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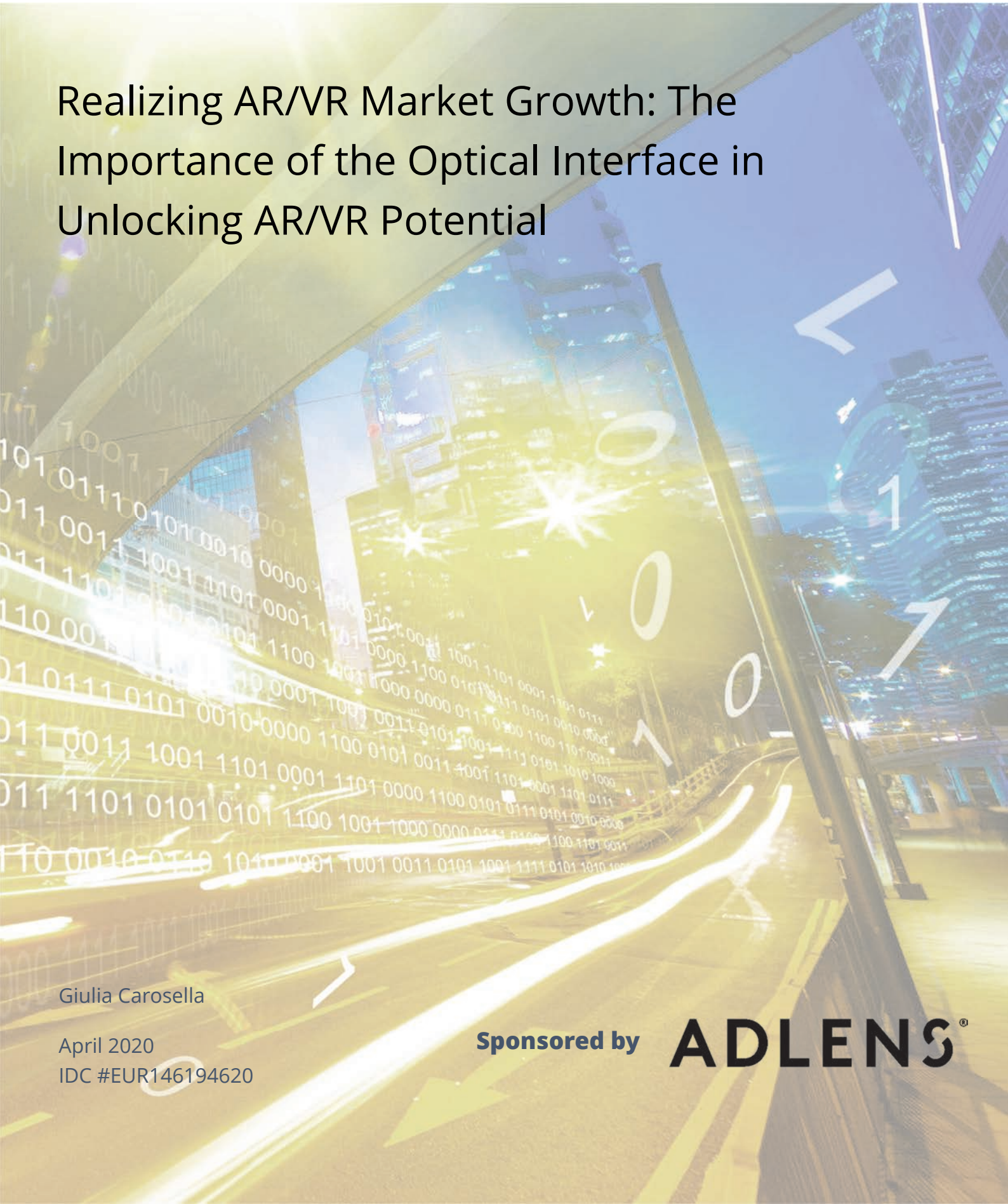
Realizing AR/VR Market Growth: The Importance of the Optical Interface in Unlocking AR/VR Potential



