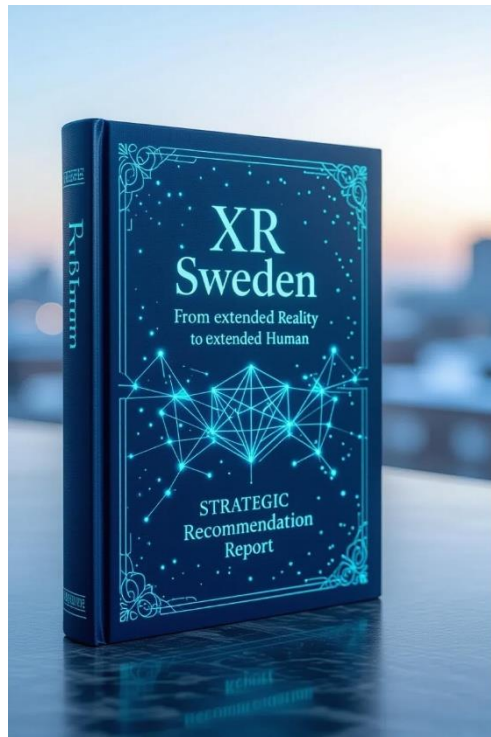


# **XR Sweden**

## **From extended reality to extended human**

### **Strategic recommendation report**



Annika Rickne, Eric Holmstedt, Per Johannesson, Mario Romero, Asreen Rostami, Fredrik Trella, Fredrik Viksten, Peter Westerdahl and Anders Ynnerman



## Background

This report 'XR Sweden: From extended reality to extended human - Strategic recommendation report' is a result of a feasibility study to design and assess a Swedish innovation platform for national resilience and sustainability within the transformative technology Extended Reality (XR) (Vinnova DNR 2024-02859).

The study was led by process manager Peter Westerdahl and Professor Annika Rickne at Visual Sweden. Based on extensive data collection, needs assessment, discussions, and interactions, the analysis was conducted by a collaborative team including Linköping University, RISE, SAAB, Meta, Ericsson, Volvo Cars, Siemens, Flowtropolis, the Swedish Police Authority, the Swedish Post and Telecom Authority (PTS), Invajo, Sweden Game Arena, Visual Sweden, WISDOME, Umeå University, Örebro University, KTH, Lund University, Malmö Museum, Universeum, Tekniska Museet, Norrköping Visualisering AB, WASP WARA Media and Language, InfraVis, AI Impact Lab, and other contributors from academia, industry, public organisations and civil society.

A detailed description of the analysis and results of the strategic forecasting - including a definition of the field, description of the sectors, trends, scenarios and strategic recommendations - can be found in the report 'XR Sweden: From extended reality to extended human - Trends & scenarios' (LiU DNR: ITN-2024-00481).

We invite you to read, reflect, reach out and engage in the process to enhance Swedish capabilities, actors base, innovations and international position within XR.

Peter Westerdahl  
Visual Sweden

## Authors and contributors

**Authors:** Annika Rickne, Linköping University, Eric Holmstedt, NOSP, Per Johannesson, Linköping University, Mario Romero, Linköping University, Asreen Rostami, RISE, Fredrik Trella, RISE, Fredrik Viksten, Linköping University, Peter Westerdahl Linköping University and Anders Ynnerman, Linköping University.

**Contributors:**

Magnus Ahlström, Vice President Global Innovation, SAAB  
Patrik Andersson, Senior Visualisation Artist & XR specialist, Volvo Cars  
Tomas Bendz, Chief Commercial Officer, Invajo  
Jan Bergdahl, Senior Adviser, Swedish Post and Telecom Authority  
Johanna Björklund, Associate Professor, WARA ML Processing, Umeå University  
Ulf Björkman, Head of System Management, Training and Simulation, SAAB  
Madelen Bodin, Director, Associate Professor, Curiosum, Wisdome Umeå, Umeå University  
Janne Elvelid, Head of Policy Meta Sweden and Finland, Meta  
Eric Ericsson, Strategy manager, Ericsson  
Mats Fastrup, Development Lead, Malmö Museum  
Carina Halvord, CEO, Universeum, Wisdome Göteborg  
Ylva Hansdotter, Co-Founder, Flowtropolis  
Emma Billington, Team Leader, Concept and Marketing Simulators, SAAB  
Eric Holmstedt, Project Manager, Visual Sweden  
Lena Klasén, Research Director, Swedish Police Authority  
Mikael Klintberg, Project Manager, Örebro University  
Jonas Kronander, Research Leader, Ericsson  
Lisa Lindgren, CEO, Norrköping Visualisering AB, Wisdome Norrköping  
Amy Loutfi, Director, Professor, Örebro University  
Kajsa M. Paulsson, Researcher, InfraVis, Lund University  
Andrii Matviienko, Assistant Professor, KTH  
Peter Skogh, Director, The National Museum of Science and Technology  
Sofia Sproge, Software Developer, SAAB  
Erik Sundén, Technical Director, Linköping University, Wisdome Norrköping  
Per Södergren, Head of Customer Technical Support, Siemens Energy  
Per Söderberg, Head of Digital PLM, Siemens Energy  
Marcus Toftedahl, Project Manager, Sweden Game Arena  
Jesper Wallerborg, Tech Lead, The National Museum of Science and Technology  
Maria Wirén, Head of Development and Learning, Universeum, Wisdome Göteborg  
Jonas Boström, Pedagog, Universeum, Wisdome Göteborg  
Anna Öst, Producer, Visualization Center C

## Table of Contents

<b>1. INTRODUCTION .....</b>	<b>5</b>
SWEDEN'S POTENTIAL IN XR AND THE IMPORTANCE OF INCLUDING HUMANS .....	5
OUR APPROACH .....	5
<b>2. NEEDS, TRENDS &amp; SCENARIOS .....</b>	<b>7</b>
WHAT DO WE MEAN WITH XR AND HOW IT RELATES TO AI? .....	7
TRANSITIONAL POTENTIAL .....	8
GLOBAL TRENDS: SOCIAL, TECHNOLOGICAL, ECONOMIC, ECOLOGICAL, POLITICAL .....	9
GLOBAL SCENARIOS ACROSS SIX CORE SECTORS .....	11
WHAT DOES SWEDEN NEED TO ENHANCE THE POSSIBILITIES AND GROWTH WITHIN XR? .....	12
<b>3. THE PROPOSED INNOVATION PLATFORM.....</b>	<b>14</b>
DOES SWEDEN NEED AN INNOVATION PLATFORM WITHIN XR? .....	14
OVERALL STRATEGY FOR THE XR SWEDEN INNOVATION PLATFORM .....	15
APPROACH OF THE XR SWEDEN INNOVATION PLATFORM .....	16

# 1. Introduction

## *Sweden's potential in XR and the importance of including humans*

Sweden has a great opportunity to reap the benefits from and lead the development within technologies and applications related to extended reality (hence XR). Already today, the Swedish research base is well advanced, and there are several companies developing applications in areas such as gaming, healthcare and industry. Importantly, in their quest to advance new solutions, companies as well as public organisations take the role as lead users and early adopters, thereby spurring the development and deployment.

