civilization's attire and accessories, depicted in sculpture and vase painting, are realistically portrayed in marble statues. Weaving and embroidery, showcased in intricate shoe styles, were valued skills. Men wore petasos and Phrygian bonnets, while both genders adorned pilos caps. Greek women used fillets, ribbons, and scarves for layered curls, and veils were featured in art. Sandals, from simple to ornate, were worn by both genders, combining practicality and decoration. Men's shoes included ankle-high or midcalf boots with trims, and military shoes featured spikes or spurs. Ancient Greece's creative expression in attire and accessories endures as a significant legacy in fashion and personal adornment. (Genova, 2012).



Figure 4. Red figure bell krater, attributed to Python Paestum

Within the grand tapestry of the ancient Roman Empire, accessories emerged as powerful symbols of status, and occupations, rich in intricate details. Roman women's hairstyling showcased jeweled hairpins or elaborate diadems and finely woven gold wire hairnets, avoiding traditional headwear. The military's galea helmets, each crafted by hand, bore distinct designs for different army units and featured plume or horsehair crests, emblematic of legion affiliations. Soldiers prized their balteus or cingulum military belts, carefully produced in the army, serving not only to secure attire but also to carry weaponry. Footwear, all, and everywhere present features conveyed social standing, with women favoring closed shoes in various colors and men adopting different styles according to their rank. In this ancient civilization, accessories blended practicality and symbolism, casting a fascinating light on the interplay of fashion and societal roles within the Roman world. (Genova, 2012).



Figure 5. Villa of the Mysteries fresco in Pompeii

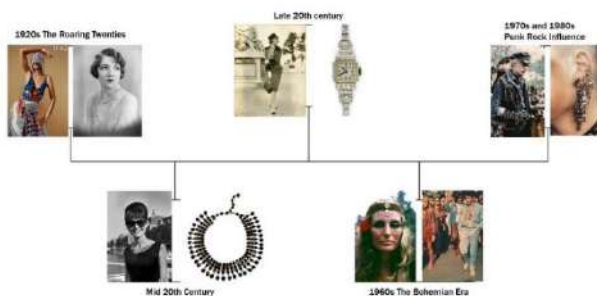


Figure 6. Timeline Accessories within the 20th Century, Integration of Artificial Intelligence in eyewear products: Opportunities and Challenges (Vorguca, 2023)

Figure 6 visually traces 20th-century fashion accessories, starting with the 1920s' flapper headbands, cloche hats, and pearl necklaces symbolizing rebellion and opulence. It progresses through mid-century oversized sunglasses and statement necklaces, the late 20th century's designer handbags and fashionable wristwatches. The 1960s showcase bohemian accessories, and the 1970s and 1980s reflect punk rock influences with studded leather wristbands, safety pin earrings, and spiked chokers. This visual timeline pays homage to iconic accessories representing distinct cultural and fashion eras.

Delving deeper into this topic has provided an understanding of the history of fashion accessories, including their cultural, historical, and design aspects. The significance of this exploration lies in the ability to appreciate how these accessories have not only adorned the human form but also served as cultural markers and expressions of individuality.

2.2. Eyewear relevance and anatomy of the Glasses

In the realm of accessory design, it has become evident that accessories serve not only as decorative elements in the world of fashion but also as crucial functional components. Within this subsection, the world of eyewear will be explored. Specifically, after briefly elucidating the term "eyewear," the attention will be on dissecting the anatomy of a pair of glasses.

The term "eyewear" encompasses any device designed to be worn on or over the eyes, serving the dual purposes of correcting vision and safeguarding the eyes from external elements. The history of eyewear can be traced back thousands of years, with early iterations primarily focused on providing basic eye protection. In contemporary times, the scope of eyewear has expanded to encompass a diverse array of products, including prescription glasses, sunglasses, and contact lenses.

The journey through the history of eyewear is a tale of remarkable innovations spanning centuries. In the 1st century C.E., Seneca the Younger observed the magnifying properties of water-filled globes and glass, laying the groundwork for optical progress. Fast forward to 1284, when Salvino D'Armato introduced the world's first eyeglasses in Italy, crafted from exceptionally thin glass components, marking a turning point in vision enhancement. Benjamin Franklin's ingenuity extended to eyewear, as he pioneered bifocals, a leap that occurred half a century before the mainstream understanding, effectively addressing both myopia and presbyopia. Concurrently, the design of eyeglass frames evolved, shifting from manual and nose-pressure configurations to more sophisticated forms. Eyewear comprises spectacles, commonly known as eyeglasses, consisting of frames with lenses worn in front of the eyes, serving the dual role of vision correction and eye protection. Corrective lenses bend incoming light to alleviate refractive errors like myopia, hypermetropia, and astigmatism. Sunglasses provide enhanced comfort and protection against intense light and UV rays. Photochromic lenses, responsive to UV light, darken accordingly, while the tinted lenses in sunglasses effectively block light transmission, reducing glare and safeguarding the eyes. This historical backdrop establishes the foundation for the detailed examination of the anatomy of glasses, a central theme in this subsection. (Singh & Kapoor, n.d.)

In the realm of eyewear, the significance of spectacles extends far beyond their conventional role as devices solely for vision correction (e.g., corrective glasses) or eye protection (e.g., sunglasses). Over the years, the dynamic interplay of fashion trends and the evolving eyewear industry has dramatically redefined eyeglasses, elevating them from mere medical aids to stylish accessories. In fact, it's increasingly common to encounter individuals sporting eyeglasses that lack prescription

lenses, as eyewear has seamlessly merged functionality within fashion in contemporary society. This paradigm shift underscores the need for a detailed exploration of the various components that comprise modern eyeglasses, known as the anatomy of glasses, as we venture deeper into this subsection. (Montalto et al., 2017)

The following part will dig into a thorough examination of the structural components that form a pair of glasses, as represented in Figure 7. Each component contributes to the functioning, comfort, and overall quality of the eyewear.



Figure 7. Anatomy of the pair of glasses (Singh & Kapoor, n.d.)

ANATOMY OF THE PAIR OF GLASSES

Bridge	A bridge is a segment that gracefully arches over the nose, residing between the lenses, bearing the primary responsibility for distributing the weight of the glasses effectively.
End piece	The end piece extends outward from the lenses and links to the temples, the end piece plays a pivotal role in the overall framework's design and stability.
Frame rim	The frame rim is the frontal section of sunglasses where the lenses are inserted, also commonly referred to as the eye wire.
Hinge	The hinge mechanism is this crucial component that connects the rim to the temple, enabling the temple to fold inward for ease of storage and transport.
Lens	Optical lenses are comprised of materials such as glass, plastic, or polycarbonate, the lenses are the optical medium through which the wearer perceives the world.
Nose pad	A nose pad is plastic piece dedicated to wearer comfort and positioning and is integral to keeping the sunglasses securely and comfortably seated on the face. It can be affixed directly to the frame or the cushion arm.
Pad arm	The pad arm serves as the support structure for the nose pad, the pad arm allows for adjustment, ensuring a personalized and snug fit tailored to the wearer's unique nose profile.
Screw	Fasteners are small metal screws, situated at the hinge and bridge locations, that play a vital role in joining the temples to the front frame and securely anchoring the nose pads.
Top bar	The top bar is present in certain eyewear styles, the top bar extends horizontally across the top of the bridge, delivering additional stability, particularly common in aviator-inspired sunglasses.
Temple arm	Temple arms often referred to as the arms, these elongated frame elements extend over the ears, maintaining the sunglass's stability and positioning.
Earpiece	Earpieces are typically composed of a plastic coating, these earpieces are situated on the segment of the temples that rest atop the ear, offering enhanced comfort for the wearer. This feature is commonly found in glasses with metallic frames.

Figure 8. Chart with definitions of Anatomy of the pair of glasses, Integration of Artificial Intelligence in eyewear products: Opportunities and Challenges (Vorguca, 2023)

A bridge is a segment that gracefully arches over the nose, residing between the lenses, bearing the primary responsibility for distributing the weight of the glasses effectively.

The end piece extends outward from the lenses and links to the temples, the end piece plays a pivotal role in the overall framework's design and stability.

The frame rim is the frontal section of sunglasses where the lenses are inserted, also commonly referred to as the eye wire.