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Introduction

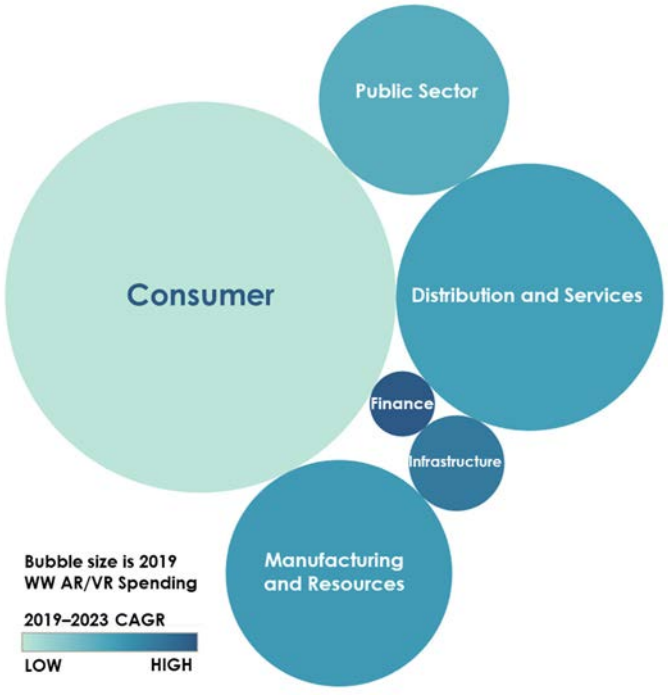
Market Overview

Augmented and virtual reality (AR/VR) technologies have the potential to truly change and empower the way we interact with our surrounding environment. The technology is progressively moving beyond its early stage and is providing opportunities for forward-looking companies from a range of businesses.

Despite their similarities, augmented and virtual reality technologies are showing different market dynamics in terms of industry applications, uptake, and challenges.

According to IDC's Worldwide Augmented and Virtual Reality Spending Guide, in 2019 VR accounted for 88% of the European AR/VR market of about $10.5 billion. Strong spending growth is also expected for AR technology, which is forecast to take over the market by 2022.

FIGURE 1
AR/VR WW Spending by Sector



Source: IDC WW Augmented and Virtual Reality Spending Guide, November 2019

AT A GLANCE

WHAT'S IMPORTANT

AR/VR technologies have huge potential, but they also face a number of challenges. Vergence-accommodation (VAC) and focal rivalry issues in particular are negatively affecting the AR/VR market, limiting device usability, prolonged use, real immersion, and accuracy. Adaptive focus lenses can tackle many of the challenges and are key to unlocking the true potential of AR/VR.

KEY TAKEAWAYS

- Solving VAC and focal rivalry issues will expand existing use cases and enable new use cases across different industries.
- Adaptive focus optics will play a major role in enabling AR and VR accessibility.
- Ecosystems of OEMs, developers, and optics and other component manufacturers will be key.

Spending on **VR solutions** is currently led by the **consumer market**, which accounted for 51% of the VR market in 2019, driven by gaming applications. VR uptake in commercial industries is more limited, due to major device challenges that still need to be overcome, even though some use cases such as training and product design and development show interesting pockets of growth.

AR spending is more commercial than consumer driven. **AR uptake** in **commercial applications** is taking advantage of AR glasses that have become lightweight and affordable, enabling ROI-proven use cases such as video and PDF step-by-step instructions and remote support from experts for maintenance and repair operations. Fully immersive AR commercial use cases, leveraging AR headsets such as Microsoft Hololens and Magic Leap, are more limited as they still face some major device challenges.

Crucial for expanding AR/VR technologies uptake in commercial applications is the ability to enable a series of use cases responding to clear business outcomes, from improving assembly, maintenance, and repair operations, to improving design and product development, from enhancing the performance and quality of service, to improving customer experience and engagement. According to the results of the recent IDC European Tech and Industry Pulse Survey, **21% of European companies** with more than 10 employees **are already using AR/VR** and only 4% are not familiar with the technology. The opportunities for both AR and VR are significant even though a number of major challenges are holding back mainstream adoption.

Current Device Challenges

There are still many challenges in the hardware space, including **weight**, **power consumption**, and **processing power** (which often require a tethered device to be connected to the headset); the **form factor trade-off** between wide field of view (FOV) and lightweight compact design; **brightness; resolution; latency**; and **aesthetic** design (which is particularly relevant in regions such as Western Europe). The optical interface is particularly important in addressing major challenges that currently inhibit the AR/VR market.

"Looking forward we will continue to invest in those same three categories. What you'll see in the next version is even more immersion, more comfort, and more applications that have more value. It's relatively easy to do any one of those things but it's hard to do all three."

