PHOTONICS21

Tematys
Exploration of photonics markets

Photonics for Virtual Worlds

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Photonics for Virtual Worlds

Contents

1. Context and introduction

Virtual reality (VR) substitutes the actual environment with a simulation, while augmented reality (AR) superimposes content into the real world. Mixed reality (MR), however, involves the interaction of virtual and real content. The umbrella term xR encompasses VR, AR, and MR. VR is being increasingly used as a training tool, facilitating telepresence and aiding in design or visualisation, as well as shaping the future of gaming. Solutions which involve AR/MR are becoming more widespread, serving purposes such as remotely guiding workers, presenting operational plans to surgeons, and acting as a replacement for smartphones in content consumption. These technologies promise to revolutionise future work processes and communication methods.

Often, xR is reduced to the use of specific glasses or masks. However, more mature application markets do not rely only on such devices; in the defence industry, where xR applications are the most advanced, screens and head-up displays are not only present in helmets with embedded AR functions. There are goggles, scopes, head-up displays (HUD), and regular displays. In the automotive market, many high-end cars now have head-up displays and games or shopping applications that use the abilities of smartphones.

The specialised optics required by AR/MR headsets have so far proved to be one of the industry's major stumbling blocks. In VR headsets, new, unconventional lens types are being used to solve the deficiencies of the Fresnel lens-based architectures that have dominated until now. For AR/MR, an entire industry of specialised, often fabless, optics firms has sprung up, offering a diverse range of competing technologies to headset manufacturers.

The advanced optics essential for AR/MR headsets have presented a significant challenge for the industry thus far. With VR headsets, an increasing trend involves the adoption of novel and unconventional lens varieties to address the limitations of the prevalent Fresnel lens-based designs. At the same time, the AR/MR sector has witnessed the emergence of a dedicated industry comprised mainly of specialised, often fabless, optics companies. These firms provide an array of competing technologies to actively engaged headset manufacturers.

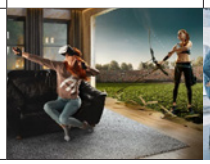
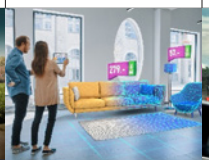
This report begins by reviewing the definition of AR, MR, and VR while providing a short description of the main applications. The subsequent section describes which functions and components xR devices have to contain in order to provide performance and comfort to users. Great challenges have not yet been fully overcome to allow for the wide adoption of xR technologies. One of the main unsolved issues is all vision impairments, from the most common, like myopia and presbyopia, to more serious issues where some demonstrations have shown that xR can be of great help to patients.

The next section of the report gives an analysis of the optical components market, followed by a question about the position of European companies within the xR device industry.

2. Definitions and applications

2.1 Defining digital realities

Table 1: Definitions of digital realities, VR, MR and AR.
Source: Digital Transformation Monitor[1], modified by TEMATYS.

Characteristics	Virtual Reality	Mixed Reality	Augmented Reality
Augments the real environment with useful information	✘	✔	✔
Combines virtual elements with the real environment	✘	✔	✘
Transports the user to a virtual environment	✔	✔	✘
Completely replace the real world	✔	✘	✘
Examples			

The characteristics of each digital reality are shown in Table 1, and the definitions of AR – VR – MR – xR proposed by the European Telecommunications Standards Institute[2] are as follows:

- **Virtual Reality (VR)** immerses the user entirely in a virtual yet interactive environment that simulates a completely different reality than the one surrounding the user.
- **Augmented Reality (AR)** is the ability to mix in real-time spatially-registered digital content with the real world surrounding the user. Unlike VR, augmented reality does not block out our surroundings; it enhances our current state of presence in the real world.
- **Mixed Reality (MR)** blends the real and virtual worlds to create complex environments where real-world and digital elements can interact in real time. It can be viewed as a continuum between the real and the virtual worlds but excludes both of them.
- **eXtended Reality (xR)** is the umbrella term used for Virtual Reality (VR), Augmented Reality (AR), and Mixed Reality (MR), as well as all future immersive technologies yet to be developed. xR covers the full spectrum of real and virtual environments.