The hinge mechanism is this crucial component that connects the rim to the temple, enabling the temple to fold inward for ease of storage and transport.

Optical lenses are comprised of materials such as glass, plastic, or polycarbonate, the lenses are the optical medium through which the wearer perceives the world.

A nose pad is plastic piece dedicated to wearer comfort and positioning and is integral to keeping the sunglasses securely and comfortably seated on the face. It can be affixed directly to the frame or the cushion arm.

The pad arm serves as the support structure for the nose pad, the pad arm allows for adjustment, ensuring a personalized and snug fit tailored to the wearer's unique nose profile.

Fasteners are small metal screws, situated at the hinge and bridge locations, that play a vital role in joining the temples to the front frame and securely anchoring the nose pads.

The top bar is present in certain eyewear styles, the top bar extends horizontally across the top of the bridge, delivering additional stability, particularly common in aviator-inspired sunglasses.

Temple arms often referred to as the arms, these elongated frame elements extend over the ears, maintaining the sunglass's stability and positioning.

Earpieces are typically composed of a plastic coating, these earpieces are situated on the segment of the temples that rest atop the ear, offering enhanced comfort for the wearer. This feature is commonly found in glasses with metallic frames. (Singh & Kapoor, n.d.)

As shown in Figure 7, this in-depth understanding offers the foundation for an excellent grasp of the challenges that are involved in the manufacturing and composition of eyewear.

The world of eyewear design is a dynamic one, where the shape and style of frames play a pivotal role in fashion and functionality. Eyeglasses come in a wide array of shapes, from rounded and oval to rectangular and squared, along with unique styles like pilot, butterfly, and cat-eye frames. Each shape not only serves an aesthetic purpose but also caters to different face types and personal preferences. These diverse frame shapes offer stylists numerous possibilities for innovation. (Montalto et al., 2017)

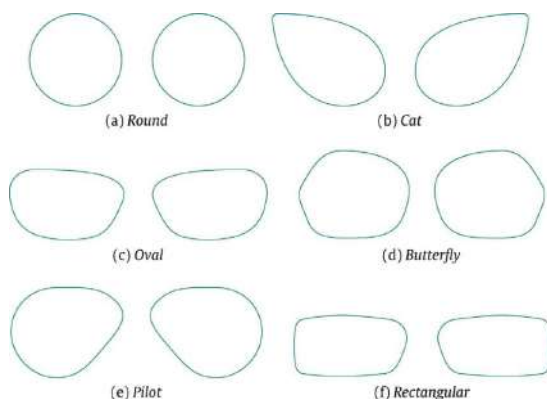


Figure 9. Diversity of Frame Shapes in Eyewear Design (Montalto et al., 2017)

2.3. AI-driven accessory design

In this subsection, the primary objective is to provide an exploration of the integration of AI within accessory design, situated within the context of the fashion industry. This exploration will be conducted in a manner that offers a concise overview of the subject without delving into extensive depth.

It is important to mention that as technology advances, numerous interconnected "things" emerge, becoming integral to people's lives. Wearable technologies capture contextual information from these devices, enhancing personalized experiences. Wearable technology, or wearables, collects and processes user's physical and physiological data, transmitting it within notifications or network connections. These electronic devices, attachable to the body or integrated into accessories like glasses and watches, monitor activities, detect gestures and emotions, and perform tasks such as message checking. Beyond monitoring, wearables enhance human capabilities in vision, hearing, and motor skills. In the last decade, technological advancements and cost reductions have popularized wearables, facilitating widespread application development by non-professionals across various fields. To continue with that, wearable technologies can be seen as a bridge that seamlessly connects the realms of fashion and technology. For instance, wearable technologies such as smart glasses, designed as accessories, are chosen not only for their functionality but also for the cyber-fashion statement they make. (Etesam, 2023)

To initiate this discussion, the pivotal query will be addressed: Do wearable technologies predominantly align with the category of digital products, or do they find their primary classification within the realm of fashion goods? Moreover, can these entities effectively bridge the divide by encompassing attributes of both categories? This discourse will further scrutinize the fluid convergence of these seemingly distinct domains and elucidate the advantages derived from this amalgamation. Furthermore, the general introduction to accessory design and delineating its relevance within this context will be mentioned. In the chapter dedicated to case studies, the center of the focus will be on the specific case of smart glasses, aiming to provide a comprehensive and detailed analysis of AI integration within the accessory category.

Fashion accessories, referring to a wide range of decorative components such as jewelry, sunglasses, handbags, belts, scarves, footwear, and more, strive to enhance the individual's outfit by adding to its visual interest.

After offering a brief explanation of the concept, the exploration will be the current state of AI integration in the fashion accessory sector and an explanation of the current potential and paths that this synergy presents, keeping in mind that from its initial purpose, they are not used just for its aesthetic and stylistic features but also for its functionality. This leads to the topic of adding technology to accessories which will elevate their value and so can potentially be seen as both functional and aesthetical products.

Before delving deeper into the explanation of the integration of AI into wearable technologies, it is important to mention the privacy concerns of such devices.

The incorporation of AI into accessories has huge potential in terms of technical development, giving plenty of opportunities to improve human experiences. However, this technological growth has its challenges, the most important of which is a growing concern about privacy. AI systems extensively rely on personal and sensitive information for main functions such as model training, predictions, and automated decision-making, giving rise to notable privacy concerns. This heavy dependence on data acquisition and analysis exposes individuals to potential privacy threats,

encompassing the vulnerabilities of information exposure, misuse, and the risk of data breaches or unauthorized access. The imperative for effective model training propels AI algorithms to require vast datasets, leading to an escalating reliance on data collection from diverse sources, ranging from social media and sensors to customer interactions and online transactions. The utilization of extensive and varied datasets empowers AI algorithms to generalize from a diverse array of examples, ultimately improving their performance and accuracy. (Ravi, 2023)

The way wearable technology is integrated with the human body has changed significantly in the last ten years. Depending on their application and functionality, such devices can be positioned and used in various ways. The past several years have seen a significant increase in wearable technology research and development activities, both in terms of quantity and quality. As a result, a number of wearable categories, such as accessories, clothing, patches, and implantables, have emerged. Since the focus is on the accessory's domain, the following part will highlight Figure 10, which provides a visual representation of the integration of AI within the realm of accessories.

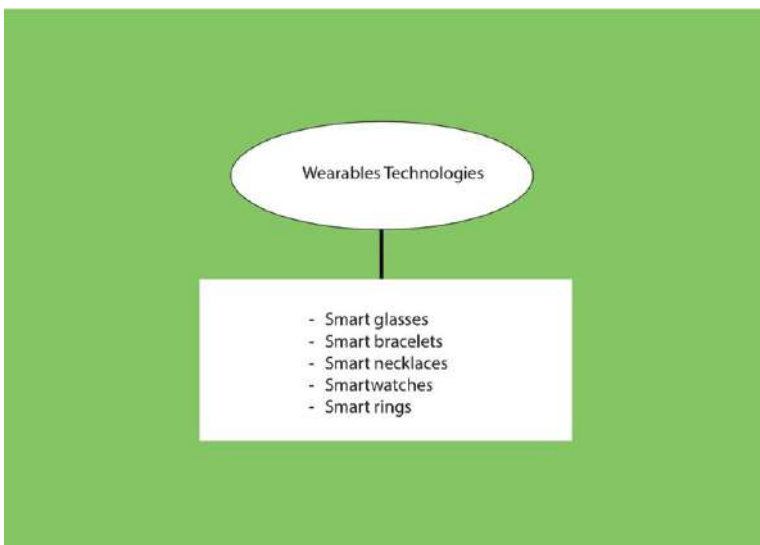


Figure 10. AI-driven accessory design, Integration of Artificial Intelligence in eyewear products: Opportunities and Challenges (Vorguca, 2023)

The incorporation of wearable technology components began with health and medical accessories. However, it is worth noting that smartphones, which appeared as the first fashionable everyday electronics, had an important effect on people's lives. Today, a diverse range of specialized markets operate to the consumers, giving solutions to improve daily comfort and fashionable appearance. The market has seen the birth of a wide range of products, from luxury smart rings, smart bracelets cutting-edge wearable systems, to smart glasses. (Etesam, 2023).