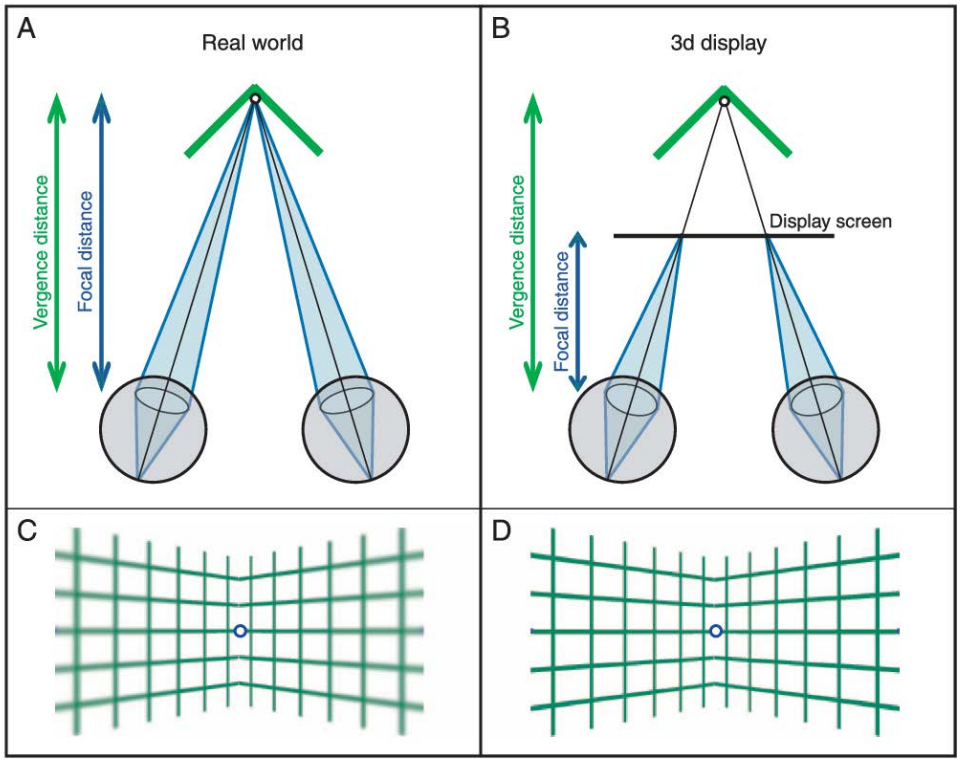
Communications Director, HMD Vendor

The **VR market** has grown steadily in recent years. The focus now is on improving end-user experience through more comfortable devices and enhanced interfaces. One of the main challenges in the space is solving the **vergence-accommodation (VAC) problem**, preventing prolonged use of the headset and imposing the "1-meter" barrier. In most of today's VR headsets, the optics are set to a single focal plane in the middle distance. Closer up, this forces users to decouple their natural accommodation response to vergence (the natural triangulation of the eyes as objects move closer or further away). The resulting mismatch makes VR feel visually unrealistic and can cause visual discomfort, eyestrain, and nausea, limiting the suggested

use to 20 minutes. In addition, VAC requires virtual content to be designed to stay at least 1 meter away and results in overall reduced immersion for users by limiting the brain's natural 3D spatial cues and making virtual space feel less realistic. This has obvious limitations across a range of industries and use-case scenarios and is especially important where VR is expected to be part of the regular working day.

FIGURE 2

Vergence and Focal Distance with Real Stimuli and Stimuli Presented on Conventional 3D Displays

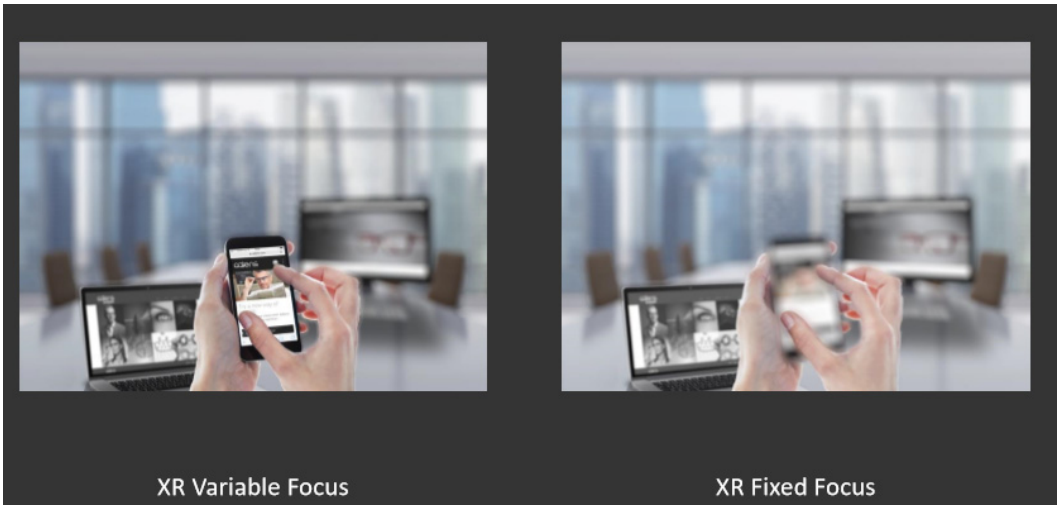


Source: Hoffmann et al (2008)

AR devices, particularly AR glasses, have been able to gain more ground in a business context as they are lightweight, comfortable, and particularly suitable for some use cases, above all step-by step instructions for assembly, maintenance, and operations. The uptake of more immersive headsets in the **AR market**, however, has been more limited due to another optics challenge, the **focal rivalry** issue, which prevents genuinely immersive experiences.