[1] Laurent Probst, Bertrand Pedersen & Lauriane Dakkak-Arnoux, "Augmented and Virtual Reality", Digital Transformation Monitor, European Commission, October 2017.
[2] ETSI, "AR, VR, XR AT A GLANCE", https://www.etsi.org/technologies/augmented-reality

2.2 Emerging applications abound, but mainstream adoption still awaits

Table 2 shows a non-exhaustive list of xR applications. Often, xR is reduced to the use of specific glasses or masks. However, more mature application markets do not rely only on such devices. xR has been developed and used for a long time in defence, especially on aircraft and terrestrial vehicles. Nowadays, foot soldiers have access to data and assistance. These applications are developed on many devices like helmets, goggles, scopes, HUDs or even full-size simulators.

The gaming sector has also explored xR and developed dedicated game searching, better immersion in a digital world, and ways to take games beyond the home (Pokémon Go) through smartphones. The automotive industry has also developed solutions that are implemented on high-end cars. Head-up displays show dashboard information through windshields and prevent drivers from looking away from the road.

Figure 1: Some advanced industries like aerospace have also adopted xR for supporting design, simulation, training and maintenance activities
Source: gorodenkoff, Istock.

Some advanced industries like aerospace have also adopted xR to support design, simulation, training, and maintenance activities. Table 2 shows that many sectors are trying to take advantage of xR for developing applications. But even if the software market is already significant in volume (section 4), and even if many demonstrations have proved the potential of xR, no applications have revolutionised a field or activity yet. Current hardware may not yet be performant or comfortable enough and is likely too costly. At the same time, the xR software industry is still maturing, and many potential uses of xR remain unexplored. However, with ongoing progress, it's not a question of if but when users will begin to adopt these technologies on a large scale.

There is no doubt that xR will become an important tool that will support and facilitate professional and personal activities. However, mainstream adoption remains an open question.

Application markets	AR		MR	
	Device	Application	Device	Application
Video games			Smartphones Glasses	Video games (Pokémon Go)
Automotive	Head up displays Glasses	Driving assistance interaction with infrastructure Maintenance assistance	Glasses	Design assistance, interaction with infrastructure
Tourism	Glasses or smartphone	Access to additional information	Smartphones Glasses	Interactive Virtual objects during a real tour
Military	Head up displays Glasses, helmets, goggles, binocular, displays	Targeting, designation, flying, driving, steering assistance		
Office work				
Aviation	Head up displays Glasses, displays	Taxi and landing assistance Maintenance assistance		
Security	Helmet Mounted Display, glasses	Firefighters assistance		
Industry	Glasses	Maintenance assistance	Glasses	Integration simulation
Medical	Glasses	Real-time access to data, intraoperative tumour or organ visualisation, vision-impaired assistance, Remote medicine		
Attendance & meetings	Glasses, displays	Real-time access to data, Remote meetings		
Training & Education	Glasses, displays	Remote lessons		
Shopping & e-commerce, Real Estate	Glasses, smartphones	Instant information about a product	Glasses, smartphones	Product demonstrations / "Try before you buy"
Sport	Glasses	Access to data in real-time: performance, scores, statistics...		
Media	Glasses, smartphones	Viewing content in a window as part of the real environment		

Application markets	VR	
	Device	Application
Video games	Mask Simulators	Video games (Super Mario Odyssey)
Automotive	Mask	Design assistance Driving training
Tourism	Mask	Virtual tours of monuments, museums, hotel rooms, etc.
Military	Mask Full simulator	Simulators, training
Office work	Mask	Metaverse Remote meetings
Aviation	Mask Full simulator	Simulators, training
Security	Mask	Simulators, training
Industry	Mask	Design assistance
Medical	Mask	Simulators, training, Therapeutic applications, including treatment of phobias and addiction
Attendance & meetings	Mask	Full VR meetings, Metaverse
Training & Education	Mask	Full VR lessons and training
Shopping & e-commerce, Real Estate	Mask	Full Virtual shops
Sport	Mask	360° immersion in a sports competition Immersive training for athletes
Media	Mask	Viewing 360° content (e g pickupVRcinema)

Table 2: non-exhaustive list of xR applications. Source: TEMATYS/Photonics21 2023.