Based on the insights garnered from various articles and papers, it is evident that wearable technologies in the accessory field originally stemmed from a focus on aiding individuals, particularly in the realms of health and medicine. Over the last decade, the opportunities within this domain have expanded significantly, resulting in the integration of AI into accessories for varied purposes, encompassing health, safety, and entertainment. To address the earlier query regarding the predominant alignment of wearable technologies, it becomes apparent that AI integration into accessory design effectively bridges the gap between functionality and aesthetics. This synthesis reaffirms that wearables are not confined to being purely digital products or solely fashion items. Looking ahead, the ever-evolving landscape of AI, combined with the perpetual innovation within

the fashion sector, suggests an endless array of possibilities and advancements waiting to be explored at the intersection of these two dynamic fields.

2.4. Smart AR integrated eyewear

In this subsection, the focus gravitates toward the pioneering realm of wearable technology. Positioned at the forefront of pervasive wearables, Smart AI-integrated eyewear signifies a pivotal advancement, targeting to redefine everyday life. This head-worn device, equipped with advanced sensors, optical displays, and potent processing capabilities, transcends the realm of mere accessories, promising transformative implications for a diverse user base. Strategically situated on the head, this technology excels at capturing diverse physiological data while facilitating unobtrusive interactions, making it an indispensable tool for a wide array of general-use applications. Whether harnessed for AR experiences, health and fitness monitoring, or seamless access to information, the adaptability of display technologies within these eyewear devices underscores their significance in a perpetually evolving technological landscape. This subsection aims to deliver a comprehensive overview of the multifaceted impact of Smart AI-integrated eyewear in everyday use. (Ravi Chandran et al., 2023)

The convergence of fashion trends with the eyewear industry has revolutionized eyeglasses, elevating them from medical necessities to stylish and fashionable accessories. Nowadays, it's not uncommon to see people wearing eyeglasses solely for their visual appeal, even when not prescribed for vision correction. This shift has notably improved the societal acceptance of eyeglasses, as supported by empirical evidence. Simultaneously, the industry's relentless focus on aesthetic attributes drives the exploration of new design horizons, the adoption of innovative materials, and the integration of novel surface textures. This innovative drive, combined with the need for rapid time-to-market cycles, underscores the dynamic nature of the eyewear industry. (Montalto et al., 2017)

Having explored the anatomical aspects of eyewear in the previous subsection, the attention now turns to a more progressive facet: wearable AI-integrated eyeglasses, representing a pioneering approach in innovative eyewear.

As previously mentioned, the inception of wearable AI-integrated eyewear primarily stemmed from the realm of medical and healthcare applications. Expanding on this notion, the direction of attention is in Figure 11. which illustrates the intricate system underpinning the functionality of AI-integrated smart eyewear. This system serves as a foundational blueprint for the integration of smart technology into wearables, with a particular focus on eyewear. Importantly, it is imperative to note that this technology transcends its initial medical applications and seamlessly integrates into various domains. Figure 9. provides a visual representation of this system's structure, offering a more comprehensive and precise understanding of the interplay between AI-integrated smart eyewear and its versatile applications. This visual depiction shows the multifaceted role these innovative wearables play in shaping the contemporary technological landscape.

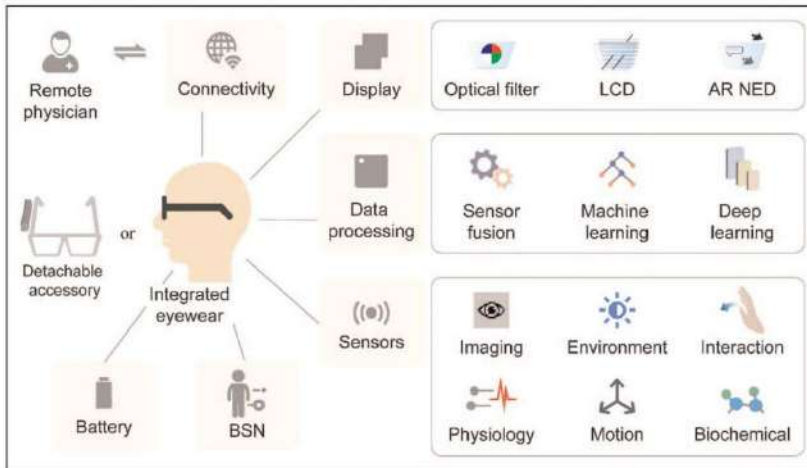


Figure 11. AI-enabled Smart Digital Eye Wearables Telehealth Framework (Ravi Chandran et. al, 2023)

Figure 11. visually encapsulates the key components and functionalities of this innovative system. The smart eyewear, at the center, is designed as a wearable device, seamlessly integrating various functional elements within its form factor. The core components include onboard sensors and a body sensor network (BSN), strategically positioned to capture physiological and environmental data. On the output side, smart eyewear incorporates advanced display technologies, exemplified by a liquid crystal display (LCD) and an augmented reality near-eye display (AR NED). These displays facilitate the presentation of information, data, and augmented reality content to the wearer. To enable efficient data processing and interpretation, the system relies on sensor fusion and AI algorithms. Sensor fusion integrates data from multiple sources to provide a comprehensive view of the user's environment and physiological status. AI algorithms play a pivotal role in processing this data, enabling real-time analysis, decision-making, and interaction. In essence, Figure 14. provides a visual roadmap of how smart eyewear seamlessly integrates these various components to create a sophisticated telehealth framework, where data collection, presentation, and analysis converge to enhance the user's experience and enable a broad spectrum of applications, from medical and healthcare to general use cases. (Ravi Chandran et. al, 2023)

In addition to the complex integration of sensor technologies within smart eyewear, we analyze commercially available smart eyewear technologies, with a special emphasis on AR based near-eye displays. This investigation shows the capabilities and specifications of these market-ready systems. These technological improvements, in combination with the insights provided by Figure 12., contribute to the full telehealth framework, changing data collecting, display, and analysis for a wide range of applications, from medical and healthcare to general use cases, which is the reason why we are collecting the data of analyzing them here as they are started in the medical and health pieces.

In addition to the intricate integration of sensor technologies within smart eyewear, we conduct a comprehensive analysis of commercially available smart eyewear technologies, with a particular emphasis on AR based near-eye displays.

Table 1. Sensor technologies embedded into smart eyewear

	Sensor technology	Measure	Application
Environment	Ambient light sensor	Illuminance, Color temperature	Light exposure, light source estimation, color sensing
	Ultraviolet sensor	Ultraviolet intensity, Exposure levels	Ambient UV intensity, digital screen exposure
Imaging	CMOS/CCD image sensor	Digital images	General purpose photography, Eye tracking and environmental mapping for AR/VR applications
Interactions	Gesture sensors	Noncontact proximity detection and gestures	Gesture-based interactions with the device
	Capacitive touchpad	Physical touch and interactions	
	Microphone	Sound	Voice control, Audio-based communication
Physiology	Galvanic skin response	Skin conductance	Emotional and afferent feedback
	Photoplethysmography	Volumetric changes in blood circulation	Heart rate, Heart rate variability, Blood glucose, Blood oxygen levels
	Electrooculogram	Corneo-retinal standing potential	Eye-tracking, Oculomotor monitoring
	Electroencephalogram	Electrical activity in the brain	Brain monitoring
	Infrared thermometer	Noncontact temperature measurement	Systemic monitoring
Motion	Global positioning system	Global location	Human activity monitoring, Spatial localization
	Accelerometer	Acceleration	Human activity recognition, fall detection, step count, gait-related measures
	Gyroscope	Orientation	

CCD, charge-coupled device; CMOS, complementary metal-oxide-semiconductor.

Figure 12. Sensor technologies embedded into Smart Eyewear (Ravi Chandran et. al, 2023)

Figure 11. and Figure 12., provide valuable insights into the capabilities and specifications of these readily accessible systems. These technological advancements, coupled with the insights offered by Figure 11., collectively contribute to the holistic telehealth framework, revolutionizing data collection, display, and analysis across a diverse spectrum of applications, spanning from medical and healthcare to general use cases.

