Augmented, Virtual & Extended Reality (AR, VR & XR)

From Immersive Experiences to Intelligent Spatial Computing

CS202 Lecture 26

Sequence of Presentation

What are **AR, VR and XR**?

Key **Benefits** & Real-World Applications

State-of-the-Art **Technologies** & Platforms

Future Directions & Research Opportunities

Comparative View: AR vs VR vs XR

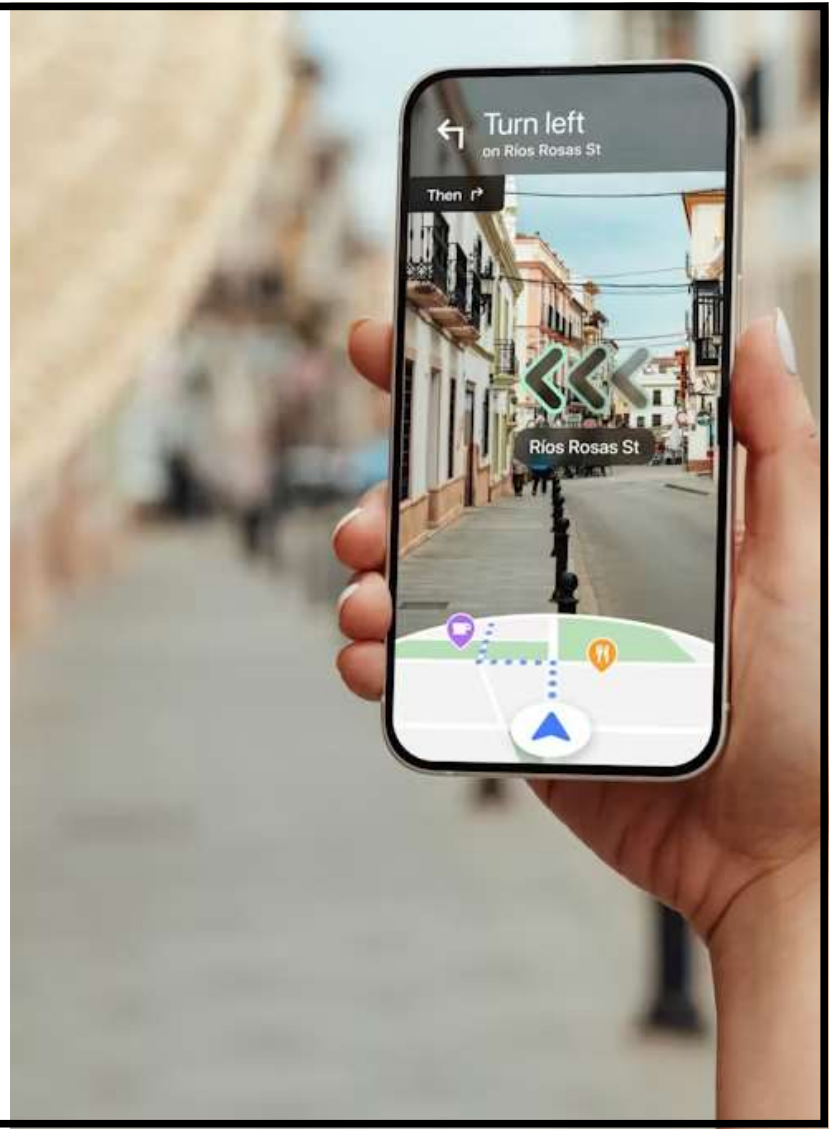
Challenges & **Concluding** Insights

Augmented Reality (AR)

Definition: AR overlays digital information (text, 3D objects, audio) on top of the real world in real time.