This issue is caused by the fact that with current viewers we can't integrate both virtual and real content in a seamless way unless they are in the same focal plane. Focal rivalry limits the ability to truly mix virtual and real objects in a realistic way, preventing the opportunity for a genuine mixed-reality experience. It has also been found to negatively affect performance of high-precision tasks. A study conducted by a research team at the University of Pisa found that it is not feasible to perform a high-precision AR task if content is placed within 2 meters of the person. This limitation negatively affects usage of AR devices in various verticals and use cases, particularly those relying on fidelity, precision, and accuracy.

FIGURE 3
Focal Rivalry, Real World/Virtual Phone — Near Focus



Source: Adlens, 2019

Cracking Existing Barriers to Device Challenges

Multiple **UX design best practices** that have emerged over the years have been used to mitigate the side effects of **VAC** and **focal rivalry**. These include:

- Using long viewing distances (having far focus cues)
- Moving digital content slowly in depth to give the eyes the time to adjust, or so quickly the blur is not noticed
- Minimizing conflicts by avoiding placing smaller overlapping objects at different depths
- Using shading to maximize the realism of other visual cues

Although UX best practices can mitigate the negative effects of the two problems, they cannot solve their root causes. Real solutions to the problems can be found only in the optics space. A number of studies, such as Matsuda et al (2017) and Stevens et al (2018), have reviewed the different hardware approaches to provide a comparison of the different options (see Table 1).

Light-Field Displays

Light-field displays (Lanman, 2013; Maimone, 2014) mimic the eye receiving the natural light-field data that we get normally from observing the natural world, and enable it to work with virtual content. Serious drawbacks with this approach are resolution and the computational power needed when using the state-of-the-art micro displays. Furthermore, light-field displays require tinted lenses which in AR seriously limit the user's ability to interact in a natural way with the surrounding environment.

Holographic Displays

Holographic displays use light diffraction to create a virtual 3D image of an object, providing realistic 3D scenes with full motion parallax and continuous depth cues. However, current wavefront limitations (including the limited number of pixels) in state-of-the-art holographic displays result in a narrow field of view and eye-box. Current computing power is also not up to the job of rendering real-time holographic content.

Multifocal Displays

Multifocal displays are systems with multiple fixed focal planes to collectively span the full depth range of the system. A major challenge with this approach is the minimum number of focal planes required. McKenzie et al estimated that at least five focal planes are needed to span the range of three diopters.

Dynamic or Varifocal Displays

Dynamic focus systems actively modify the focal depth of the focus plane of the display by using a variable focus lens in the display optics train. To choose the distance to which the focus should be shifted, a VR system must also incorporate eye tracking to monitor the gaze direction of the user. In AR, the system must monitor the gaze direction of both eyes to determine the vergence and/or must know the surrounding 3D environment so that the focal plane distance can be properly adjusted.

Video Pass-Through Displays

Visual or video pass-through displays capture through a camera a video of the real world and digitally combine it with digital content before redisplaying it to the user. In this way the users can see the "real environment" in a completely digital environment. These displays provide a shortcut to solve AR focal rivalry problems by eliminating the conflict with the real content and the latency between world imagery and virtual objects. However, they are more prone to distorting world imagery, and require more computing resources for video capture, processing, and rendering, and therefore causing lags in content while diminishing the perception of natural interaction and the resolution of the real world.

TABLE 1

Comparison of Different Approaches for VAC and Focal Rivalry

	Resolution	Field of View	Image Quality	Eye Box	Depth of Focus	Retinal Blur	Eye Tracking Required	Adaptive Lenses
Varifocal	High	Wide	High	Wide	Wide	Partially correct	Yes	Yes
Fixed multifocal	Moderate	Moderate	Moderate	Narrow	Moderate	Near correct	Yes	No
Adaptive multifocal	High	Narrow	High	Narrow	Wide	Near correct	Yes	Yes
Light-field: layered attenuators	Low	Wide	Moderate	Moderate	Wide	Near correct	Optional	No
Light-field: integral imaging	Moderate	Narrow	High	Moderate	Moderate	Near correct	No	No
Holographic	High	Narrow	Moderate	Narrow	Wide	Correct	No	Yes
Video pass through	Moderate	Narrow	Moderate	Narrow	Moderate	Partially correct	No	No

Source: Adapted from Matsuda et al (2017)

Drawing on the comparison carried out by the studies mentioned above, while different approaches can be effective in solving the VAC and focal rivalry issues, with the current technology only varifocal approaches maintain high resolution, wide field of view, high image quality, and wide eye-box. A key component of varifocal approaches is the **adaptive focus lens**. Stevens et al (2017) reviewed some of the possible technologies for adjustable lenses which include telescopes, fluid lenses, Alvarez lenses, and liquid crystals. A comparison of their main characteristics is provided in Table 2.