	Google Glass Enterprise Edition 3 [73]	Microsoft HoloLens 2 [74]	Magic Leap 2 [79]	Nreal Air [75]	Xiaomi Wireless AR Glass Discovery Edition [80]	
Manufacturer	Google	Microsoft	Magic Leap	Nreal	Xiaomi	
Form-factor	Module on a frame	Headwear	Eyewear	Eyewear	Eyewear	
Device type	Standalone AR	Standalone AR	Standalone AR	Phone-powered AR	Standalone AR	
Year of introduction	2019	2019	2022	2022	2022	
Display	Mono/biocular	Monocular	Binocular	Binocular	Monocular	
	Optical element	Prism	Waveguides	Waveguides	Birdbath optics	Waveguides
	Display/projection	1x LCoS	2x LBS	2x LCoS	2x Micro OLED	1x Micro LED
	Resolution per eye [px]	640 x 360	1440 x 936	1440 x 1760	1920 x 1080	640 x 480
	Diagonal field of view [°]	-	52	70	46	29
Refresh rate [Hz]	-	60	-	60	30	
Sensors	Motion	3 DoF IMU	6 DoF IMU	3 DoF IMU	3 DoF IMU	Yes
	RGB camera	8 MP	8 MP	12.6 MP	No	5 MP
	Depth camera	No	1x	1x	No	No
	Eye tracking camera	No	2x	4x	No	No
	Head tracking camera	No	4x	3x	No	No
	Microphone	Yes	Yes	Yes	Yes	Yes
Interactions	Integrated audio	Mono speaker	Stereo speaker	Stereo speaker	Stereo speaker	Stereo speaker
	Gesture touchpad	Yes	Yes	Yes	Yes	Yes
	Handheld controller	No	No	Yes	No	No
System	Processor	Snapdragon Qualcomm XR1	Qualcomm Snapdragon 850	AMD QuadCore Zen2	-	Quad-core ARM processor
	Memory [GB]	3	4	-	-	-
	Weight [g]	51	566	260	77	51
	Connectivity	WiFi, Bluetooth, USB-C	WiFi, Bluetooth, USB-C	WiFi, Bluetooth, USB-C	WiFi, Bluetooth, USB-C	WiFi, Bluetooth, USB-C
	Battery capacity [mAh]	800	-	-	-	-
	Battery life [hrs]	8	2-3	3.5	5	-

DoF, degrees of freedom; IMU, inertial measurement unit; LBS, laser beam scanning; LCoS, liquid crystal on silicon; LED, light emitting diode; MP, megapixels; OLED, organic light emitting diode.

Figure 13. Commercially available AI-smart eyewear technologies (Ravi Chandran et. al, 2023)

Moreover, the reason we delve into the intricacies of the medical-integrated smart eyewear system is that it serves as a pioneering model within the realm of smart AI-integrated eyewear. It offers a valuable reference point for comprehending how this framework functions. By laying this foundation within the medical and healthcare sector, we create a robust basis for the subsequent benchmark analysis in the following subsection. This examination will shed light on how the same

system is applied to smart eyewear designed for general use, thereby providing a comprehensive understanding of this innovative technology, across different domains.

2.5. Benchmark Analysis

Having thoroughly explored the realm of Smart AI-integrated eyewear in the preceding subsection, delving into its technological intricacies and transformative potential, focus is on the different facet of the investigation. In this new subsection, the embarking is on a journey into benchmark analysis, shedding light on the commercial landscape of smart eyewear technologies that are readily available for everyday use. The captivating realm of smart glasses has materialized as a cutting-edge solution, presenting an intriguing alternative for individuals seeking a seamless means to engage with our interconnected world. These visionary devices unlock a unique avenue for accessing a diverse array of functionalities, typically residing within the domain of smartphones presented through a heads-up display seamlessly integrated into a pair of glasses.

When the Internet became popular in the 1990s, it was characterized by a one-way direction, that is, a majority of users were consuming content that was published by very few people or organizations. Social media are characterized by providing consumers with a second “virtual” reality. For example, users might feel in their “social media world” while browsing on their social media and feel in their “physical world” when they’re offline. Indeed, there are links between these two worlds, as the users might take pictures from the “physical world” and post them in the “social media world”. However, these two “worlds” were still distinct. The next phase of Internet technology evolution aims at bridging the gap between these two worlds, often referred to as AR. One of the most intensively discussed devices in this context is smart glasses. These devices, in essence, capture both real-world and digital information, seamlessly integrating them into a user's field of view. To define, smart glasses can be described as wearable computers equipped with a mobile Internet connection, designed to be worn like conventional eyeglasses or attachable to them, and they present information directly within a user's field of vision. This marks a significant evolution in how we interact with the digital and physical worlds, and it's an area mentioned in case studies on smart AI-integrated eyewear. (Rauschnabel et al., 2015)

This discussion introduces the critical key performance indicators (KPIs) metrics for the benchmark analysis. The focus is on the dynamic sphere of everyday lifestyle use, connected with social media and communication with our friends while merging “online” and “offline”. Delving into the topic by considering one more important need how smart glasses cater to the multifaceted needs and preferences of users who ardently seek a hands-free and versatile experience. This encompasses a spectrum of activities, including but not limited to photography, video recording, music enjoyment, and seamless communication via hands-free calls. Within this context, the KPIs metrics we examine step into the spotlight, revolving prominently around the crucial aspects of customer satisfaction and the cost-effectiveness of these transformative wearables. In doing so, the aim is to provide a comprehensive perspective on the intrinsic value they bring to the realm of daily life.

Figure 14. below presents a visual representation of the commercially available smart eyewear technologies, offering a more vivid understanding of the landscape. Among these, are notable options for general purposes.

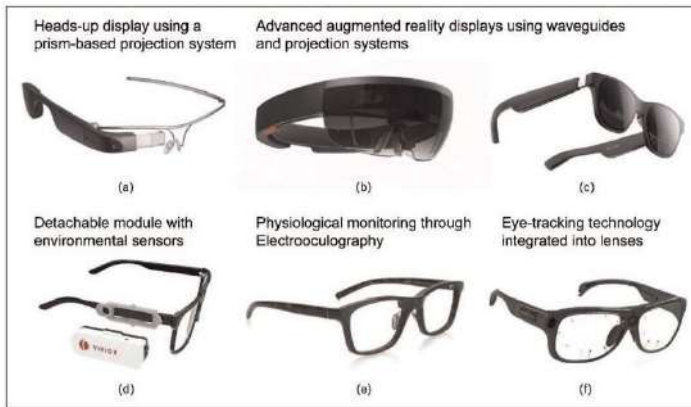


Figure 14. Market examples of Commercially available smart eyewear (Ravi Chandran et. al, 2023)

Commercially accessible smart eyewear technologies provide a wide range of options that are geared to a wide range of user lifestyles and preferences.

The Figure 14. includes a wide range of smart eyewear technologies, with Google Glass (a) being a prominent example recognized for its heads-up display and contextual notifications, providing a streamlined method of information access. In contrast, the HoloLens (b) and Nreal Air (c) introduce augmented reality displays that represent the beginning of an augmented reality era, appealing to people seeking rich digital content experiences. For those who prefer traditional eyeglasses, there are choices such as VIVIOR (d), which allows sensorized devices to be connected to current frames, enabling behavioral monitoring. JINS MEME (e) also provides customers with physiological monitoring capabilities via electrooculography technology. Finally, Tobii Pro (f) includes eye-tracking sensors in the lenses. (Ravi Chandran et. al, 2023)

In the realm of smart eyewear, the integration of AI serves as a profound purpose in augmenting the everyday lives of users. These technologically advanced eyewear devices are designed to provide a seamless and hands-free gateway to a world enriched with information, communication, and immersive digital experiences. With AI, they offer real time data access, efficient communication, and personalized interactions, enhancing convenience and efficiency. Furthermore, these devices extend their utility to health and fitness monitoring as virtual aides for daily tasks, and catering to individual preferences. Inclusivity is a key facet as well, with AI-powered eyewear accommodating users with diverse needs, making technology an accessible and integral part of their daily routines.

In the next chapter, focus is on the case studies. The most significant smart AI-integrated eyewear models, guided by carefully crafted lifestyle-based metrics. This chapter promises to offer invaluable insights into the real-world applications and user experiences of these transformative wearables.

3. Case studies

The prior chapter's examination of smart eyewear technology laid the basis for a more in-depth and targeted analysis. The insights gathered from the benchmark study served as the primary parameter for the case studies.