Key characteristics:

- Real-world view remains visible
- Digital content is registered to real space (tracking & alignment)
- Typically delivered via smartphones, tablets, smart glasses, or head-mounted displays



Augmented Reality (AR)

Enabling technologies:

- Computer Vision & SLAM (Simultaneous Localization and Mapping)
- Spatial Computing, Sensors (camera, IMU, GPS)
- Cloud Connectivity & AI for Recognition and Interaction (TECHi)

Benefits of AR

Enhanced perception & understanding

- Information in context (on-machine, on-patient, on-product)

Hands-free guidance & productivity

- Ideal for maintenance, assembly, remote assistance

Better learning & training

- Visual step-by-step explanations and simulations

Improved customer engagement

- Interactive retail, product visualization, “try before you buy”

Safer operations

- Overlay hazards, instructions or warnings in real time

Real-World AR Examples

Industry & manufacturing

- Technicians wearing AR glasses to see overlayed assembly steps or wiring diagrams

Healthcare

- AR-guided surgery, vein visualization, anatomy education with 3D overlays (Qodequay)

Retail & e-commerce

- IKEA-style “place furniture in your room”; virtual try-on for glasses, shoes, cosmetics (MagineU)

Navigation & logistics

- Indoor AR navigation in airports, malls, hospitals with arrows overlaid on the floor (TECHi)

Education

- Interactive textbooks where pointing the camera shows 3D models, simulations, and animations

AR State-of-the-Art (2025)

High-end spatial computing headsets

- Apple Vision Pro blurs AR/MR with high-resolution passthrough and spatial apps (Reydar)

AR wearables & smart glasses

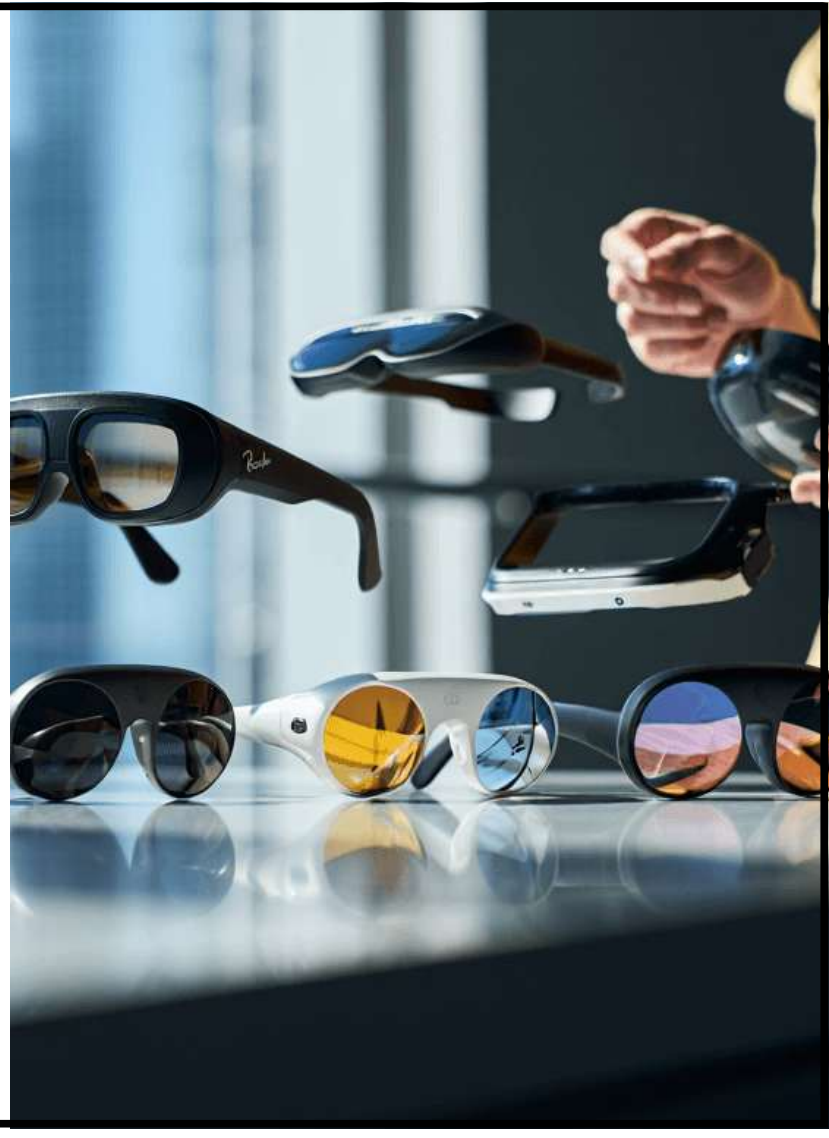
- Warby Parker + Google AI-powered AR smart glasses targeted for 2026, built on Android XR and Gemini AI (Reuters)