TABLE 2
Comparison of Adaptive Focus Lenses

		Adjustable Telescope	Fluid Membrane	Alvarez	Liquid Crystal
	Source	Ubiquitous	Adlens, Holochip	Adlens, Eyejusters	Deep Optics, E-Vision
	Cost	Low (mechanism)	Medium-high	Very low	Medium
Physical	Size	Large dimension along line of sight	Up to 80mm	200mm (power, thickness dependent)	~20mm for 3D
Physical	Share/boundary constraints	Arbitrary shape	Generally circular (Adlens: non-round)	Arbitrary shape	Currently formed in rectangular substrate
Physical	Thickness/weight	Heavy and bulky	Thin as a refractive singlet	1.5x–3x thicker than singlet	Very thin (Fresnel/ diffractive)
	Visual artefacts	Good paraxial, poor off-axis	None-refractive	Non-overlapping area, unusual reflections	FoV limit, diffractive
Optical	Transmission	High	>99% (2-surface AR)	99% (4-surface AR)	~80%
Optical	Abbe #	30–80	30–40	30–80	—
Optical	Range	High	15D (2 membrane)	50D (15 practically)	3D (diffractive)
Optical	Response time (fastest)	20–50ms	10–100ms	10ms (actuator dependent)	100ms (for 20mm, 3D)

Source: Stevens et al (2018)

Adjustable telescope lenses are a proven affordable technology but in terms of physical characteristics they are heavy, bulky, and are not compatible with the wide fields of view. Fluid-membrane lenses, however, have better characteristics in terms of thickness and weight, and are typically circular although non-round lenses are also feasible. The sophisticated materials and engineering required make these lenses more expensive. Alvarez lenses are more cost effective but slightly thicker than fluid membrane, and can be produced in any shape. The major challenges with these lenses relate to power range dependency and the optical aberrations in the non-overlapping area. The latter disadvantage is overcome in AR/VR headsets thanks to the form factor that places the lenses behind the aperture of the main objective lens. Liquid crystal lenses have attracted a lot of interest, with Facebook releasing a prototype of a varifocal headset with switching liquid crystal lenses, and Magic Leap holding some patents in this area. However, truly continuously adjustable liquid crystal lenses face some challenges, including optical power range, field-of-view, and response-time trade-offs.

"There's a chicken-and-egg problem: software developers don't want to invest big dollars in creating XR experiences until they see that the hardware is selling, but people won't want the hardware until there are plenty of games and entertainment to play on it."

UX Strategy Consultant, Freelance

A Closer Look at the Key Benefits Beyond the Challenges

Solving vergence-accommodation issues and focus rivalry challenges will create major opportunities for the market, and offer a series of benefits to VR and AR respectively. In the **VR market** solving the vergence-accommodation challenge will:

- **Reduce discomfort** in using head-mounted displays, eliminating visual fatigue and all the other side-effects associated with **prolonged use** of the devices, such as headaches and nausea. This is crucial to unlock the potential of VR, turning VR headsets into **an all-day wearable** and driving mainstream adoption. This will be further enhanced by using particularly thin adaptive focus lenses that will enable the production of **lighter and thinner** devices.
- Enable **greater immersion**, overcoming the 1-meter barrier and enabling developers to design completely immersive user experiences.

In the **AR market**, overcoming the focal rivalry challenge will:

- Enable developers to accurately place virtual objects in the real world, unleashing truly mixed-reality experiences and **natural interactions** with both real and digital objects.
- Improve **accuracy**, overcoming the 2-meter barrier and enabling the performance of high-precision tasks in the near field of view with a strong impact on commercial applications.
- Improve device usability through the production of **lighter and thinner** devices.

Adaptive-focus-lens benefits go beyond the ability to sustain and nurture AR/VR market potential, generating enormous opportunities in terms of **accessibility**, enabling developers to configure and personalize devices according to personal prescriptions and eye shape. This will make AR/VR devices accessible to everyone and comfortable for all users, eliminating the discomfort of wearing personal glasses as well as the head-mounted displays, removing the risk of having eyewear glasses that don't fit with the device, and reducing the risk of scratching them. Statistics from the U.S. Vision Council suggest that 64% of U.S. adults wear eyewear to correct their vision, while in the EU the figure is 70% and in Asia 80% (with only 10% wearing contact lenses). Therefore, enabling access to the whole market means taking into account personal prescriptions and eye shapes — and adaptive focus lenses are key to this.

Taking AR/VR Use Cases to the Next Level

Use Case Trends

Solving these issues will lead to major opportunities for the market, expanding uptake of current use cases and unlocking new ones. The specific impact of adaptive optics will vary widely across industries and use cases.