In the context of the case studies chapter, it's important to highlight that some of the most notable smart glasses with AR capabilities used for lifestyle human-computer interaction, including Google Glass, Ray-Ban Meta Stories, and Apple Vision Pro have been the subject of discussions and exploration. These devices are on the cutting edge of smart eyewear technology and have garnered significant attention due to their potential to seamlessly integrate digital information and AR experiences with the physical world. As going deeper into the case studies, a closer look is taken at

these innovative devices and their real-world applications, with the aim of providing comprehensive insights into their importance and user satisfaction within the realm of everyday commercial use.

3.1. Case Study 1: Google Glass

The first case study delves into Google Glass (GG), a remarkable milestone in the smart eyewear landscape. The year 2013 witnessed a groundbreaking moment as Google announced the release of GG, heralding the concept of commercially available smart glasses for personal use. GG perfectly aligns with our definition of smart glasses, serving as a wearable computer endowed with mobile internet connectivity. It can be worn in the manner of traditional glasses or mounted upon them, providing users with an uninterrupted display of digital information seamlessly integrated within their field of vision (Rauschnabel et al., 2015).



Figure 15. GG 1st Edition (Official site)

Exploring the features: GG represents a remarkable piece of wearable technology, featuring an optical head-mounted display (OHMD) that projects information in front of the user's eyes, effectively operating as a fully functional wearable computer. Its impressive hardware specifications include a TI OMAP4430 Dual 1.2GHz (ARMv7) processor, 2GB of RAM, 16GB of storage, an InvenSense MPU-9150 housing a gyroscope, accelerometer, and compass, a Wolfson WM7231 MEMS microphone, and a 5-megapixel camera. A Bone Conduction Speaker delivers audio directly to the inner ear. While running on Android 4.4 KitKat, GG boasts a customized interface tailored to its unique capabilities. User interaction is primarily facilitated through voice-activated commands and a right-side Touchpad on the frame. Impressively lightweight at just 36 grams, it matches the weight of conventional glasses. Activating GG involves tilting one's head or tapping the frame, and its display goes to sleep after 15 seconds of inactivity. To enhance the user experience, Google introduced the MyGlass app, compatible with both Android and iOS, enabling users to configure and manage their Google Glass settings.



Figure 16. MyGlass app (Google search)

GG can be coupled with EEG headsets, offering mind-controlled functionality and making it well-suited for hands-free and high-pressure scenarios. Its primary purpose is to complement rather than replace smartphones, providing information to users when they need it, and allowing for a quick glance. However, its public use has prompted concerns related to privacy, copyright, and safety. The price tag for GG is relatively high, considering the technology inside, but its popularity is vital for social acceptance and affordability.

As GG continues to evolve, its latest iteration marks a groundbreaking step in the realm of smart eyewear technology. Building upon its already impressive features such as the head-up display and natural language voice commands, the new GG is poised to integrate advanced AI capabilities. This evolution is particularly exciting with the potential incorporation of Google's sophisticated Large Language Model-Bard. Such integration could dramatically enhance user interaction, offering real-time information, augmented reality experiences, and personalized assistance. The enhanced GG stands as a testament to the fusion of cutting-edge AI with wearable technology, redefining how users interact with and see their environment, creating a seamless blend of the digital and physical worlds. (Pichai, 2023)

The battery life of GG is notably limited, and it tends to heat up when used extensively. Despite a somewhat limited selection of apps, some, like the Star Chat app, offer unique and engaging experiences. Intriguingly, Google persisted in developing the product despite discontinuing the prototype, releasing a 2nd edition in 2022. (Li Zhao, 2015). This edition is primarily intended for business use, which is not under the focus of our metrics and the reason why we will not take on a journey of exploring it. Although both editions experienced a decline in sales and consumer interest, they remain a pivotal force in the development of smart eyewear, with their technological legacy continuing to shape future innovations.

As further exploration of the case studies, and additional smart AI-integrated eyewear models, each with its unique set of features and user experiences in order to further enrich the understanding of their role in everyday life.

3.2. Case Study 2: Ray-Ban Meta

Therefore, the focus is on 2nd case study - the Ray-Ban Meta Stories, a ground-breaking partnership between the industry leader in eyewear, Ray-Ban, and Meta. This next-generation line of smart glasses, created in collaboration with EssilorLuxottica and unveiled at Meta Connect, represents a substantial advancement in the field of smart eyewear. Pre-orders for the smart glasses, which started at \$299 USD, were accepted on meta.com and ray-ban.com where on October 17, the glasses went on sale both online and in physical locations.

With the Ray-Ban Meta Stories, Meta and EssilorLuxottica have reshaped the conventional design for smart glasses. With these glasses, users may effortlessly capture and share millions of memories, above ordinary constraints. Liberating users from the constraints of conventional handheld cameras, the Ray-Ban Meta Stories offer a hands-free, unique point of view, allowing users not just to relive the moment but truly live in it.



Figure 17. Ray-Ban Meta Stories Smart Glasses (The Verge, 2023); (Gulf Insight 360, 2023)

Exploring the features: Going into the technological features of the Ray-Ban Meta Stories, the discovery is about the extensive range of capabilities that redefine the smart eyewear experience. The custom-designed speakers provide extended bass, increased maximum volume, and improved directional audio, boosting calls, music, and podcasts even in difficult circumstances. The newly developed 12 MP ultra-wide camera provides greater photo and video quality and 1080p video recording lasting up to 60 seconds. These smart glasses, which are powered by the Qualcomm Snapdragon AR1 Gen1 Platform, promise quicker computing and higher-quality photo and video processing. A redesigned charging case can contain up to eight additional charges, giving users a total of 36 hours of use. The glasses are prescription-lens compatible, and their weight has been reduced, making them more lightweight and comfortable. The glasses are additionally water-resistant (IPX4) and have an upgraded touchpad and interface earcons for faster and more reliable answers to user inquiries.

In the AI landscape, Meta, a major player, stands out for crafting the substantial Large Language Model, "LLama." This model, similar to ChatGPT, plays a crucial role. This significance becomes evident in the functionalities of Ray-Ban Meta Stories. The integration of Meta AI into Ray-Ban Meta Stories marks a convergence of cutting-edge technology and advanced conversational capabilities. Meta AI, accessible in beta in the United States, introduces a hands-free, on-the-go experience for users through the command "Hey Meta." This synergy positions the smart glasses at the forefront of innovation, leveraging Meta's role in the AI domain. (Touvron et al., 2023)

Last but not least, the Ray-Ban Meta Stories redefines the smart eyewear landscape by seamlessly blending cutting-edge technology with iconic eyewear design. As we navigate through our case studies, each unveiling unique features and user experiences, we gain deeper insights into the multifaceted role these smart eyewear models play in shaping the future of human-computer interaction.

3.3.Case Study 3: Apple Vision Pro

With the arrival of the Apple Vision Pro, which represents an extraordinary development in wearable technology, the research into innovative smart eyewear takes us to the newest example of innovation. Planned to be introduced at the beginning of the next year (2024), the Apple Vision Pro sets new standards in the realm of smart glasses, embodying the seamless integration of AR and sophisticated design principles. Similar to its previous work, the Apple Vision Pro sets the standard for luxury and effectiveness in the world of smart glasses, revolutionizing how people engage with the digital realm.



Figure 18. Apple Vision Pro Smart Glasses (Apple Developer Official Site, 2023)

Examining the features: Its defining feature is a spatial computing system that effortlessly blends digital content with the physical environment, offering users an unparalleled augmented reality experience. Boasting an optical display system with a custom micro-OLED display featuring an impressive 23 million pixels, the Apple Vision Pro delivers stunning resolution and colors, creating a visual landscape that transcends conventional expectations.

The gadget is powered by a dual-chip design, with the M2 chip running visionOS—a unique spatial operating system that enables powerful interactions by eyes, hands, and voice commands. The R1 chip, which is dedicated to processing input from cameras, sensors, and microphones, offers a virtually lag-free, real-time view of the world, which contributes to the device's overall efficiency.