WebAR & AR Cloud

- AR experiences running directly in the browser and global 3D maps of the world for persistent content (MagineU)

Industrial AR platforms

- Enterprise solutions integrating AR with ERP/PLM systems for field service and manufacturing (Qodequay)



Future Directions in AR

Everyday AR wearables

- Lightweight, all-day smart glasses for notifications, translation, navigation and contextual AI assistance (Reuters)

AI-native AR experiences

- Scene understanding, object recognition, and conversational agents blended into physical environments

Persistent shared AR worlds

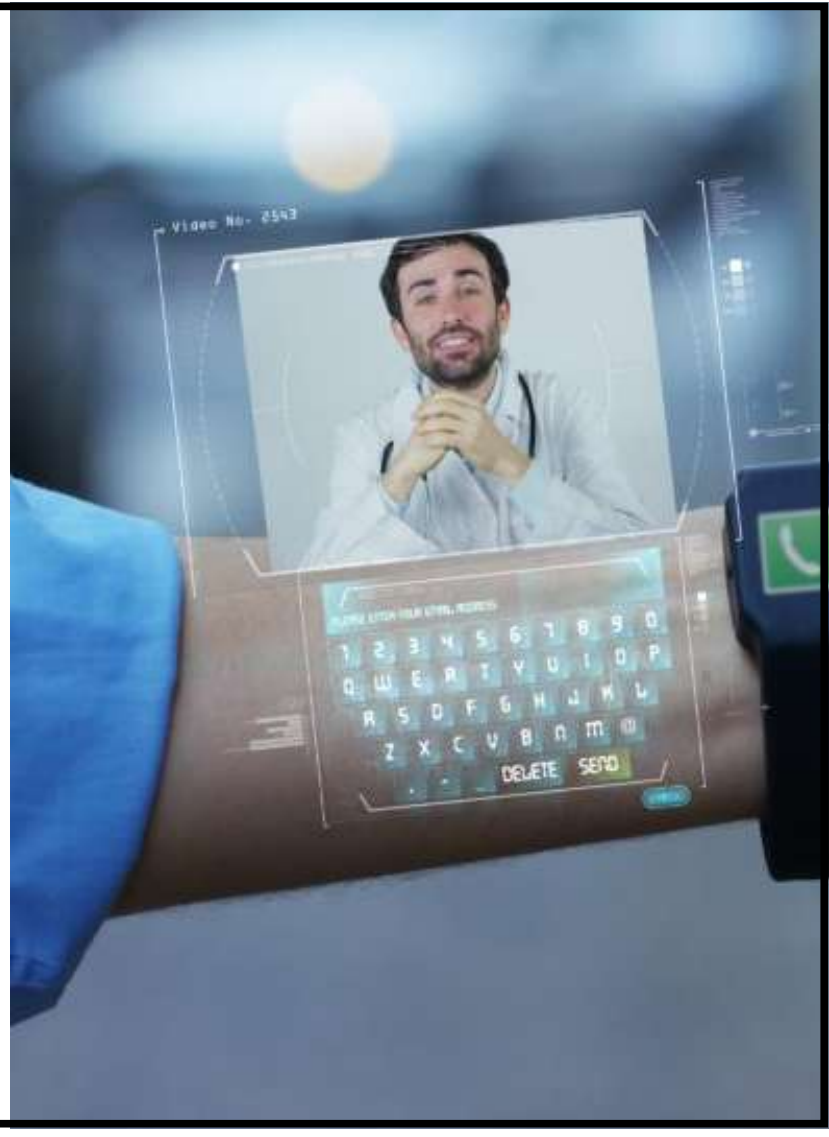
- Multi-user AR where digital content is anchored long-term to real locations (AR cloud / spatial anchors) (MagineU)

Vertical-specific innovation

- AR in surgery, remote diagnostics, precision agriculture, smart factories

Improved ergonomics & privacy

- Battery life, comfort, eye-health and responsible handling of spatial data (faces, interiors, objects)



What is Virtual Reality (VR)?