3. XR devices rely on the most advanced photonic technologies

Fundamentally, xR hardware is a photonic device, given that its primary function is to deliver visual information and images to the eyes (which are essentially a pair of biological photonic sensors).

3.1 The challenge set by the functional requirements

To provide comfortable devices that can be worn for a long time is challenging. This is especially true for AR glasses, as users might want to wear them as their primary glasses. Additionally, AR glasses can address vision impairments like myopia (short-sightedness), a topic discussed in the next section.

Several studies have attempted to define the requirement for smart AR glasses to become sufficiently performant and comfortable. These glasses can be worn up to 18 hours a day[3]. They must be light and comfortable. According to Microoled[3], the eyewear industry has endeavoured to make the glasses as light as possible, with an average weight of 26g. However, studies have shown that beyond 39g, comfort and wearability issues arise.

Sources:
(1) Wearing comfort and perceived heaviness of smart glasses, YM Kim, 2021; Expected to be less than 40g for "dynamic" activities.
(2) Eyewear Weight Distribution model from Microoled internal sources and undisclosed eyewear partner database.

Figure 2: Eyewear weight distribution model[3]. Source: Microoled[3].

In other words, developing AR glasses for permanent use, like regular ophthalmic eyeglasses, presents great challenges. These glasses must offer excellent optical performance (including resolution, field of view, brightness, and contrast) while maintaining low power consumption.

[3] Microoled, "Smart AR Glasses: a Very Low Power Companion Device", EPIC Meeting on Photonics for AR/VR/MR", 11 May 2023.

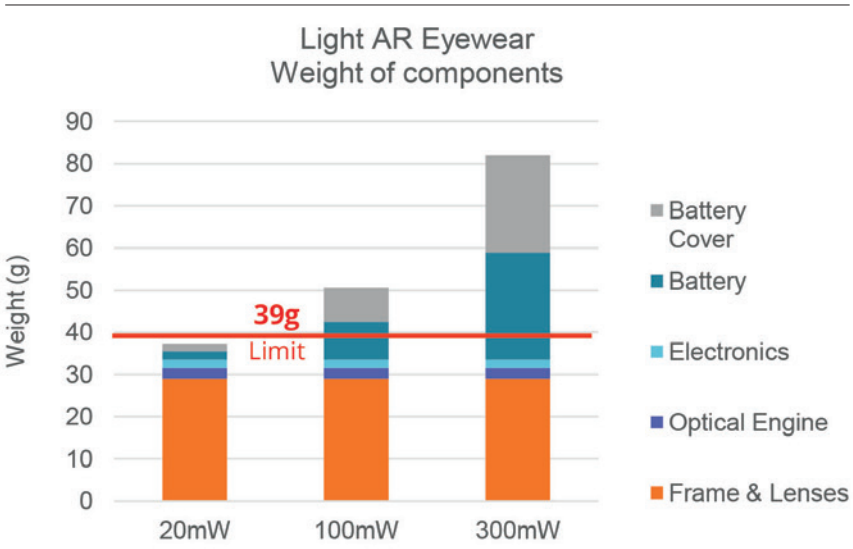


Figure 3: An analysis by Microoled for their ActiveLook® light AR glasses design. In order to stay below the 39g limit and maintain 18 hours' autonomy, only a battery of 20mW can be implemented inside[3].
Source: Microoled[3].

Figure 2 shows a distribution of weight targets for each part of lite AR eyeglasses to be worn all day. The whole optical engine, i.e. all the active optical components, cannot weigh more than a few grams.