Significant advancement in AI capabilities is dedicated to the integration of the M2 chip. This chip, particularly notable for its Enhanced Neural Engine, enables the processing of a plethora of AI models, significantly enhancing functionalities like superior voice assistance, advanced audio and spatial mapping, and improved image generation. The Apple Vision Pro, akin to its predecessors, establishes itself as a paragon of luxury and efficiency, revolutionizing user interaction with the digital world through its innovative features which include the powerful AI capabilities of the M2 chip. (Ortiz, 2022)

The user experience increases with responsive, precision eye tracking and a high-performance eye tracking system made of LEDs and infrared cameras, allowing users to navigate without using control devices. The powerful sensor system of the Apple Vision Pro, in conjunction with real-time 3D mapping capacities, enables an in-depth understanding of the user's surroundings, facilitating accurate head and hand tracking.

The aesthetic concept of the Apple Vision Pro reflects its advancements in technology. The gadget, which contains in just one piece of three-dimensionally created glass that has been laminated and an aluminum alloy frame, is both a work of engineering and a fashion statement. Apple's focus to customer comfort and enjoyment is highlighted by the Light Seal, which gently adapts to the face, and the Head Band with its Fit Dial for accurate adjustments. With features like Optic ID—a secure authentication mechanism that makes use of the peculiarity of the user's iris—privacy and security are of the utmost importance. A reliable and secure user experience is ensured by the device's integration with current Apple privacy and security measures.

Even while the Apple Vision Pro is a significant advancement in smart glasses, there are still some obstacles to overcome, such as worries about pricing and public acceptance. The external battery of the device provides a compromise between mobility and extended usage, with up to two hours of use while plugged in and an all-day option when not.

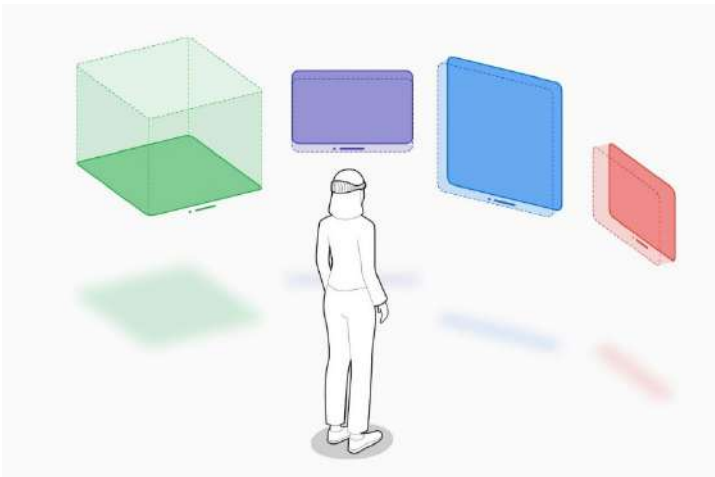


Figure 19. A spectrum of immersion (Apple Developer official site, 2023)

The Apple Vision Pro features a large spatial canvas that invites users to explore, experiment, and play, giving them an opportunity to create new versions of their 3D experiences. Users can interact with programs while keeping linked to their near surroundings or completely immersing themselves in a precisely constructed virtual world. These experiences are fantastic in their fluidity which we can describe as starting in a window, integrating 3D features, harmoniously shifting to a fully immersive setting, and then rejoining. This adaptable and dynamic capability is controlled by the spatial computing principles included in visionOS. As presented in Figure 19., customers could personalize their interactions by selecting options that suit their tastes and needs within this technology.

Closing to the end of this chapter of case studies, it is discovered an array of smart eyewear models, each with a different approach to the growing landscape of human-computer interaction. With its visionary attitude, the Apple Vision Pro not only captures the essence of today's innovation but also fuels our imagination for the future. It's not just about devices in this tech-driven symphony it's about the experiences they enable and the promise they have for shaping our digital future.

4. Future Developments

After examining case studies like Google Glass, Ray-Ban Meta Stories, and the upcoming Apple Vision Pro, the identified five key trends shaping the future of AI-integrated smart eyewear. These include seamless AI and AR integration, improved user interaction through advanced AI assistants, a focus on privacy and security, anticipated aesthetic improvements, and efforts to overcome barriers to mainstream adoption. This analysis incorporates customer satisfaction metrics to unravel why smart glasses, despite their potential, face challenges in gaining widespread acceptance. Through this exploration, the contribution it on the discourse of the future of human and computer interaction, shedding light on the complexities of smart eyewear adoption.

4.1. Anticipated trends in AI-integrated smart eyewear

After studying the case studies of Google Glass, Ray-Ban Meta Stories, and the soon-to-be-released Apple Vision Pro in the previous chapter, five major themes are identified that have the potential to transform the subject of human-computer interaction in AI-integrated smart glasses.

1. AI and AR integration

2. The future of AI-integrated smart eyewear envisions a seamless fusion of AI functionalities (real-time object recognition, personalized information delivery, and gesture controls, all integrated to enhance user experiences and create a seamless interaction between AI and AR) thereby improving users' phygital experience.

2. Improved user interaction through advanced AI assistants

Expected developments include the incorporation of advanced AI assistants, as demonstrated in Ray-Ban Meta AI, indicating a shift toward more intuitive and hands-free user engagements. Future AI assistants are likely to improve on Google Glass and Ray-Ban Meta Stories in terms of natural language processing, extended functions, and deeper integration into everyday activities.

3. Focus on privacy and security

As AI capabilities in smart eyewear improve, more importance is placed on addressing privacy and security concerns. In the era of AI-driven wearable technology, the projected trend is to add full security measures for privacy, like Apple Vision Pro's Optic ID verification, to ensure secure interactions and protect user data. This tendency stems from the privacy problems raised by Google Glass and the advancements achieved by Ray-Ban Meta Stories.

4. Aesthetic improvements

Inspired by ongoing enhancements seen in devices such as Ray-Ban Meta Stories, which underwent a serious redesign, the future of AI-integrated smart eyewear is expected to see a continued evolution in the aesthetic and shape factor. Future versions are likely to integrate advanced capabilities effortlessly while retaining the comfort and design of classic eyeglasses.

5. Overcoming limits to mainstream adoption:

Understanding smart eyewear's obvious innovation in addressing difficulties relating to cost effectiveness, public acceptance, and battery life are essential for general acceptance. Manufacturers are expected to make organized efforts to tackle these difficulties in the future. The creation of Google Glass and Ray-Ban Meta Stories offers insights into both progress and challenges, providing useful industry lessons. Furthermore, the next-generation Apple Vision Pro might bring additional advances in solving these adoption challenges as well.

As the reflection is on the case studies discussed in the preceding chapters, we gain a comprehensive understanding of how these anticipated trends align with the current trajectory of AI-integrated smart eyewear. Through an examination of these innovative devices, we contribute perspectives to the ongoing discourse on the future of human-computer interaction in the realm of smart eyewear. As we embark on the next section, we will delve into a SWOT analysis to critically evaluate the strengths, weaknesses, opportunities, and threats associated with AI-integrated smart eyewear technologies. This analysis will provide a nuanced understanding of the internal and external factors influencing the development and adoption of these technologies. Finally, bring together what have been discovered and draw insightful conclusions, or form a full picture of the current state and future potential of AI-enabled smart eyewear in the framework of interaction between humans and computers.

4.2. SWOT of AI-integrated smart eyewear

The SWOT analysis goes into complex areas to discover the ambiguity surrounding the adoption of AI-integrated smart eyewear, incorporating the customer satisfaction metrics: social aspects, economic factors, aesthetics, technological features, and wearability. This analysis covers both the

challenges and hidden potentials in the market by examining case studies of GG, Ray-Ban Meta Stories, and the upcoming Apple Vision Pro.