In **VR**, minimizing physical and visual discomfort and increasing usability of devices will increase the likelihood of the device becoming an all-day wearable, particularly impacting those use cases requiring prolonged use of the viewers, such as product development and training. In addition, removing the 1-meter barrier and enabling more meaningful and closer interaction with the digital content will unleash full immersive experiences, which are expected to benefit both consumer entertainment and commercial applications. Examples are training applications, particularly in healthcare and manufacturing, but also digital twin simulations and product development applications where it is key to see every small detail (e.g., the quality of materials used) in engineering and luxury industries.

In **AR**, overcoming the focal rivalry challenge will positively impact those highly critical use cases where there is high cost per part, high precision required, and high risk of errors. This includes use cases such as design, especially in the automotive, aerospace, and luxury subindustries, but also in surgery and anatomy diagnostics in the healthcare space. At the same time it will enable more natural interactions between digital and real content, creating truly immersive experiences, with a positive impact for example on media and entertainment use cases.

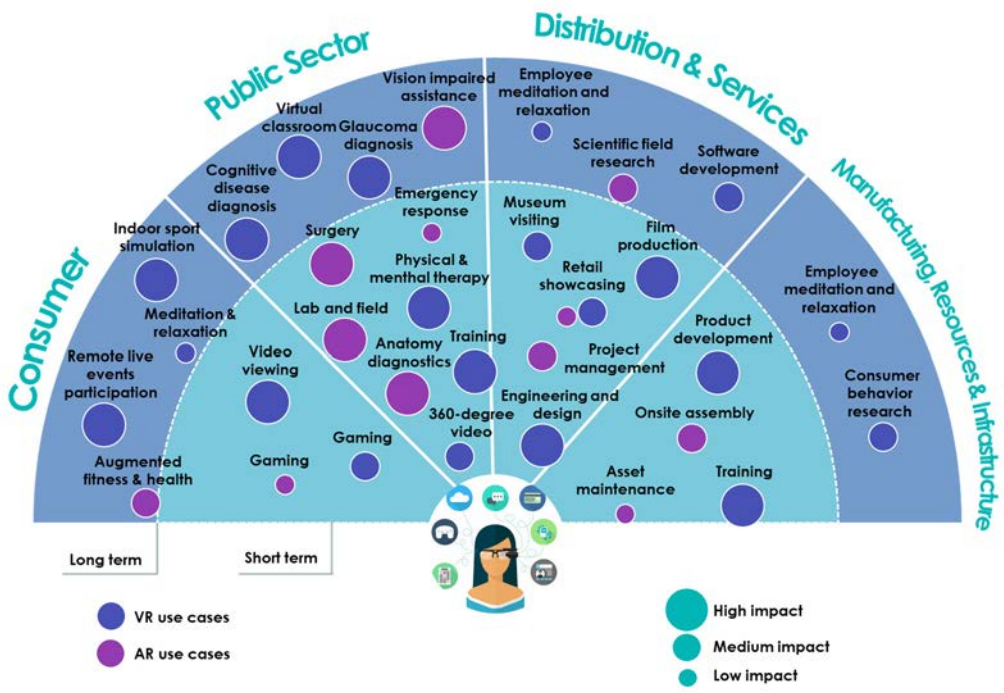
Figure 4 highlights the potential impact of adaptive optics in turbocharging existing use cases in the short term and pushing the new use cases in the long term. The analysis focuses on selected use cases by sector.

Four sectors have been analyzed, covering the entire market:

- **Consumer**, including the consumer industry
- **Public sector**, including healthcare, education, and government
- **Distribution and services**, including media, personal and consumer services, professional services, retail, transportation, wholesale, and finance
- **Manufacturing, resources, and infrastructure**, including construction, manufacturing, resource industries, telecommunications, and utilities

FIGURE 4

Impact of Adaptive Optics on Selected AR/VR Use Cases by Sector



Note: The impact on use cases has been analyzed in terms of time (short versus long term) indicated by the distance of each use case from the center of the circle and the level of impact (from low to high) indicated by the size of the bubble.

Source: IDC augmented humanity research, 2020

Consumer

In the consumer market adaptive optics show a lot of potential for use cases that take advantage of prolonged use, more interactivity, and where compatibility with personal prescriptions is crucial. In the short term we expect the impact to be greater in video-viewing use cases where issues with device comfort and usability are limiting mass market opportunities. In **VR gaming** we expect a medium-level impact considering that the gamer community has already adopted the technology, so barriers to adoption are lower, even though we expect benefits in terms of enhanced game experience. The impact on **AR games** is forecast to be lower, as the AR gaming market is still limited and a major driver for mass adoption is expected to be the progressive integration of AR features in mobile applications. In the longer term, we expect adaptive optics to unlock and sustain several use cases enabled by having lighter and enhanced optic devices that can be worn all day long. This includes using AR to enhance **fitness experiences** with real-time data such as weather and terrain conditions, running or cycling paths, analytics, and health data.