The potential for products and services is wide spanning, and a range of consumer needs and societal challenges could be addressed. Indeed, the concept of XR has rapidly matured and expanded, from the XR technology itself to an XR ecosystem enhanced by e.g. AI technologies and multisensory, multimodal interaction. The path is moving from extended reality to what we may call 'extended human'. Development of technologies and applications are, however, in early phases, and the market is far from mature. Therefore, for Sweden to take an international position, urgent action is needed to pave the way and create XR readiness at all levels. It is essential to integrate human in the loop of XR applications to ensure ethical, user-centred innovation and effective support structures.

In this situation, it is important that Swedish policy has recognised the pervasiveness of the XR field and pushes for joint initiatives and investments. In particular, an innovation platform is seen as a main vehicle to move the area ahead, and shape Sweden's response in leadership, research, technologies, applications, market development.

## *Our approach*

This mission for this feasibility study was to define prerequisites for national readiness, sustainability and resilience for Sweden in the area of XR. The need for a national platform is underlined by the rapidly maturing technology and potential applications in a wide range of sectors. The current situation creates new opportunities for development, commercialization and market penetration of XR. This study thus aimed to lay the foundation for if a Swedish innovation platform for XR is called for, and what such a platform should contain and how it should be organised. We have called this platform 'XR Sweden'.

Our team brings perspectives from various technologies, products, sectors and regions, and builds on a close collaboration between experienced and well-established organisations: Visual Sweden, Linköping University, WISDOME, WASP WARA Media and Language, InfraVis, AI Impact Lab and RISE, SAAB, Meta, Ericsson, Volvo Cars, Siemens, Flowtropolis, The Swedish Police, PTS, Invajo and Sweden Game Arena. Within XR and AI, this constellation possesses world-class research and applied expertise, competence and long-term experience of leading innovation processes and platforms. The constellation also extends to a network of relevant actors, in a comprehensive range of sectors, partnering with research units, companies, public organisations and authorities across Sweden. An active Development Team ensured that all types of actors and perspectives are heard and considered. In addition, a wide range of Contributing Partners were involved in various tasks. The organisational inclusivity helps us to truly capture the Swedish position and needs, and gives a solid foundation for technology, product and market foresight, and high competence in, and experience of, analysis and strategic design of XR Sweden.

The study takes a research based and foresight-oriented approach and developed actionable recommendations for if and how XR Sweden could be developed and

implemented. Guided by strategic foresight, we focused on trend analysis, scenario building, agenda setting, stakeholder engagement, verification and organisational development. This structured approach ensured an inclusive and coordinated effort.

As a starting point for the work, we identified key enablers for the advancement of the XR concept in terms of technology trends, AI-driven solutions, multimodality, and distribution of resources. We also addressed issues related to privacy, security and ethics from a policy perspective. Based on the enablers and accelerators, and our collective competence, we systematically analysed trends and potential scenarios for a range of contexts, assessed the potential benefits of an innovation platform, detailed its content, structure and organisation, and assessed risk and contingencies. This resulted in a related report *XR Sweden From extended reality to extended human Trends and Scenarios*, and in enactable recommendations that create a foundation for a novel XR innovation platform, positioned in the fast-moving global context.

## 2. Needs, Trends & Scenarios

### *What do we mean with XR and how it relates to AI?*

Extended Reality together with AI technology redefines how information is experienced by enabling embodied interaction through gaze, gesture, spatial audio, sensing, smells, and shared digital environments. This mode of engagement restores subtle, non-verbal cues and allows participants to perceive each other at life-size, hear voices positioned in space, and interact with shared digital artefacts. The result is a heightened sense of co-presence and a more intuitive interface for engaging with both people and AI systems. When algorithms are represented as spatial collaborators, users interact with data through natural modalities (gesture, voice, and visualization) making the exchange more fluid and perceptive. The expressive bandwidth of XR surpasses traditional formats: a picture may convey more than words, a video more than pictures, and an interactive application more than video. XR environments extend this progression further, offering experiences that are too complex to capture in text alone.

Technologically, XR systems are composed of multiple interdependent layers. They begin with sensing and interpreting the real world through devices such as cameras, depth sensors, IoT nodes, haptic wearables, displays, and actuators. These components serve as the system's sensory and output channels, capturing geometry, motion, voice, and biometrics, and delivering forces, sound, and light back to the user. At the core are XR engines that transform raw signals into structured, computable knowledge. Functions such as viewpoint matching, object detection, segmentation, tracking, SLAM, and 3D reconstruction convert sensor data into geometry, textures, physics, and sound. Rendering, real-time simulation, and spatial audio generate immersive environments. These modules also capture user interaction (gaze, hand poses, controller states) and feed it back into actuators or AI services, maintaining responsiveness and presence.

XR Fusion refers to the integration of XR with AI-driven agents and generators. This convergence enables immersive environments enriched with real-time analysis, data fusion, and generative content. The fusion layer is supported by trained AI models that provide reasoning, representation, and generation capabilities, enhancing the XR experience with semantic interaction and adaptive support.

From a technical perspective, AI bolsters XR via computer vision algorithms for real-time object detection, tracking, and 3D reconstruction using for example simultaneous localization and mapping (SLAM), enabling precise digital overlays on physical environments. Generative models like GANs and diffusion techniques create adaptive content such as avatars and simulations, personalized through reinforcement learning. Explainable AI (XAI) integrates with XR for transparent multimodal interactions, like NLP-powered gesture and voice recognition, reducing biases in applications such as industrial and therapeutic systems.

Surrounding the core XR technologies are enabling systems that extend functionality and scalability. These include edge and cloud rendering for performance distribution, high-speed connectivity (5G/6G), generative AI for content and graphics enhancement, blockchain and NFT-based commerce rails, security and privacy frameworks, and data platforms for digital twins. These components ensure that XR sessions can be distributed across devices, personalized, synchronized, and verified. The overall system operates through a continuous flow of sensing, simulation, knowledge generation, fusion, augmentation, actuation, perception, and human interaction. Each component contributes to a loop where real-world events are captured, interpreted, enhanced, and responded to, either through digital

feedback or physical action. This structure enables XR to function as a responsive and intelligent interface between the physical world, digital systems, and human users.

### *Transitional potential*

Sweden is poised to lead a renaissance through the transformative potential of Extended Reality (XR), which spans virtual, augmented, and mixed reality. Rather than driven solely by technological advancement, XR's momentum in Sweden is propelled by societal and user demand. The country's strong international research position in human-centred XR, visualization, and image analysis, combined with dynamic experimentation across both large and small companies, positions it as a global leader. As hardware and development costs decline, especially with generative AI, XR is expected to revolutionize key sectors including information and communication technology (ICT), education, healthcare, industrial manufacturing, games and culture, and public services.