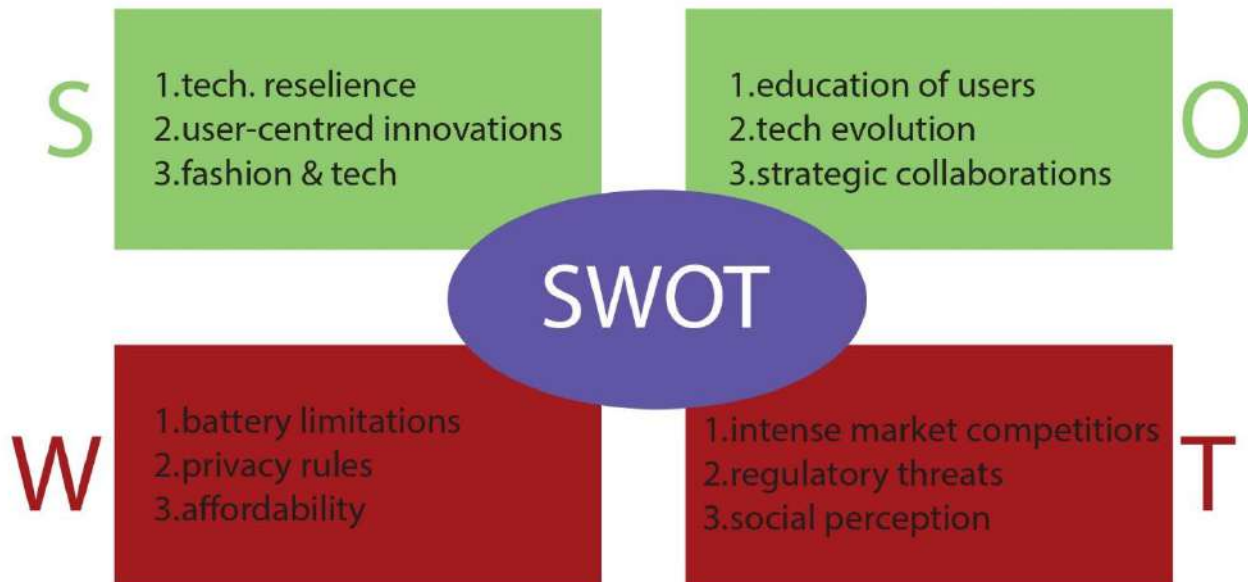


Figure 20. Table SWOT, Integration of Artificial Intelligence in eyewear products: Opportunities and Challenges (Vorguca, 2023)

Strengths

AI-integrated smart eyewear demonstrates constant technological advancement, delivering AR experiences, hands-free functionality, and seamless device interaction. GG set the trend with its OHMD, and Ray-Ban Meta Stories pioneered new capabilities such as immersive audio recording and Meta AI integration.

User-centered design: Voice commands, AR overlays, and AI assistants are examples of advanced features that demonstrate a dedication to user-centric design. With its spatial processing system and superior eye tracking capabilities, Apple Vision Pro demonstrates a pursuit of innovation.

Fashion and technology immersion: Collaborations with major eyewear brands, such as Ray-Ban Meta Stories, bridge the gap between technology and fashion, presenting AI-integrated smart eyewear as fashionable and on-trend.

Weaknesses

Battery Limitations: Universal issues with limited battery life impede customer's ability to use their devices for extended periods of time. Both GG and Ray-Ban Meta Stories are concerned about battery life.

Worries regarding privacy: The incorporation of AI creates real worries about user privacy, as evidenced by the GG experience, which contributes to uncertainty among potential users.

Struggles with Affordability: As seen in the Apple Vision Pro context, the relatively high cost of AI-integrated smart eyewear remains a barrier to accessibility and mass adoption, highlighting pricing and affordability concerns.

Opportunities

Integrated User Education: There are numerous opportunities to educate users about the practical benefits and various applications of smart eyewear, dispelling fears and driving wider acceptance. The GG experience highlights the significance of great user education.

Continuous Technological Evolution: As AI, AR, and materials technology evolve, manufacturers will have more chances to improve features, cut prices, and improve overall performance. Ray-Ban Meta Stories reflects technology advancements through incremental improvements.

Strategic Partnerships: Collaborations with technological companies, fashion labels, and healthcare institutions allow for the customization of solutions to individual consumer demands. Ray-Ban and Meta's collaboration exemplifies the power of strategic alliances.

Threats

High Market Competition: The smart eyewear market is battling for consumer attention with rising technologies and products. Maintaining market relevance requires navigating this scenario.

Legislative Challenges. Evolving privacy, data security, and technology usage rules offer challenges to the development and acceptance of AI-integrated smart eyewear. It is critical for market compliance to adhere to growing regulatory norms.

Social Perception: Omnipresent opinions and assumptions linked with wearing smart glasses might prevent mainstream acceptance, highlighting the need to get past negative stereotypes.

So to speak, the success of AI-integrated smart eyewear relies on a variety of customer satisfaction indicators. Socially, it is dependent on public perception and approval, with the goal of effortlessly integrating into cultural standards. The economic factor takes affordability and perceived value for money into account, ensuring that these advances are both accessible and worthwhile. Aesthetics are important, as user pleasure is linked to the design, style, and overall visual appeal of smart eyewear. The pleasure received from technologically beneficial elements is critical, highlighting the incorporation of sophisticated capabilities. Finally, wearability includes comfort, fit, and the whole experience of wearing smart eyewear for an extended period of time, enabling positive interactions between users and their wearable devices. These parameters impact the user experience collectively, influencing the emergence and acceptance of AI-enabled smart eyewear in the broader consumer market.

This SWOT analysis, exploring the dynamics of strengths, weaknesses, opportunities, and threats, is rooted in the trends of AI-integrated smart eyewear. It seeks to unravel the enigma of why, despite their potential, smart glasses haven't achieved broad public adoption. By delving into these nuanced dimensions, stakeholders can navigate the intricate landscape of human-computer interaction with smart eyewear, setting the stage for future innovations.

4.3. Conclusion

AI and AR Integration			
Feature	Google Glass	Ray-Ban Meta Stories	Apple Vision Pro
AI Functionalities	Basic	Meta AI Integration	Spatial Computing, AR
Integration Progress	Potential Future Integration	Implemented & Optimized	Advanced
Improved User Interaction through Advanced AI Assistants			
Interaction Methods	Voice Commands, Touchpad	Meta AI, Voice Commands, Touchpad	Enhanced Neural Engine, Eye Tracking, Spatial Computing
Progress in AI Assistant	Basic Commands	Advancement in the Functionality	Superior Voice Assistance, Advanced Audio,
Focus on Privacy and Security			
Addressing Privacy Concerns	Concerns Increased	Measures for AI Data Security	Optic ID, Apple Privacy Measures
Aesthetic Improvements			
Design Philosophy	Functional and Lightweight	Redesigned, Lightweight, Iconic	Fashionable, 3D Glass, Aluminium Alloy Frame
Emphasis on Comfort and Style	Comfort Focus	Iconic Eyewear Design	Stylish Design and Comfortability
Overcoming Limits to Mainstream Adoption			
Target Audience	Initially Consumer, Shifted to Enterprise	Mainstream Collaboration with EssilorLuxottica	Aim for Mass Adoption

Figure 21. Comparison Chart with findings, Integration of Artificial Intelligence in eyewear products: Opportunities and Challenges (Vorguca, 2023)

In conclusion, the integration of AI into eyewear represents a significant advancement in the fashion industry, blending technology with style and functionality. This thesis has demonstrated that AI-enabled eyewear, while still in its nascent stages, has the potential to revolutionize how we interact with our environment and with technology.

The case studies of GG, Ray-Ban Meta, and Apple Vision Pro reveal that each product, despite its unique features and market positioning, underscores a broader trend toward more intelligent, responsive, and user-focused accessories. These products not only enhance user experience through features like AR, voice commands, and health monitoring but also pose new challenges and questions, particularly in the areas of privacy, data security, and aesthetic integration.

Looking ahead, the future of AI in eyewear is bright but uncertain. Technological advancements promise more sophisticated, seamless, and not easily noticed integration of AI in eyewear. However, challenges such as mainstream adoption, balancing functionality with fashion, and addressing ethical and privacy concerns remain significant hurdles. The fashion industry, technologists, and policymakers must work collaboratively to navigate these challenges, ensuring

that AI-integrated eyewear evolves in a way that benefits users and respects their rights and preferences.

This thesis contributes to the understanding of AI's role in fashion accessories, specifically eyewear, offering a comprehensive analysis of its current state and potential trajectory. As AI continues to permeate various aspects of human lives, its integration into everyday objects like eyewear will undoubtedly continue to evolve, offering exciting possibilities for the future of fashion, technology, and human-computer interaction.