On the VR side, new use cases include **indoor sports simulations** that simulate outdoor environments and courses, **remote live event participation** (enabling consumers to virtually attend live events such as concerts and sports matches), and **meditation and relaxation** applications leveraging VR for more immersive and personalized mindfulness exercises. In the longer term, the impact is expected to be greater on indoor sports simulations and remote live event participation considering the average time spent and importance of embedding personalized prescriptions in the viewer.

Public Sector

The public sector offers a wide range of use cases that could benefit from adaptive focus lenses both in the short and long term. In the short term, for VR the biggest opportunity is expected in **training**, especially surgical training, considering the average length of surgical operations, and **physical and mental therapy**, which also require prolonged use of the viewer. In the therapy space, improved device usability could particularly benefit use cases involving children, such as distraction therapy, where VR is used to help children cope with a painful or difficult situation. Up till now, device usability challenges have raised concerns around whether it was appropriate or not to have children using it.

On the AR side, the main benefits are expected in use cases where there is high precision needed, where there are high costs from mistakes, and where there is a need to interact closely with digital content, such as **surgery** and **anatomy diagnostics** in the healthcare sector. **Lab and field**, in the education sector, is also considered a very popular use case requiring high interaction and precision. It involves the use of AR to promote learning in hands-on environments including nature/biology, mechanics/engineering, and health/medicine, as well as machinery, materials, production, and agriculture. In the longer term, new use cases are forecast to emerge and take advantage of advances in optics. These include using AR to assist people with impaired vision and using VR for early detection of eye diseases such as glaucoma and cognitive disease such as Alzheimer's, enabled by analyzing patients' behavior and responses to virtual stimuli.

Distribution and Services

The distribution and services sector covers several industries with multiple AR/VR applications. In the short term, advances in adaptive optics are expected to drive **engineering and design** use case in the professional services industry, where VR enables users to virtualize drawings with 3D imaging to improve overall efficiency and quality throughout multiple stages of a project. This use case applies to both professional designers and other stakeholders in the project including investors, builders, financers, community members, and vendors. Adaptive optics can boost this use case by enabling designers to work long hours and make live changes to designs. Similar benefits also apply to the media industry where advanced lenses can improve production processes in **film production**. A medium-level impact is forecast for the **museum and gallery visiting** use case in the personal consumer industry, where advanced lenses are expected to improve visitors' experience but with a lower impact than in the previous use cases considering the different amount of time required by the use case.

On the AR side, among the use cases with a medium-level impact there is **project management**, where AR is used to situate an architectural design onto the live site for planning and management purposes. This includes improving processes for change management orders as well as design flaw identification and overall project management objectives. New high-potential use cases unlocked by optics development include **scientific research**, using AR to visualize and analyze complex phenomena where it is crucial to interact with digital content and analyze both the big picture and the small detail. On the VR side, it is worth mentioning the opportunities in **live coding and software programming**, where adaptive focus lenses can enable faster

feedback, enabling developers to program in a virtual world, quickly identify bugs, and interactively modify their work.

Manufacturing, Resources, and Infrastructure

Adaptive optics in the manufacturing, resources, and infrastructure sector offer significant potential in expanding use cases such as **product development** and **training** in the VR space. Removing the 1-meter barrier will unleash those manufacturing applications where it is key to see every small detail, such as the different components and the quality of the materials and fabrics used for product design in the luxury, automotive, and aerospace subindustries. Advances in optics can also drive further expansion of training, increasing the average number of hours for employee training, making it more programmatic and part of companies' talent development plans rather than being ad hoc or occasional. This will particularly benefit hands-on learning of (virtual) physical objects that include tools, equipment, and materials.

On the AR side, greater precision will be beneficial for construction and manufacturing use cases that leverage AR to carry out **maintenance** tasks and **assembly** of components, especially when instructions come in the form of text and when operations are related to critical assets such as aircraft assembly and maintenance in the aerospace subindustry. New emerging use cases in the sector include employee meditation and relaxation, and **consumer behavior research**. This manufacturing use case relates to the use of VR enhanced by adaptive optics and eye tracking to capture users' reactions to and behavior around virtual stimuli, for example product shelf designs and in-store layout — critical in the fast-moving consumer goods (FMCG) subindustry.

The Importance of the Ecosystem

Driving AR/VR market growth by developing a use case road map will also require AR/VR market players to think about the role and relevance of other **ecosystem players** in their go-to-market strategies. Hardware, components, software, content, and services can no longer be seen in isolation and should now be seen as mutually dependent ingredients in the recipe for AR/VR market success. Traditional partner ecosystems of hardware, software, and service providers are also changing to include **new players and influencers** to leverage **deep expertise and co-creation**. Optics and eye- and hand-tracking tech manufacturers, developers, human behavior research centers, language and speech research centers, and vertical-specific players such as clinics and medical institutes for health devices are becoming increasingly relevant to provide enhanced solutions and improved user experience and to unlock new opportunities for the market.