**ICT and XR** forms and will form a symbiotic engine for digital transformation. ICT provides the infrastructure, software, and connectivity essential for distributed XR systems, while XR reshapes ICT by introducing spatial computing, multimodal interfaces, and real-time collaboration. This convergence accelerates adjacent technologies such as edge computing, 5G/6G, and digital twins, transforming ICT into a dynamic infrastructure for extended human experience. In **education**, XR enables immersive classrooms, vocational simulations, and lifelong learning platforms. It supports adaptive learning, identity exploration, and collaborative research, with initiatives like WISDOME, Expert Learning Lab (ELL), and Wadströms Exploratorium Laboratory showcasing its impact on STEM outreach and national competence development.

In **industrial manufacturing**, XR enhances efficiency and innovation through virtual prototyping, AR-guided assembly, and VR-based training. Companies like Volvo, Epiroc, AstraZeneca and Siemens Energy use XR for remote diagnostics, predictive maintenance, and human-robot collaboration. XR also enables mass customization, allowing customers to co-design products in immersive environments. As XR becomes embedded across the industrial value chain, it supports safer training, distributed design collaboration, and AI-guided maintenance. Swedish firms, startups, and universities co-develop XR platforms aligned with Industry 5.0, advancing sustainability, competence development, and global competitiveness. Public organisations and policymakers play a key role in scaling adoption through shared infrastructure, funding, and regulatory alignment, ensuring inclusive access and long-term impact.

In **healthcare**, organisations such as the centre for medical image science and visualization (CMIV) and Karolinska Institutet integrate XR across clinical, educational, and research domains. XR supports surgical planning, AR-assisted navigation, and VR-based training, while also advancing mental health therapies and rehabilitation. It improves accessibility through remote consultations and interfaces for individuals with cognitive or sensory impairments, aligning with Sweden's commitment to equitable healthcare.

The **cultural sector** embraces XR as a new expressive medium, transforming games, film, music, and art into immersive experiences. Sweden's renowned gaming industry and vibrant artistic community drive innovation in interaction models and content formats. XR enables embodied gameplay, emergent storytelling, and AI-driven narratives. Platforms like Wisdome promote accessibility, heritage preservation, and inclusive design. Artistic experimentation in XR influences other domains, enhancing industrial training, education, and healthcare through gamified environments and collaborative design spaces.

**Societal applications** include where public organisations and research units adopt XR to simulate complex systems, visualize data, and foster interdisciplinary collaboration. XR supports participatory research and public outreach in climate science, medicine, and urban development. In public services, XR enhances healthcare, police training, transport planning, and education. Museums and cultural venues use XR for virtual exhibitions and inclusive experiences. XR fosters social inclusion, empathy, and identity exploration, while supporting digital transformation and citizen engagement across municipalities. In urban planning, XR enables interactive design assessment and virtual exploration of proposed changes, aligning with smart city initiatives in Kista, Hammarby Sjöstad, Norrköping, and Gothenburg.

In the **civil-military interface**, XR strengthens preparedness through immersive simulations for defence, emergency response, and inter-agency coordination. It supports disaster training, first aid education, and strategic planning. XR also contributes to sustainability and the green transition by visualizing climate data, modelling environmental change, and educating citizens on biodiversity. These immersive tools facilitate ecological storytelling, behavioural change, and public engagement in climate governance. Through XR, Sweden can align societal goals with ecological action, driving innovation and shaping a future where imagination meets reality.

## **Global Trends: Social, Technological, Economic, Ecological, Political**

XR is rapidly evolving into a foundational layer of our digital society, shaped by five interdependent trend domains: social, technological, economic, ecological, and political. These forces collectively define the opportunities, risks, and strategic choices that will determine Sweden's position in the global XR ecosystem.

**Social trends** reveal a cultural shift toward digital-first lifestyles, virtual communities, and human-centred design. We seem to increasingly prefer virtual interaction for work, learning, and entertainment, driving demand for immersive platforms that support collaboration, identity expression, and community-building. Digital identities and virtual communities are central to how individuals connect and express themselves, influencing XR adoption. Expectations for intuitive, portable, and accessible XR devices are rising, while concerns around privacy, mental health, and digital addiction call for ethical design and responsible use. Businesses are adapting to hybrid work models and seeking XR solutions that enhance remote collaboration, reduce travel costs, and support scalable training. XR's potential to support mental health care and inclusive digital spaces positions it as a tool for wellbeing and social cohesion.

**Technological trends** accelerate XR's capabilities through convergence with AI, advanced computing, and real-time data. Breakthroughs in 5G and 6G, spatial computing, and generative AI enable more adaptive, personalized, and scalable XR experiences. Sweden's leadership in connectivity and open data infrastructure provides a strong foundation for innovation. Real-time data from public and industrial sources supports XR innovation when combined with edge analytics and generative AI. Spatial computing and 3D mapping are maturing, enabling precise interaction with physical environments. Portable hardware and head-mounted displays have evolved significantly, offering onboard computing and high-fidelity experiences. Neural interfaces and brain-computer integration are emerging, supporting adaptive training and entertainment. Generative AI transforms XR content creation, enabling rapid prototyping and democratizing development. However, the rise of proprietary platforms and closed ecosystems threatens openness, competition, and developer autonomy. Open standards and cross-platform interoperability are essential to sustaining innovation and developer freedom.

**Economic trends** show that XR hardware has become easier to use and more cost-effective, boosting uptake and deployment. XR is increasingly used in virtual communities and industrial productivity, with training, simulation, and digital twins driving adoption in manufacturing, logistics, and public services. Healthcare and gaming remain high-impact sectors, with XR supporting diagnostics, therapy, and immersive storytelling. Blockchain-based monetization models offer creators new revenue streams, embedding scarcity and royalty logic into virtual goods. These models enable creators to sell, rent, or license immersive assets across platforms, though they raise regulatory and ethical questions. Security threats in immersive environments escalate, with features of superrealism, such as realistic avatars and spatial audio enabling persuasive fraud and social engineering. Digitalization drives winner-takes-all dynamics, with dominant platforms capturing market share through scale and data feedback loops. XR inherits this structure with even greater switching costs due to volumetric assets and biometric data. Regional hubs and public-private collaborations are key to ensuring inclusive growth and exportable solutions. Continued support for academic research, early-stage ventures, and open standards is essential to sustaining XR's economic potential.

**Ecological trends** highlight the need to embed sustainability into XR's design and deployment. Energy consumption, e-waste, and hardware obsolescence are pressing concerns, especially in Metaverse-scale environments. Frameworks like C3Meta aim to create energy efficient XR systems. XR supports industrial green transition through workforce reskilling and energy optimization, particularly when integrated with digital twins. XR enhances environmental awareness and education through immersive experiences that communicate climate impacts and promote sustainable behaviours. It supports urban planning and architectural education by visualizing sustainable design choices. Remote work enabled by XR reduces travel and infrastructure needs, contributing to national climate targets and low-carbon workflows. Sweden's climate commitments and industrial transformation goals align well with XR's ecological applications, provided sustainability is prioritized from the outset.