Another analysis by Bernard Kress, Director of xR Hardware at Google[4], provides a functional and form factor analysis of each type of xR device. There are six types of devices, from audio glasses with only a camera and audio function to the heavy mask used for a complete immersion into virtual reality. The usage differs significantly, particularly in terms of session duration, as computing power and optical requirements vary, influencing acceptable weight and power limits.

The weight and power consumption are not the only challenges. The optical performance is also critical, especially in the field of view, which is the width and height of the image seen by the eye. The human field of view is around 210° horizontally (with two eyes) and 130° vertically. For AR, only a part of the vision can be used to display simple information. In MR, objects can be inserted anywhere in the human field of view, though they do not cover the entire field. In VR, the eyes are fully covered by a headset, and the whole scene is artificially generated and viewed. Unfortunately, current technology cannot achieve a 210° field of view, even if each new generation of devices achieves great progress to reach the Holy Grail of full wide-angle vision.

Depending on the function and the specific usage of xR devices, they must also have other features like cameras, audio, gesture sensing or eye movement tracking. These modules, especially optical components, are detailed in the next section.

[4] Bernard Kress, "Display system technology improvements are vital to AR/VR headset adoption", September 2023, https://spie.org/news/photonics-focus/septoct-2023/improving-display-system-tech-for-arvr-headsets?SSO=1#_=_

3.2 Photonic components for xR

Creating a completely immersive virtual reality would mean mobilising the perception of the five senses by artificial stimulation. Aircraft simulators used for pilot training attempt to achieve this goal but are several meters wide and cost millions of euros.

VR masks provide a much less realistic but still immersive experience by activating vision and hearing. Some companies also propose haptic equipment like gloves or even around the torso.

AR and MR only aim to add visual and audio information or virtual objects to reality. AR and MR devices maintain the perception of reality whether they are eyeglasses, head-up displays or smartphones.

In short, all xR devices need to produce images and are, in essence, photonic devices.

Contrary to aircraft simulators, xR devices are wearable, and all the functions have to be extremely miniaturised and light.

xR devices contain many of the most advanced photonic technologies, from freeform, metasurfaces, waveguides, microdisplays, and high-index substrates to diffractive components, to name a few.

The company IDTechEX has listed all types of photonic components necessary for developing AR and VR devices[5]. The objective of this report is not to describe all of them in detail. However, it is important to note the complexity of these devices and the expertise required to manufacture them.

Even though the market of consumer xR devices is dominated by USA and Asian companies (section 5), the xR market offers great opportunities for European companies that have the right expertise for designing and manufacturing certain components.

3.3 Vision impairment, a "blind spot" of AR/VR technologies

While there have been attempts to address the issue, current devices do not yet provide a solution for accommodating vision impairment. This is a "blind spot" of the AR/VR industry. For people wearing eyeglasses – like those who have myopia (short-sightedness), for example – the only solution is to wear devices over their glasses, which is very uncomfortable. This issue is even more complicated for seniors with presbyopia who wear progressive lenses.

And yet, the Vision Council of America stated that in 2020, over 50% of all women worldwide and 42% of all men wore glasses[5]. In 2020, 34% of the global population was affected by myopia alone, i.e. 2.62 billion people

[5] IDTechEX, "Optics for virtual augmented and mixed reality 2022-2032 – technologies, players and markets" https://www.idtechex.com/en/research-report/optics-for-virtual-augmented-and-mixed-reality-2022-2032-technologies-players-and-markets/870

worldwide – a figure that could potentially reach 49.8% in 2050, according to the study. The second major impairment is presbyopia, with 1.09 billion people estimated to be affected[6].

xR can also be a useful tool for enhancing the vision of patients suffering from severe conditions like age-related macular degeneration (AMD)[7].