From this perspective, adaptive focus optics provide a wide range of benefits to other AR/VR ecosystem players. For headset manufacturers, adaptive lenses offer a unique opportunity to differentiate from competitors and create new monetization opportunities from prolonged use of the technology and a broader range of use cases and applications. Similarly, developers will have more opportunities in terms of content creation, removing any restriction in terms of UX design, and in revenue opportunities from new and enhanced applications. There will be some additional benefits for the content production process itself, making it more comfortable and more natural for the developers working with the technology.

"The industry has to change the way we design, and that has required a shift in skills. I do hiring for the team and I see we need more of a hybrid of design and engineering talent. Because we are so constrained in our control of the technology, we need people who are technically savvy and understand the basic performance issues, and also the user's needs, in order to make trade-offs."

Design Lead, Software Provider

Adlens Solutions for Adaptive Optics

Adlens, born out of Oxford University 15 years ago, develops lenses that change focus just like the human eye — enhancing vision in AR, VR, and eyewear. Using adaptive focus lenses, the company entered the AR and VR market to solve the key challenges that are limiting AR and VR market potential. In particular, it aims to leverage the potential of adaptive focus lenses to tackle the problems that are affecting three markets: **virtual reality**, **augmented reality** (called mixed reality), and **reality** itself. Different advanced lenses solutions have been developed by the company to address these markets.

FIGURE 5
Adlens Core Technologies

Source: Adlens, 2019

In **VR**, Adlens is developing **SEE (stimulated eye engagement) technology** based on **Alvarez lenses**, which reengages the natural accommodation response to enable the human eye to focus on virtual content in a natural way, restoring the natural link between vergence and accommodation. This aims to:

- Enhance believability and immersion by reengaging the brain's natural 3D spatial cues
- Relieve the eyestrain and nausea that typically restrict usage to 20 minutes
- Remove the 1-meter barrier that limits engagement with virtual content and restricts potential commercial uses

In 1Q19 the company completed proof of concept and internal trials and is now working on a demo-kit product.

In **AR**, Adlens is developing **DFI (dynamic focal integration) technology**, based on **fluid filled** technology, to enable better ophthalmic experiences. The company owns several patents, including a material IP to enable large lenses for ophthalmic use, and actuation for non-round lenses, which is crucial to fit the human face. The technology overcomes the focal rivalry issue, making it possible to place real and virtual objects together accurately and believably in the real world to create a genuine mixed reality.

Inspired by the science of sight, Adlens has a broader mission to drive the uptake of adaptive lens technology to improve vision in general and promote access to vision correction. Leveraging adaptive focus lenses, it is developing solutions to be used in regular eyewear to solve presbyopia, the long-sightedness that naturally occurs in most middle-aged people.

Challenges

While Adlens' technology has the potential to overcome major challenges in the AR/VR market, its success will depend on its ability to:

- Identify and leverage in **go-to-market messaging** the use cases that are expected to benefit most from adaptive focus lenses
- **Educate the market** around AR/VR opportunities from enhanced optics
- Establish **key partnerships** with other ecosystem players
- Help solve other device challenges such as **weight** and **power consumption**

Conclusion

AR and VR technologies have the potential to be real game-changers, but there are some major challenges that need to be overcome. Challenges such as VAC and focal rivalry are limiting usability, true immersion, natural interactions, and the degree of accuracy. While some cost-effective UX design best practices have emerged to mitigate these challenges, solving the problems will require a rethink of the hardware approach, leveraging advanced optics solutions. Solving these challenges will unleash market potential by turbocharging existing use cases in the short term and unlocking new use cases in the longer term.

On the VR side, greater usability and prolonged use of the technology will particularly benefit use cases such as training and product development in the manufacturing, resources, and infrastructure sectors, and in mental and physical therapy in the public sector. In the AR space, greater accuracy in placing digital objects and improved accuracy will support use cases in surgery and anatomy diagnostics in the public sector.

IDC expects the AR/VR market to reach $128 billion by 2023, driven by multiple technology factors such as the ability to overcome current device challenges. Adaptive focus lenses have great potential to help solve some major optical challenges in the space and help unlock market growth, generating new opportunities for the broader AR/VR ecosystem.

Definitions

We have used the following definitions in this document:

- **Augmented reality (AR)** technology overlays digital content onto a user's view of the real world. Different devices can be used to this end, including headsets, smartphones, or tablets.
- **Virtual reality (VR)** technology immerses the user in a completely virtual world, using a headset, screenless viewer, tethered device, or head-mounted display.
- **Use cases** are funded projects that support a business goal and are aimed at fulfilling a strategic priority. Examples include training, industrial maintenance, and assisted surgery.

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Giulia Carosella is a research analyst for IDC's European Customer Insights & Analysis group. She leads the augmented humanity research, analyzing the impact of emerging technologies such as AR/VR and wearables on shaping human senses, capabilities, and insights.

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