**Political trends** shape XR through regulation, governance, and strategic investment. Data privacy, ethical AI, and platform accountability are central to emerging policy frameworks. Regional disparities in regulation complicate global collaboration, while standardization efforts like OpenXR and glTF offer pathways to interoperability. Public investment is shifting toward capital assets that deliver long-term savings, positioning XR as a fiscally responsible tool for municipalities and agencies. Sweden's proactive stance on digital sovereignty and innovation policy will be critical in navigating geopolitical tensions and platform dependencies. Ethical AI and the threat of deepfakes are gaining political urgency, prompting calls for transparency, accountability, and ethical standards. Standardization and interoperability are advancing rapidly and support innovation. Public investment in XR is shifting toward strategic capital allocation, with immersive systems delivering labour savings and faster service.

Thus, XR is no longer a niche technology but is becoming a foundational layer of digital society. Human-centred design and ethical safeguards are essential, with trust, wellbeing, and inclusion built into XR systems from the start. Open standards and interoperability are strategic imperatives to prevent fragmentation and monopolization. Sustainability must be embedded early, with energy use, hardware lifecycle, and ecological impact actively managed. Public-private collaboration is key to national leadership, with Sweden's innovation system supporting experimentation, regional hubs, and exportable solutions. Regulatory foresight and digital sovereignty will shape Sweden's global position, requiring active engagement in international standards and governance frameworks to protect national interests and democratic values.

## *Global scenarios across six core sectors*

Clearly, XR is positioned to become a foundational technology across Sweden's digital and societal landscape. The six scenarios developed for Sweden's core sectors illustrate how immersive technologies can support inclusive governance, sustainable development, and national competence, while identifying opportunities and risks. These scenarios are not predictions but possible or plausible futures we jointly can form, and that can guide innovation, policy, and collaboration.

In **ICT & digital infrastructure**, XR is integrated into platforms used by municipalities and national agencies to manage transport, energy, and emergency services through spatial data and immersive dashboards. These applications rely on high-speed connectivity, edge computing, and cloud systems. System integrators and platform providers enable deployment but face challenges with legacy systems and procurement. Hardware developers focus on durable, energy-efficient devices, while software developers build spatial interfaces and AI-driven tools. Data scientists and AI engineers apply predictive analytics, managing ethical risks tied to biometric data. Public organisations coordinate infrastructure investment and promote open standards. Policymakers and financiers support digital inclusion while navigating regulatory complexity. Professional users gain tools for oversight and collaboration, and citizens benefit from improved services, though digital literacy and access remain key concerns.

In **education and training**, XR is embedded across schools, universities, and vocational centres to support immersive learning, skills development, and lifelong education. It enables simulation-based training, adaptive tutoring, and remote access to complex subjects. Universities lead research and curriculum development, while vocational institutes use XR to prepare learners for roles in healthcare, manufacturing, and public services. Startups and content developers create modular learning tools and AI-driven tutors, often in partnership with educators. Hardware developers design classroom-ready devices, and software developers build platforms for personalized instruction. Public organisations invest in inclusive education and regional upskilling. Policymakers and financiers support infrastructure and pedagogical innovation, while navigating procurement and equity challenges. Teachers and trainers adopt new roles as immersive facilitators, and learners benefit from more engaging and accessible education, though disparities in access and digital competence remain.

In **industrial manufacturing**, XR supports workforce training, product design, and remote collaboration across large firms, SMEs, and startups. It enables virtual prototyping, immersive diagnostics, and AI-enhanced planning. Universities and research institutes co-develop training modules and ergonomic simulations with industry partners. Startups offer low-code XR tools and conversational interfaces for operators, while SMEs adopt XR to improve onboarding and safety. Hardware developers produce rugged, high-performance devices for industrial environments, and software developers build simulation platforms and collaborative design tools. Public organisations promote lifelong learning and industrial innovation. Policymakers and financiers fund pilot programs and support standardization. Engineers, technicians, and planners use XR to optimize workflows and reduce risk, while firms benefit from increased efficiency and reduced travel. Challenges include integration with legacy systems, skill gaps, and uneven access to infrastructure.

In **healthcare**, XR is integrated into clinical education, patient care, and public health outreach. It supports training for medical staff, intraoperative guidance, rehabilitation, and mental health interventions. Universities, regions, municipalities and hospitals collaborate on simulation-based learning and therapeutic applications. In this scenario, there are solutions for sharing and co-developing XR-based solutions in the public sector, both in terms of policy

and law, business models and sharing of resources between actors from different municipalities of regions. Startups develop AI-powered XR agents and immersive treatment environments, while SMEs adopt XR for onboarding and specialist training. Hardware developers focus on ergonomic, clinical-grade devices, and software developers build adaptive platforms for care delivery and patient engagement. Public organisations deploy XR for inclusive care and competence development. Policymakers and financiers support pilots and ethical frameworks, while navigating GDPR and procurement complexity. Healthcare professionals use XR to improve precision and empathy, and patients benefit from reduced anxiety and improved access. Key risks include data sensitivity, validation requirements, and uneven adoption across regions.

In **games and culture**, XR evolves into a medium for artistic expression, storytelling, and community engagement. Indie studios, cultural organisations, and cross-disciplinary teams create immersive experiences that blend performance, interaction, and generative content. Universities explore new dramaturgical formats and digital identity, while museums and venues use XR for outreach and education. Startups build creative automation tools and multiplayer platforms, and SMEs develop regionally relevant content such as heritage tours and interactive theatre. Hardware developers integrate multisensory tech into public spaces, and software developers support cross-platform creation and user participation. Public organisations commission XR works and promote cultural access. Policymakers and financiers invest in open infrastructure and ethical standards for biometric data. Artists and performers adopt hybrid roles in immersive production, and audiences engage through participatory formats. Challenges include market fragmentation, content moderation, and sustainable funding.

In **societal applications**, XR enables inclusive urban planning, participatory governance, and civil preparedness. Municipalities and agencies use XR to model traffic, simulate crises, and audit accessibility in collaboration with citizens. Universities develop tools for urban analytics and emergency training, while startups create modular applications for public consultation and environmental impact visualization. Defence and civil protection bodies use XR for multi-agency coordination and scenario planning. Hardware developers support location-based access and mobile deployment, and software developers build simulation platforms and inclusive interfaces. Public organisations coordinate cross-sector pilots and promote regional equity. Policymakers and financiers support strategic investment and ethical data use, while navigating regulatory complexity. Planners, responders, and citizens engage in co-creation and decision-making, though digital divides and infrastructure gaps remain barriers to full participation.

## ***What does Sweden need to enhance the possibilities and growth within XR?***

Our detailed study has revealed that to enhance the possibilities and growth of XR in Sweden, there are three main components that the actor in the ecosystem need: **a governance framework & arena, enhanced resources**, and **innovation support**.