Definition:

VR immerses the user in a completely computer-generated environment, blocking out the physical world.

Key characteristics:

- 360° visual and auditory immersion
- Head-tracking and motion-tracking
- Interaction via controllers, hand-tracking, or full-body tracking

Typical hardware:

Head-mounted displays (e.g., Meta Quest 3, HTC Vive XR Elite, Apple Vision Pro in full VR mode) (technologicinnovation.com)

Benefits of VR

Full immersion & presence

- Strong sense of “being there” in simulated environments

Risk-free training & simulation

- Practice hazardous or expensive scenarios virtually (surgery, firefighting, aviation)

Deeper engagement & motivation

- Gamified, exploratory learning; compelling storytelling

Cost and time savings

- Virtual labs, virtual site visits, and virtual prototypes

Global collaboration

- Shared virtual meeting spaces for distributed teams

Real-World VR Examples

Education & training

- VR labs for STEM, history field trips, language immersion classrooms (Elite IT Team)

Healthcare

- VR-based therapy for phobias, Post-Traumatic Stress Disorder (PTSD), pain management

Industry & engineering

- Virtual prototyping, digital twins, safety training, equipment operation simulations (Vagon)

Entertainment & gaming

- Beat Saber-style rhythm games, VR e-sports, narrative experiences

Tourism & culture

- Virtual museum tours, historical site reconstructions

VR State-of-the-Art (2025)

Standalone, mixed-reality capable headsets

- Meta Quest 3, Pico 4, HTC Vive XR Elite, Apple Vision Pro offer higher resolution, inside-out tracking and passthrough mixed reality (technologicinnovation.com)

Cloud-streamed VR

- Cloud rendering allows complex VR apps without high-end GPUs locally (Vagon)

Enterprise VR platforms

- Specialized platforms for training, design review, and remote collaboration in architecture, automotive, and manufacturing (technologicinnovation.com)

Location-based VR arenas

- Dedicated VR entertainment centers and arenas for multi-user experiences; e.g., new VR arena developments in cities (The Times of India)

Future Directions in VR

Higher fidelity & comfort

- Lighter headsets, better optics, wider Field of View (FOV), higher refresh rates

Embodied interaction

- Full-body tracking, haptics, and physical props for more realistic interactions

AI-generated virtual worlds

- Procedural environments & characters generated in real time by AI

VR in mainstream education and workforce training

- Standardized curricula, accreditation, and integration with LMS/HR systems (Elite IT Team)

Social VR & the metaverse

- Persistent social spaces, events, and virtual economies

What is Extended Reality (XR)?

Definition:

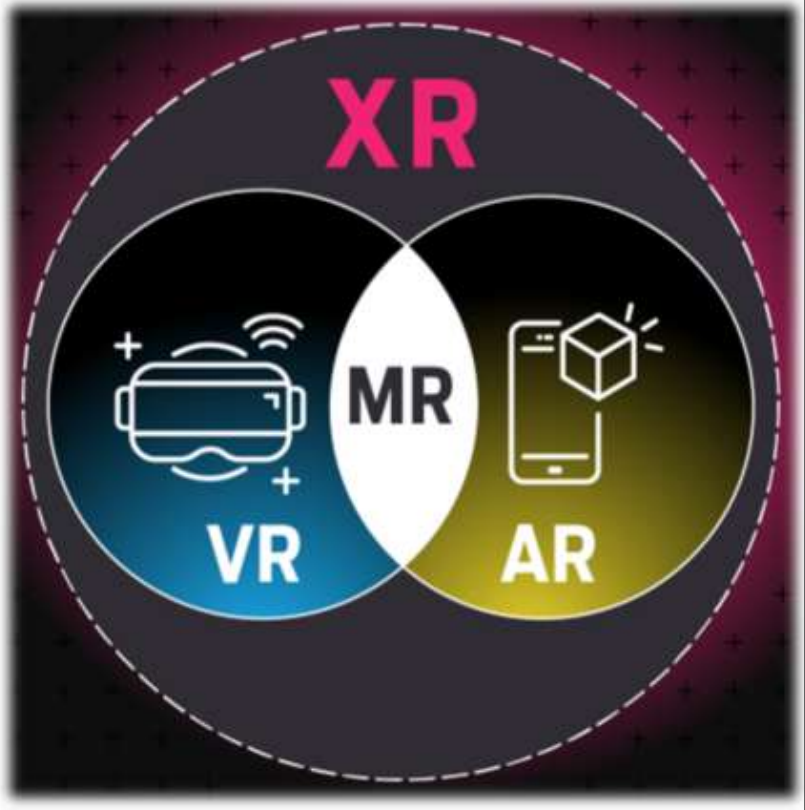
XR is an umbrella term that encompasses VR, AR and MR (Mixed Reality) — any technology that blends real and virtual environments. (MDPI)

Spectrum of immersion:

Real world ⟶ AR ⟶ MR ⟶ VR (fully virtual)

Mixed Reality (MR):

Digital objects anchor and interact with the physical environment (occlusion, physics, spatial audio, hand tracking).



Occlusion

- Technique that makes virtual content **realistically hide behind** real-world objects (or vice-versa)
- **Creating depth and immersion** by blocking parts of digital models with physical elements like tables, walls, or even your own hands
- To determine **what's in front and what's behind**
- **Without it,** virtual items appear as flat overlays, breaking the illusion of a shared space

Benefits & Use Cases of XR

Unified design & interaction space

- Same 3D assets reused across AR, VR and MR scenarios

Cross-industry applicability

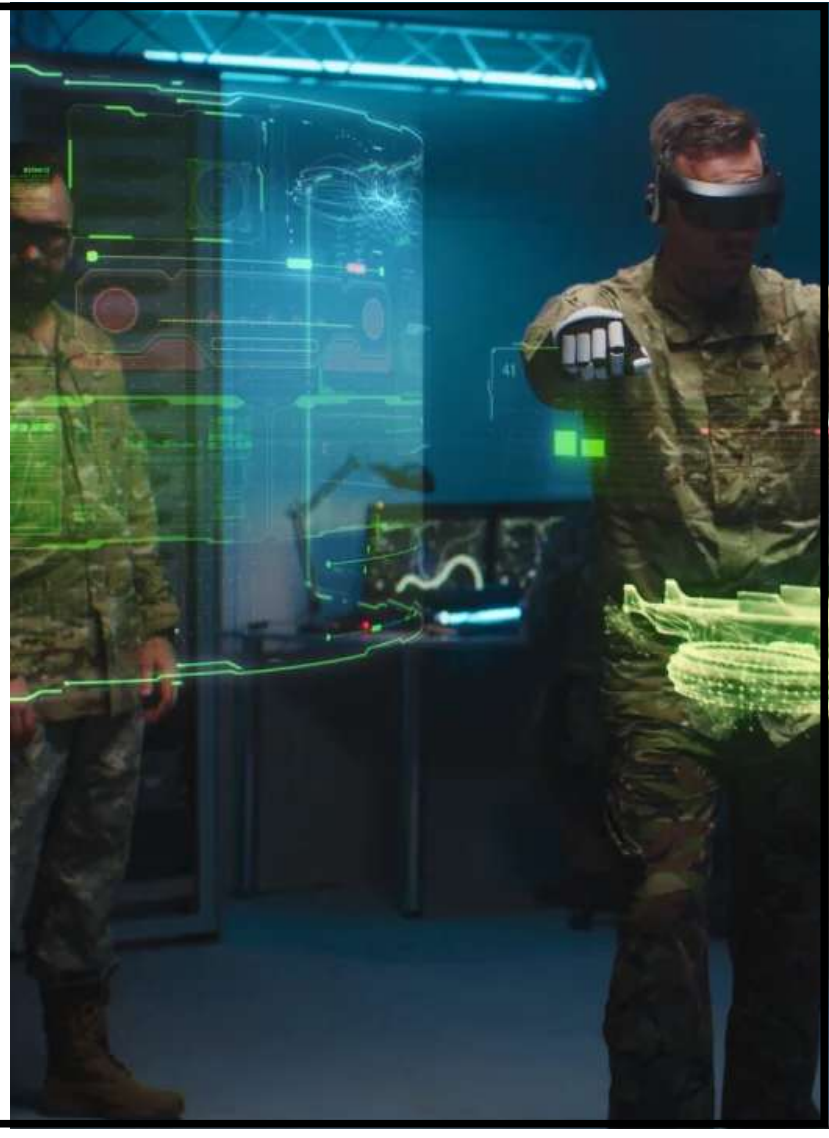
- Healthcare, education, retail, manufacturing, defense, entertainment, smart cities (StartUs Insights)