Bibliography

- Asiminidis C. (2023). Augmented and Virtual Reality: Extensive Review. IJSET - International Journal of Innovative Science, Engineering & Technology.
https://www.researchgate.net/publication/370211081_Augmented_and_Virtual_Reality_Extensive_Review
- Boden M. (1987). Artificial Intelligence.
<https://www.sciencedirect.com/book/9780121619640/artificial-intelligence#book-description>
- Carmigniani et al. (2011). Augmented Reality: An Overview. Handbook of Augmented Reality. Florida Atlantic University.
https://www.researchgate.net/publication/227164365_Augmented_Reality_An_Overview
- Denaro G. (2023). A New Manufacturing Fashion System: 4.0 Competences and Roles in Italian Clothing Design and Production. Fashion Highlight.
https://www.researchgate.net/publication/373891613_A_New_Manufacturing_Fashion_System_40_Competerences_and_Roles_in_Italian_Clothing_Design_and_Production
- Etesam M. (2023). Accessory-based Wearable Technologies, Digital products or fashion goods?. University of Bologna, Department of the Arts.
https://www.researchgate.net/publication/372646798_Accessory-based_Wearable_Technologies_Digital_products_or_fashion_goods
- Etesam M. (2023). Accessory-based Wearable Technologies, Digital products or fashion goods? University of Bologna. https://www.researchgate.net/publication/372646798_Accessory-based_Wearable_Technologies_Digital_products_or_fashion_goods
- Genova A. (2012). Accessory Design. <https://www.amazon.it/Accessory-Design-Aneta-Genova/dp/1563679264>
- Karthikeyan et al. (2021). Learning Outcomes of Classroom Research.
https://www.researchgate.net/publication/358050961_Learning_Outcomes_of_Classroom_Research
- Kopeinig et al. (2023). Industry 4.0 Technologies and their Implications for Environmental Sustainability in the Manufacturing Industry. Procedia Computer Science
https://www.researchgate.net/publication/374757388_Industry_40_Technologies_and_their_Implications_for_Environmental_Sustainability_in_the_Manufacturing_Industry
- Lee et al. (2021). Visioning the Future of Smart Fashion Factories Based on Media Big Data Analysis. Basel, Switzerland.
https://www.researchgate.net/publication/353974983_Visioning_the_Future_of_Smart_Fashion_Factories_Based_on_Media_Big_Data_Analysis
- Li Zhao. (2015). Google Glass Review. University of Birmingham, England.
<https://intranet.birmingham.ac.uk/it/innovation/documents/public/Google-Glass-Review.pdf>
- Luce L. (2019). Artificial Intelligence for Fashion. How AI is Revolutionizing the Fashion Industry.
<https://link.springer.com/book/10.1007/978-1-4842-3931-5>

- Lucizano et al. (2022). Mapping of 4.0 Industry Revolution Enabling Technologies. 1st Australian International Conference on Industrial Engineering and Operations Management. Sydney, Australia https://www.researchgate.net/publication/366985992_Mapping_of_40_Industry_Revolution_Enabling_Technologies
- Mendoza-Ramírez et al., (2023). Augmented Reality: Survey. School of Engineering and Sciences, Tecnológico de Monterrey, Av. Eugenio Garza Sada 2501 Sur, Monterrey 64700, NL, Mexico; a01251967@tec.mx (C.E.M.-R.). <https://www.mdpi.com/journal/applsci>
- Montalto et al., (2017). Combining aesthetics and engineering specifications for fashion-driven product design: A case study on spectacle frames. Politecnico di Milano – Department of Mechanical Engineering, Via La Masa 1, 20156 Milan, Italy b Politecnico di Milano – Department of Aerospace Science and Technology, Via La Masa 34, 20156 Milan, Italy. <https://www.sciencedirect.com/science/article/abs/pii/S0166361517301689>
- Nääs at al. (2022). Fashion Industry 4.0: A Bibliometric Review in the Fashion Industry. Research Society and Development. https://www.researchgate.net/publication/363773246_Fashion_Industry_40_A_Bibliometric_Review_in_the_Fashion_Industry
- Ortiz S. (2002). Everything you need to know about the Apple M2 chip. <https://www.zdnet.com/article/everything-you-need-to-know-about-the-apple-m2-chip/>
- Pichai S. (2023). An important next step on our AI journey. <https://blog.google/technology/ai/bard-google-ai-search-updates/>
- Rathore B., Integration of Artificial Intelligence& It's Practices in Apparel Industry. Birmingham City University, Birmingham, West Midlands, United Kingdom https://www.researchgate.net/publication/368837157_Integration_of_Artificial_Intelligence_Its_Practices_in_Apparel_Industry
- Rauschnabel et al., (2015). Mixing Physical and Virtual Realities: Implications of Augmented Reality Smart Glasses for the Management of Innovation. 2015 Summer AMA conference, Chicagi. https://www.researchgate.com/publication/275155829_Mixing_Physical_and_Virtual_Realities_Implications_of_Augmented_Reality_Smart_Glasses_for_the_Management_of_Innovation
- Rauchnabel et al., (2015). Who will buy smart glasses? Empirical results of two pre-market-entry studies on the role of personality in individual awareness and intended adoption of Google Glass wearables. The University of Michigan-Dearborn, United States University of Southern Denmark, Denmark University of Bamberg, Germany. <https://www.sciencedirect.com/science/article/abs/pii/S0747563215001880>
- Ravi Chandran et al., (2023). Artificial intelligence enabled smart digital eye wearables. Wolters Kluwer Health. <https://journals.lww.com/co-ophthalmology/pages/default.aspx>
- Ravi I. (2023). Privacy in the AI Era-Navigating Challenges and Safeguarding Data in the Age of Innovation. Information Systems Security. https://www.researchgate.net/publication/374584731_Privacy_in_the_AI_Era-Navigating_Challenges_and_Safeguarding_Data_in_the_Age_of_Innovation
- Reyes- Cárdenas P. (2023). What kind of "intelligence" is Artificial Intelligence?. Oblate School of Theology, San Antonio, Texas.

https://www.researchgate.net/publication/372761007_What_kind_of_intelligence_is_Artificial_Intelligence_Que_tipo_de_inteligencia_es_la_Inteligencia_Artificial

Singh & Kapoor, n. d. Evolution of Eyewear- From monocolo to Google Glasses.

<https://www.scribd.com/>

Singh S. (2023). Digital Fashion. LWRN Studio.

https://www.researchgate.net/publication/375497371_Digital_Fashion

Touvron et al. (2023). LLaMA: Open and Efficient Foundation Language Models.

https://www.researchgate.net/publication/368842729_LLaMA_Open_and_Efficient_Foundation_Language_Models

Yongjun Xu et al., (2021). Artificial intelligence: A powerful paradigm for scientific research. The Innovation Journal. [https://cell.com/the-innovation/fulltext/S2666-6758\(21\)00104-](https://cell.com/the-innovation/fulltext/S2666-6758(21)00104-1?_returnURL=https%3A%2F%2Flinkinghub.elsevier.com%2Fretrieve%2Fpii%2FS2666675821001041%3Fshowall%3Dtrue)

[1?_returnURL=https%3A%2F%2Flinkinghub.elsevier.com%2Fretrieve%2Fpii%2FS2666675821001041%3Fshowall%3Dtrue](https://cell.com/the-innovation/fulltext/S2666-6758(21)00104-1?_returnURL=https%3A%2F%2Flinkinghub.elsevier.com%2Fretrieve%2Fpii%2FS2666675821001041%3Fshowall%3Dtrue)

Zhang & Lu. (2021). Study on artificial intelligence: The state of the art and future prospects.

<https://www.sciencedirect.com/science/article/abs/pii/S2452414X21000248>

Ziyue Guo et al., (2023). AI Assisted Fashion Design: A Review. Zhejiang University-University of Illinois Urbana-Champaign Institute, Zhejiang University, China; Hangzhou Dianzi University, China. This article has been accepted for publication in IEEE Access.

Acknowledgments

I want to convey my deep appreciation to Professor Paola Bertola for her consistent guidance and Professors Angelica Vandi and Greta Rizzi for their meaningful contributions as co-supervisors. I am thankful to my colleagues, companions, friends, and particularly my family for their constant encouragement.

This thesis is dedicated to my grandparents, whose enduring faith in me has been a guiding presence, even in times of self-doubt. Their belief echoes throughout this work, and for that, I am profoundly grateful. *Where you stopped, I will keep walking.*