A strong **governance framework** is needed to unite actors across academia, industry, public organisations, policy units, and support structures. This includes creating *neutral arenas* and events that foster *dialogue, collaboration, and shared learning*. A joint understanding must be developed around the opportunities and challenges facing developers, users, and civil society. Comprehensive *mapping and analysis* of XR in Sweden, covering research, technologies, infrastructure, actors, innovation processes, and system dynamics, should provide the foundation for *informed decision-making*. Policymakers and organisations must be made aware of the sector's needs and potential, and encouraged to act and invest accordingly. It is equally important to demonstrate how XR can address

societal challenges, and to ensure *regulatory stability* through mechanisms such as sandbox environments. Key regulatory concerns include privacy and data protection, intellectual property rights for virtual assets and digital twins, and ethical considerations around synthetic data, propaganda and deepfakes. It is also important to distinguish between propaganda and deepfakes, in the sense that the former is an intent along the lines of malign foreign interference: where someone does attempts to affect the political views or cause disturbances in our democratic system, where the XR content *could be* a deepfake. Deep fakes on the other hand can be used for other purposes like for example advanced identity theft, scamming and phishing. *Visibility and promotion* of XR must be strengthened, within the ecosystem itself, across Swedish society and policymaking circles, and internationally. A *national agenda* and shared strategic direction are needed, supported by a leading organisation or platform that works in close partnership with the ecosystem. A national innovation platform for XR can, for example, mediate the risks of becoming dependent on foreign suppliers.

The actors express that they need enhancement of **resources**. Sweden requires a *centralised knowledge depository* for XR domain expertise, encompassing research actors, applications, sectors, markets, trends, financing, and international collaborations. The *legitimation* of XR as a strategic field is vital. *Access to state-of-the-art infrastructure* such as research labs, physical infrastructure, open-source platforms, and tools must be expanded, with facilities open to companies, organisations, and the public. These spaces can serve as incubators for experimentation, learning, and testing, bridging the gap between research, education, and industry. Scaling up experimentation in technology and product development, commercialisation, and use is essential, along with ensuring the longevity of initiatives and investments. A *critical mass* of developers, particularly innovative firms, must be cultivated. Policy support and long-term *financing* are key, as is guidance on funding opportunities. This includes help identifying relevant national and European grants, coordinating and process support to strengthen innovation proposals. Strong *networks and collaboration* with *international* financiers and ecosystems will help Sweden remain globally connected and competitive. *Human resources* are equally important: Sweden needs access to talent, training programmes, and workshops that build XR and AI competence across sectors, from foundational knowledge to advanced development.

**Innovation support** is another cornerstone of XR growth. The innovation process encompasses the full iterative cycle of research, development, business modelling, market engagement and large-scale adoption. Strengthening these processes across the XR ecosystem will be key to unlocking Sweden's potential in immersive technologies. Sharing examples and *best practices*, ranging from research findings to industrial applications and business models, can inspire new directions and validate emerging approaches. Regular conferences, seminars, and *networking events* will foster collaboration and idea exchange. Businesses must be given *access* to cutting-edge academic *research*, while researchers need insight into *industry* and *societal needs*. *Joint research initiatives* between industry and leading academic organisations can accelerate development across the ecosystem. Facilitated workshops and seminars can help generate new ideas and identify promising XR applications. *Project matching* services and platforms can connect developers, researchers, users, and public sector actors based on shared interests and complementary expertise. This could include a searchable *database* of competencies and needs. *Access to prototyping environments* and *testbeds* is crucial for validating new solutions before scaling. Regional strengths and specialised expertise should be leveraged to build a diverse and resilient national landscape. Establishing arenas where businesses and the public can explore and experiment with technologies, products and services could support adoption and help translate scientific advances into practical use. Finally, targeted support is needed to address *market acceptance* and *adoption* challenges.

### 3. The proposed Innovation Platform

#### *Does Sweden need an Innovation Platform within XR?*

Clearly, Sweden has strong possibilities within the area of extended reality. We envision Sweden as a global leader in the development, application and use of XR and related AI-based visualization and interaction technologies. The focus for Sweden will be to move the area from extended reality to extended human. The country has world-class research, globally competitive companies in many of the leading sectors, a vibrant start-up scene, public organisations that act as early adopters and lead users, a competent and interested civil society, and financiers, support structures and policy organisations that see the importance of the field. Already today, XR-based solutions are applied across sectors such as ICT, education, healthcare, manufacturing, culture, and public services. These applications are not only technologically advanced but also marketwise and socially relevant, contributing to inclusion, sustainability, and national competence. However, the presence of potential does not guarantee progress. The question is not whether Sweden can lead in XR, but whether the ecosystem is equipped to fully realise its opportunities and address its challenges.

The answer from the ecosystem itself, and in particular from all the partners contributing to this study, is clear: Developers, researchers, public organisations, and policymakers consistently express the need for structured support. The XR landscape in Sweden is rich but fragmented. Even though there are some important co-development already in place, actors sometimes operate in silos, infrastructure is unevenly distributed, and strategic alignment is lacking. Without coordination, efforts risk duplication, momentum is lost, and opportunities are missed. What is needed is a collaborative structure that can bring together representatives from the public, private, and research sectors – from all sectors – from users and civil society - to identify needs, align priorities, facilitate innovative solutions, foster business opportunities, and jointly move Sweden forward. To strengthen national, regional and local initiatives is crucial to build national fortitude.

An innovation platform should act as a neutral arena to map, coordinate and market stakeholders; increase public understanding and acceptance; share best practice, use cases and success stories; discuss and alleviate hinders; form a national agenda for XR; access and share resources and infrastructure; enhance knowledge transfer and link knowledge, technology, strategy, and market opportunities; facilitate experimentation; accelerate technological and commercial development; contribute to regulatory frameworks; augment market adoption; illustrate benefits and effects of XR adoption and use; and strengthen international collaboration. The effects could be innovation, new business models, company growth, value for society, national resilience in XR, enhanced national Sweden's competence and competitiveness.

In conclusion, Sweden does not only have the potential to lead in XR—it has the responsibility to organise that potential into a coherent, inclusive, and resilient national effort. An innovation platform is the structure that can make this possible. It is not just a support mechanism, but the strategic vehicle needed to help the ecosystem grow, collaborate, and deliver lasting value to users, civil society, and the country. This goes hand-in-hand with important and high-profile investments such as Wallenberg's 'Spherical AI', the governments focus on 'Advanced Digitalization'. And without such an innovation platform, Sweden risks to lose out on opportunities and perhaps see stagnation of some parts of the industrial landscape, not gain access to international financing, or perhaps become too dependent on foreign suppliers.

## Overall Strategy for the XR Sweden Innovation Platform

The innovation platform is designed to support Sweden's ambition to become a global leader in the development, application, and responsible use of extended reality. The strategy is built on a clear understanding of the ecosystem's needs, the transformative trends shaping potential scenarios, and the platform's mission to empower the ecosystem, support innovation, and catalyse industrial and societal transformation. The platform which we call *XR Sweden*, will help Sweden take the lead in a field that moves from extended reality to extended human. The overall strategy of XR Sweden should therefore be structured around three pillars, and these should be coherently developed during the coming 10-year period.