Blended workflows

- Example: Design in VR → review in MR → guide installation in AR

Improved decision-making

- Data visualized spatially (e.g., digital twins) for situational awareness



XR State-of-the-Art (Market & Technology)

Explosive market growth

- Global XR market was about USD ~142 billion in 2023, projected to exceed USD 1 trillion by 2030, with ~33% CAGR. (Grand View Research)
- Other reports project XR market > USD 100B by 2025 with ~35% CAGR from 2025–2033. (Data Insights Market)

Key technologies:

- Real-time rendering & spatial computing
- High-precision tracking, depth sensing, eye-tracking
- 5G/edge computing for low-latency experiences (StartUs Insights)

Applications:

- Healthcare, education, entertainment, industrial training, retail, tourism, defense (StartUs Insights)

Future Directions in XR

Convergence with AI & digital twins

- Intelligent agents inhabiting XR worlds; data-driven virtual replicas of factories, cities, and supply chains (StartUs Insights)

Interoperable XR ecosystems

- Open standards for assets, avatars, identity, and cross-platform experiences

Context-aware, personalized XR

- Experiences that adapt to user behavior, preferences, and physiological signals

Large-scale enterprise deployments

- XR as a standard tool for training, remote operation, and decision support

Ethics, safety & inclusivity

- Guidelines for motion sickness, mental health, accessibility, and responsible spatial data use

AR vs VR vs XR: Comparative View

Aspect	AR	VR	XR (incl. MR)
Reality Visibility	Real world + digital overlays	Only virtual world	Mix of real & virtual
Immersion	Low–medium	High	Medium–high (context-dependent)
Typical Hardware	Phones, tablets, smart glasses	Headsets (Head-Mounted Displays)	Advanced headsets, smart glasses
Main Use Cases	Guidance, info overlay, retail, navigation	Gaming, training, simulation, education	Complex workflows, collaboration, twins
Interaction	Touch, gestures, limited haptics	Controllers, hand tracking, body tracking	Spatial mapping, hand tracking, passthrough
Adoption Level	Growing fast in mobile & enterprise	Strong in gaming, rising in enterprise	Emerging, driven by enterprise & high-end

Key Challenges

1. Hardware cost, comfort, and battery life
2. Motion sickness and ergonomics
3. Content creation cost and skills gap
4. Interoperability & fragmentation of platforms
5. Privacy, security, and ethical concerns (spatial data, biometrics)