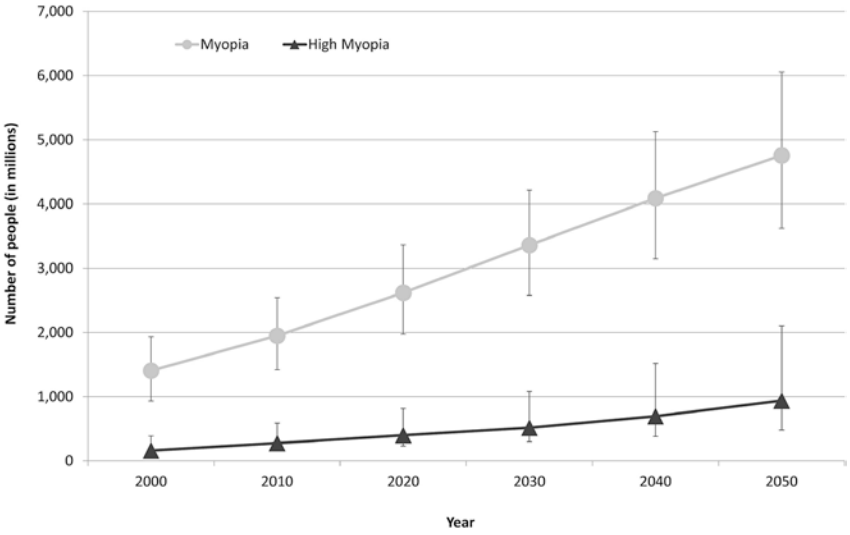


Figure 4: Number of people estimated to have myopia and high myopia for each decade from 2000 through 2050.
Source: Holden et al. 2016[8].

[6] Overnight Glasses "Eyewear Industry Statistics and Facts [2023], May 17, 2023, https://www.overnightglasses.com/eyewear-industry-statistics/

[7] https://www.lightvision.fr/en/

[8] Global Prevalence of Myopia and High Myopia and Temporal Trends from 2000 through 2050, Brien A. Holden, PhD, DSc, Timothy R. Fricke, MSc, David A. Wilson, PhD, Tien Y. Wong, MD, Thomas J. Naduvilath, PhD, Serge Resnikoff, MD, 11 February 2016; DOI: https://doi.org/10.1016/j.ophtha.2016.01.006

4. AR/VR xR market

The AR/VR market has existed for a long time and is considerably mature in the defence sector. In the consumer market, many products have been launched, with Google Glass being the most symbolic. However, a vast majority of users have not yet adopted AR as a common device, in the same way that smartwatches have become ubiquitous, for example[9] [10]. Even in gaming, a sector that is more open to innovation, the use of xR is still a niche market. Automotive HUD, the most mature application, is implemented on high-end cars; medical and tourism applications are mainly demonstrations; industrial applications are now more common but only for the design, assembly or maintenance of complex equipment like aircraft.

The slow adoption of xR arguably derives from the current performance and comfort of devices, which are not yet satisfactory. The lack of success of the first Google Glasses was also due to their performance, the high cost of the available applications, and the fear of people regarding privacy because of the embedded cameras. However, privacy concerns have become less of an issue today, given the prevalence of people taking and sharing photos on social media. The attitude toward privacy issues has changed, especially in younger generations, thanks to regulations like GDPR or the EU Digital Services Act, which brought back minimum control over the use of personal data.

The game Pokémon Go, developed by The Pokémon Company and Niantic and launched in 2016, is based on smartphones and demonstrates that with a creative application and the use of an accessible device, the success and wide adoption of xR are reachable.

A report by Visionary Analytics made for the European Commission identifies barriers to the application in the healthcare and education sectors (see Table 3)[11]. However, the observations apply to many other industries.