The first pillar is to reinforce ***national engagement***, strategic ***coordination*** and ***leadership***. XR Sweden will act as a neutral and trusted platform, bringing together academia, industry, public sector, and civil society, ensuring representation and legitimacy.

The platform should:

- gather the ecosystem; provide a joint arena for dialogue and knowledge exchange across sectors, promote visibility;
- disseminate Swedish XR expertise through international events and networks; represent Sweden in global contexts;
- engage in policy dialogue; support public organisations with assessments and impact studies;
- coordinate a shared national agenda and roadmap that promotes sustainability, equality and is human centred; align efforts to reach this national strategy;
- engage in regulatory discussions, standardisation efforts and ethical frameworks.

The second pillar is to ***expand competence, infrastructure*** and ***resources*** throughout the entire country. Based on the strengths of existing XR-infrastructure partners such as the Wisdome sites, RISE, university labs and industrial facilities, the entire ecosystem can learn and grow. It is a matter of mapping the nodes and infrastructural resources, finding models for resource sharing, creating meeting places for innovation, and enabling regional and national collaboration.

The platform should:

- map and link to specific resource needs of all sectors;
- map and engage both national and regional hubs for infrastructure and competence
- facilitate knowledge and resource sharing; promote access to labs, software, development tools, etc.;
- support interdisciplinary education and training;
- connect actors to funding opportunities and innovation support structures.

The third pillar is to ***accelerate innovation, application, commercialization*** and ***use***. This is the engine of XR Sweden and ensures that XR technologies address pressing societal and industrial challenges, and the opportunity for Sweden to take international lead. XR Sweden should not develop or innovate but assist the ecosystem in these processes. It involves supporting the transition from research to real-world solutions by shortening the distance between concept and implementation, and by creating conditions for rapid development, testing, and deployment of XR solutions. Innovation and development will surely be strengthened by the other two pillars: For example, national leadership and international visibility is crucial to connect to development partners within EU and beyond.

The platform should:

- foster new ideas; promoting best practices and success stories to inspire new applications; enable project matching and enhance access to financing; identify shared interests and complementary expertise; connecting actors across sectors to form consortia and initiate joint projects;
- promote experimentation; facilitate collaborative innovation through workshops and co-creation labs; facilitating collaborative innovation through workshops, hackathons, and co-creation arenas;
- bridge the gap between cutting-edge research and industrial applications; provide access to testbeds and prototyping facilities for experimentation;
- support proof-of-concept development; enable rapid prototyping, use cases, user testing in controlled environments, business modelling and market tests.

### ***Approach of the XR Sweden Innovation Platform***

The innovation platform should be built on a long-term, inclusive, and strategically grounded approach that reflects the needs of the ecosystem, responds to global trends and scenarios, and supports Sweden's ambition to lead in XR. The strategy and activities of XR Sweden are grounded in theory and international best practice. The platform draws on state-of-the-art knowledge to guide its development, ensuring that Sweden's efforts are informed, credible, and globally competitive.

The design of XR Sweden is created by central actors from industry, academia, public organisations, etc. All types of actors in this ecosystem, users, policy and civil society must be continuously involved to ensure that we capture the dynamics of various sectors, the diversity of perspectives and needs, and maintain trust and legitimacy. The structure should be a neutral, transparent and trusted arena that enables collaboration across sectors and regions, while adapting to a rapidly evolving technological and societal landscape. The platform operates across a wide range of sectors, with focused efforts in ICT, education and training, societal applications, industrial manufacturing, healthcare, and games and culture. This breadth reflects the transformative potential of XR and the need for cross-sectoral collaboration.

The platform is designed to take national leadership, not through top-down orchestration, but through bottom-up coordination. It supports distributed initiatives and processes, recognising that each organisation, region, and sector has its own strategies, culture, and motivations. The platform facilitates collaboration rather than directing it, enabling actors to align around shared goals while maintaining autonomy.

At the core of the approach is a long-term vision, where XR Sweden should function as a learning organisation, where goals and activities are continuously refined in response to new insights, changing conditions, and emerging opportunities. Such an adaptive mindset ensures that the platform remains relevant and resilient over time.

# XR Sweden

## From extended reality to extended human

### Trends & scenarios



Annika Rickne, Eric Holmstedt, Per Johannesson, Mario Romero, Asreen Rostami, Fredrik Trella, Fredrik Viksten, Peter Westerdahl and Anders Ynnerman



## Background

This report '*XR Sweden: From extended reality to extended human - Trends & scenarios*' presents a detailed description of the analysis and results of a project on strategic forecasting for Extended Reality (XR). It includes a definition of the field, description of the sectors, trends, scenarios and strategic recommendations.

The study was led by process manager Peter Westerdahl and Professor Annika Rickne at Visual Sweden. Based on extensive data collection, needs assessment, discussions, and interactions, the analysis was conducted by a collaborative team including Linköping University, RISE, SAAB, Meta, Ericsson, Volvo Cars, Siemens, Flowtropolis, the Swedish Police Authority, the Swedish Post and Telecom Authority (PTS), Invajo, Sweden Game Arena, Visual Sweden, WISDOME, Umeå University, Örebro University, KTH, Lund University, Malmö Museum, Universeum, Tekniska Museet, Norrköping Visualisering AB, WASP WARA Media and Language, InfraVis, AI Impact Lab, and other contributors from academia, industry, public organisations and civil society.

A full presentation of the analysis and conclusions from the feasibility study to design and assess a Swedish innovation platform for national resilience and sustainability within the transformative technology Extended Reality (XR) (Vinnova DNR 2024-02859), can be found in the report '*XR Sweden: From extended reality to extended human Strategic recommendation report*' (LiU DNR: ITN-2024-00481).

We invite you to read, reflect, reach out and engage in the process to enhance Swedish capabilities, actors base, innovations and international position within XR.

Peter Westerdahl  
Visual Sweden

## Authors and contributors

**Authors:** Annika Rickne, Linköping University, Eric Holmstedt, NOSP, Per Johannesson, Linköping University, Mario Romero, Linköping University, Asreen Rostami, RISE, Fredrik Trella, RISE, Fredrik Viksten, Linköping University, Peter Westerdahl Linköping University and Anders Ynnerman, Linköping University.