* **Ergonomics:** Designing workplaces to fit human well-being

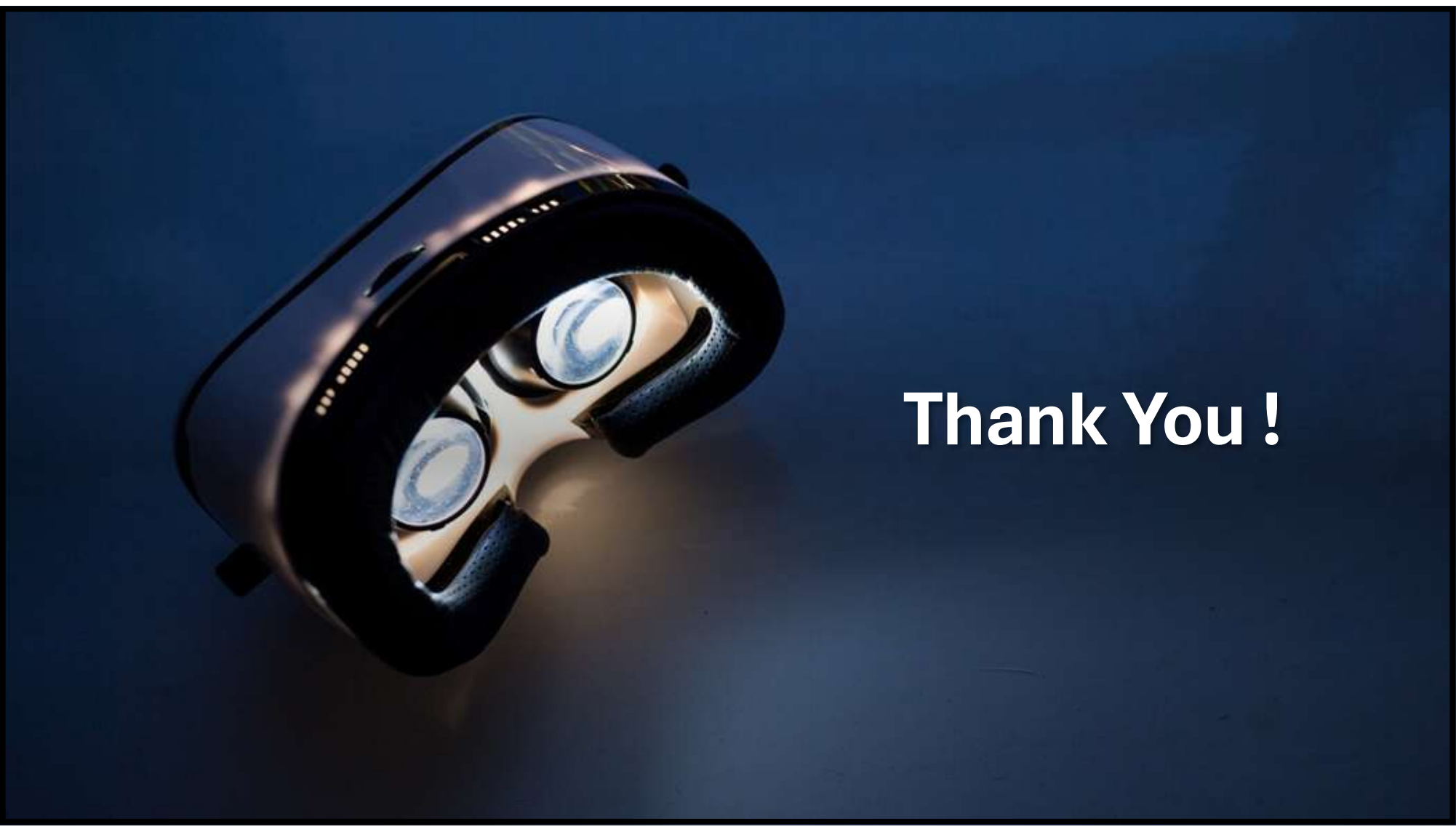
Conclusion

AR Augments Reality: Ideal for contextual information and field work.

VR Immerses Users: Powerful for training, simulation and experiential learning

XR Integrates AR, VR, and MR into a Continuum: Enabling end-to-end digital-physical workflows

Market Forecasts indicate Rapid Growth toward 2030: Making AR/VR/XR strategically important for education, industry and research. (PatentPC)


Thank You !