Table 3: Summary of barriers to the application of xR in the healthcare and education sectors, Source: Visionary Analytics, 2022 in Boel. C. et al. (2022).[11]

Cross-sectoral barriers		
Market-related • Lack of awareness and acceptance of xR technologies • Financial constraints • Lack of skilled professionals in the market	**Technical limitations** • Low image resolution • Design issues • Limited computing speed and battery life of HMDs • Health concerns	**Other** • xR regulation and government policies • Ethical and privacy issues
Health sector-specific barriers		**Education sector-specific barriers**
Market-related • Market fragmentation • Limited availability of content	**Technical limitations** • Lack of realism	**Market-related** • Availability of xR devices, i.e. lack of hardware penetration

[9] https://en.wikipedia.org/wiki/Smartglasses#Discontinued
[10] https://www.engineering.com/bad-news-for-augmented-reality-as-multiple-startups-fold/
[11] Carl Boel, Kim Dekeyser, Fien Depaepe, Luis Quintero, Tom Van Daele, Brenda Wiederhold, VISIONARY ANALYTICS, Ella Desmedt, Steven Knotter IDEA CONSULT for the EUROPEAN COMMISSION, "eXtended Reality: opportunities, success stories and challenges (health, education)", ISBN 978-92-76-56746-2, doi: 10.2759/121671, sept. 2022

In the list of identified barriers, the technical limitations are significant, along with the "market-related" barriers. In these barriers, the financial constraint is also related to the technology, which is still too expensive for wide adoption by consumers.

The other "market-related" barriers are a lack of awareness and a shortage of skilled professionals. The success of the game Pokémon Go demonstrates that these barriers are rather "chicken and egg" issues that could disappear quickly.

5. Manufacturers of consumer devices – position of europe

A **breakdown of xR product manufacturers by country**, based on a list of available consumer products[12], is shown in Figure 5 (below). The USA leads with 42 companies, followed by China with 25 manufacturers. France, Japan, and Taiwan follow with six each. In total, there are 21 manufacturers in Europe, including 15 from the European Union.

But this comparison might be misleading. Among the six Japanese companies, four are major consumer electronics manufacturers: EPSON, SONY, CANON and FUJITSU. It is the same in Taiwan with ASUS, ACER, HTC, and D-LINK, and in South Korea, it has two groups, SAMSUNG and LG, over four companies. In Europe, the main groups are CARL ZEISS and ESSILOR-LUXOTICCA, two major companies in the ophthalmology market. All others are Start-ups or SMEs.

In conclusion, Europe is developing expertise, but it is not probable that it will become a major player in the consumer xR device market. This observation may be different for other markets where THALES in defence or VALEO in automotive are significant.

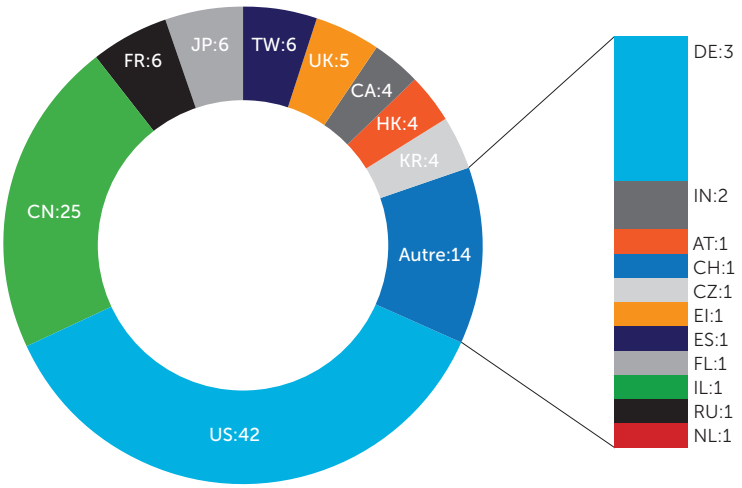


Figure 5: xR consumer devices manufacturers, breakdown per country of origin. Data source VRcompare[12], processed by TEMATYS, 2023.

France (6 SME/6)
UK (5 SME/5)
DE (1 group/3)
Carl Zeiss

South Korea (2 groups/4)
Samsung
LG

Taiwan (4 groups/6)
ACER
ASUS
HTC
D-Link

Japan (4 groups/6)
Epson
Sony
Canon
Fujitsu

[12] https://vr-compare.com/

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