**Contributors:**

Magnus Ahlström, Vice President Global Innovation, SAAB  
Patrik Andersson, Senior Visualisation Artist & XR specialist, Volvo Cars  
Tomas Bendz, Chief Commercial Officer, Invajo  
Jan Bergdahl, Senior Adviser, Swedish Post and Telecom Authority  
Johanna Björklund, Associate Professor, WARA ML Processing, Umeå University  
Ulf Björkman, Head of System Management, Training and Simulation, SAAB  
Madelen Bodin, Director, Associate Professor, Curiosum, Wisdome Umeå, Umeå University  
Janne Elvelid, Head of Policy Meta Sweden and Finland, Meta  
Eric Ericsson, Strategy manager, Ericsson  
Mats Fastrup, Development Lead, Malmö Museum  
Carina Halvord, CEO, Universeum, Wisdome Göteborg  
Ylva Hansdotter, Co-Founder, Flowtropolis  
Emma Billington, Team Leader, Concept and Marketing Simulators, SAAB  
Eric Holmstedt, Project Manager, Visual Sweden  
Lena Klasén, Research Director, Swedish Police Authority  
Mikael Klintberg, Project Manager, Örebro University  
Jonas Kronander, Research Leader, Ericsson  
Lisa Lindgren, CEO, Norrköping Visualisering AB, Wisdome Norrköping  
Amy Loutfi, Director, Professor, Örebro University  
Kajsa M. Paulsson, Researcher, InfraVis, Lund University  
Andrii Matviienko, Assistant Professor, KTH  
Peter Skogh, Director, The National Museum of Science and Technology  
Sofia Sproge, Software Developer, SAAB  
Erik Sundén, Technical Director, Linköping University, Wisdome Norrköping  
Per Södergren, Head of Customer Technical Support, Siemens Energy  
Per Söderberg, Head of Digital PLM, Siemens Energy  
Marcus Toftedahl, Project Manager, Sweden Game Arena  
Jesper Wallerborg, Tech Lead, The National Museum of Science and Technology  
Maria Wirén, Head of Development and Learning, Universeum, Wisdome Göteborg  
Jonas Boström, Pedagog, Universeum, Wisdome Göteborg  
Anna Öst, Producer, Visualization Center C

## Executive summary

Sweden is poised to become a global leader in Extended Reality (XR), leveraging its strong research base, innovative industry, and public sector engagement. This foresight-oriented report outlines how XR technologies are evolving into a foundational layer of digital society, with transformative potential across sectors. XR is no longer confined to hardware and software but is increasingly shaped by AI, multimodal interfaces, and human-centred design. The fusion of XR with adjacent technologies such as AI, 5G/6G, digital twins, and generative content creation enables immersive environments that enhance communication, training, decision-making, and collaboration.

The report identifies five key trend domains, **social, technological, economic, ecological, and political**, that influence XR's trajectory. Socially, XR supports digital-first lifestyles, inclusive education, and mental health care. Technologically, Sweden's leadership in connectivity and open data infrastructure accelerates XR innovation. Economically, XR is gaining traction in industrial manufacturing, healthcare, and gaming, though challenges remain in scaling adoption. Ecologically, XR contributes to sustainability through remote work, energy optimisation, and environmental education. Politically, emerging regulations and public investment shape XR's governance and strategic direction.

Six scenarios illustrate XR's future impact:

1. **ICT Infrastructure** – XR becomes a civic utility for public services and decision-making.
2. **Education & Training** – XR transforms learning through immersive, adaptive, and inclusive platforms.
3. **Industrial Manufacturing** – XR enhances design, training, and operations, supporting Industry 5.0.
4. **Healthcare** – XR improves clinical training, patient care, and remote access.
5. **Games & Culture** – XR evolves into a collective medium for storytelling and artistic expression.
6. **Societal Applications** – XR supports inclusive urban planning, crisis response, and civic engagement.

Strategic conclusions emphasise the need for open standards, ethical design, sustainability, and public-private collaboration. Sweden's innovation ecosystem must continue to support experimentation, regional hubs, and exportable solutions. XR is not just a technology but an enabler of extended human experience, societal resilience, and sustainable transformation.

## Table of contents

<b>1. INTRODUCTION .....</b>	<b>6</b>
<b>2. XR &amp; ITS TRANSITIONAL POTENTIAL .....</b>	<b>7</b>
HOW XR CHANGES COMMUNICATION .....	7
WHAT DOES EXTENDED REALITY ENTAIL? .....	7
TRANSITIONAL POTENTIAL .....	10
LEADING APPLICATION FIELDS AND SECTORS .....	11
<b>3. TRENDS .....</b>	<b>15</b>
SOCIAL TRENDS .....	15
TECHNOLOGICAL TRENDS .....	16
ECONOMIC TRENDS .....	18
ECOLOGICAL TRENDS .....	20
POLITICAL TRENDS .....	21
CONCLUSIONS ON THE FUTURE OF XR .....	22
STRATEGIC CONCLUSIONS .....	23
<b>4. SCENARIOS.....</b>	<b>24</b>
XR AS A BACKBONE OF ICT INFRASTRUCTURE .....	24
XR IN EDUCATION AND TRAINING: TRANSFORMING LEARNING ACROSS SWEDEN .....	27
XR IN INDUSTRIAL MANUFACTURING: ENABLING A SMARTER, SAFER, AND MORE AGILE PRODUCTION ECOSYSTEM .....	31
XR IN HEALTHCARE: ENHANCING CARE, COMPETENCE, AND ACCESS ACROSS SWEDEN .....	34
XR IN GAMES AND CULTURE: A MATURING MEDIUM FOR COLLECTIVE CREATIVITY .....	37
XR IN SOCIETAL APPLICATIONS: BUILDING INCLUSIVE, RESILIENT, AND DATA-DRIVEN COMMUNITIES .....	40

## 1. Introduction

Sweden is well positioned to lead the development and adoption of extended reality (XR) technologies and applications. The country already benefits from a strong research base and an emerging industry landscape, where both companies and public organisations act as lead users and early adopters. These dynamic fosters innovation, accelerates deployment, and strengthens Sweden's competitiveness.

Immersive technologies hold transformative potential for industries central to Sweden's sustainability agenda, including healthcare, education, manufacturing, and urban planning. XR applications can enhance human capabilities, workflows, improve training, and reduce resource use and environmental impact. In healthcare, XR supports remote diagnostics and skills development; in education, it enables immersive learning; in manufacturing, it optimises processes; and in urban planning, it empowers citizen participation in decision-making.

The scope of XR extends far beyond technology itself. What began as hardware and software development has rapidly evolved into a broader ecosystem, increasingly shaped by AI, multisensory interfaces, and multimodal interaction. This progression marks a shift from *extended reality* to what may be described as *extended human*.

To define the prerequisites for national readiness, sustainability, and resilience in XR, we have assembled a diverse consortium representing leading expertise across research, industry, and the public sector: Visual Sweden, Linköping University, KTH, Lund University, RISE, WISDOME, WASP WARA Media and Language, InfraVis, AI Impact Lab, SAAB, Meta, Ericsson, Volvo Cars, Siemens, Flowtropolis, the Swedish Police, PTS, Invajo, and Sweden Game Arena. Collectively, this group brings world-class research capacity, applied expertise, and long-term experience in driving innovation and building platforms. The analysis presented here takes a research-based, foresight-oriented perspective. It identifies key enablers for XR advancement, such as emerging technology trends, AI-driven solutions, multimodality, and resource distribution, and systematically explores potential scenarios for their application across different contexts.

## 2. XR & its transitional potential

### *How XR changes communication*

Extended Reality (XR) is more than a new technology. It reshapes how we communicate, collaborate, and engage with information. Unlike traditional media, XR does not just transmit information; it *embodies* it. By enabling natural interaction through gaze, gesture, spatial audio, and shared environments, XR restores much of the tacit communication that is lost in today's flat-screen telepresence. Participants perceive one another at life-size, hear voices in space, and interact with the same digital artefacts, creating a genuine sense of co-presence despite distance.

This embodied presence strengthens empathy, trust, and collaboration, while also opening new forms of interaction with AI systems. When algorithms are represented as spatially present collaborators, users can engage with data through natural cues, gesture, voice, and visualization, making human-AI collaboration more intuitive and powerful. From a purely information bandwidth perspective, if a picture is worth a thousand words, then a video is worth a thousand pictures, an interactive application a thousand videos, and an XR environment yet another order of magnitude beyond. Even today's prototypes deliver experiences far too complex to capture in text, underscoring XR's unparalleled potential to convey information and context.

Societal, environmental, educational and industrial applications and implications are equally significant. For example, when design reviews, surgical rehearsals, or board meetings in XR become as effective as physical meetings, the need for travel is reduced, leading to climate change reduction. At scale, XR-enabled telepresence becomes a structural lever for reducing emissions, while also countering social fragmentation by fostering authentic interaction across distances. XR can be used in a broad range of educational and industrial contexts, to create and experience situations which may be difficult or dangerous to interact with in reality. In this way, XR should be seen not only as a communication tool, but as an enabling infrastructure that supports innovation, sustainability, and societal cohesion.

### *What does Extended Reality entail?*

Effective XR solutions depend on far more than traditional VR-headsets. They require sensing and interpreting the real world, robust real-time engines, intuitive interaction models, and knowledge from fields such as cognitive science and pedagogy. These are supported by a constellation of adjacent technologies that provide bandwidth, intelligence, and economic incentives.

An XR system connects the physical and digital worlds through equipment such as cameras, depth sensors, IoT devices, haptic wearables, displays, and actuators, as well as through the users themselves. These devices act as the system's eyes, ears, and hands, capturing geometry, motion, voice, and biometrics, while also delivering forces, sound, and light back to the user. In the technology model, these real-world links are shown as the *world*, *augmented world*, *robotics/actuators*, and *human interface* (yellow circles in the diagram).

At the centre are the **core XR technologies**: the engines that transform raw signals into computable knowledge. Functions such as viewpoint matching, object detection, segmentation, tracking, simultaneous localization and mapping (SLAM), and 3D reconstruction convert sensor data into geometry, textures, physics, and sound. Rendering, real-time simulation, and spatial audio then create believable immersive environments. These modules also capture user interaction (e.g. gaze, hand poses, controller states) and feed it back into actuators or AI services, ensuring responsiveness and presence.

**XR Fusion** describes the convergence of XR with AI-driven agents and generators. This synergy enables immersive environments enriched with real-time analysis, data fusion, and generative content. The result is highly interactive, data-rich visualizations with applications in design, training, healthcare, and beyond, though continued progress in hardware, accessibility, and scalability remains essential.

XR Fusion is the integration of XR with AI and unlocks powerful applications across industries:

- *Immersive Design & Prototyping*: Architects and engineers can optimize designs with AI and review them at full scale in XR, identifying errors early and reducing costs.
- *Real-Time Data Visualization*: In complex domains such as fusion energy or logistics, XR can display live sensor and simulation data, while AI detects anomalies and predicts outcomes.
- *Training & Simulation*: AI-enhanced XR environments provide adaptive, risk-free training for surgeons, pilots, or factory workers, tailoring scenarios to user performance.
- *Retail & Marketing*: AI insights into customer preferences combined with XR virtual try-ons and immersive product demos increase engagement and conversion.
- *Healthcare*: AI-processed medical data can be visualized in XR for diagnostics, surgical planning, and enhanced clinical decision-making.

**XR-adjacent technologies**, surrounding the core, are enabling capabilities that do not *define* XR, but super-charge it. It can involve edge/cloud rendering, 5G/6G connectivity, generative-AI agents and generative-AI for content creation or graphics enhancements, blockchain/NFT commerce rails, security & privacy layers, and data platforms for digital twins. These components add scale, intelligence and business logic, ensuring that an XR session can be shared across devices, personalised by AI, settled in real currency, and audited for trust.

Figure 1 illustrates a dynamic and continuous interaction between the physical world, digital systems, and human users. By reading the diagram from right to left one can trace how real-world events are sensed, interpreted, and acted upon through XR and AI technologies with human in the loop. Imagine a technician turning a valve in a factory and continuously updates on new information by prompting or talking.

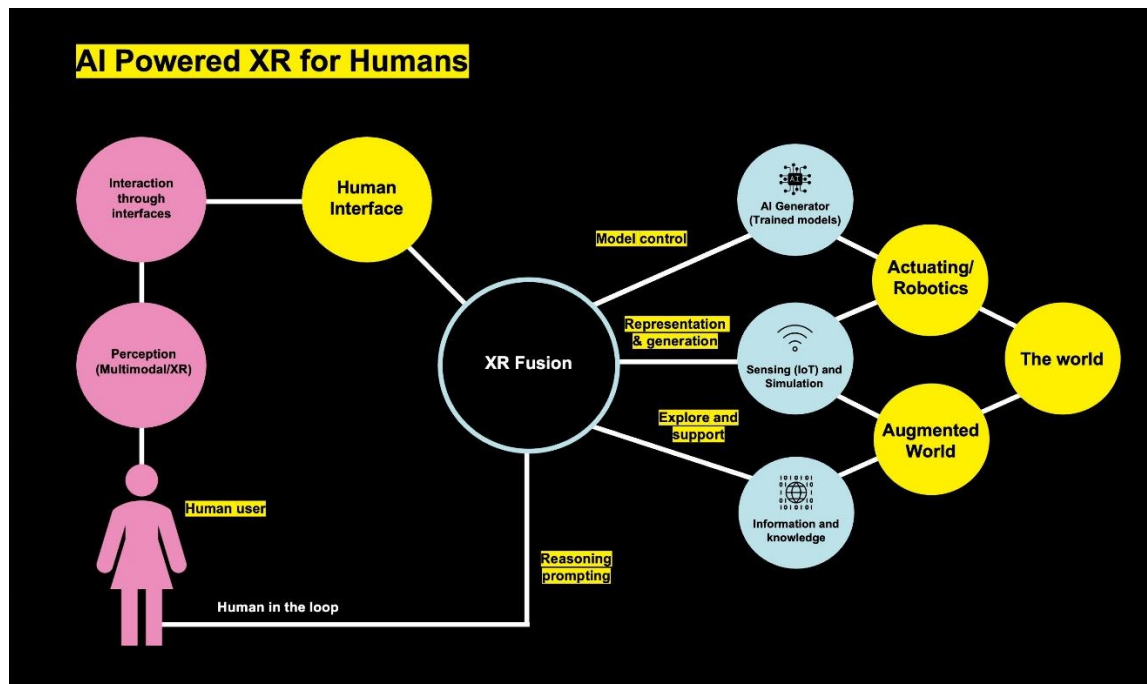


Figure 1 XR Fusion

This physical action is:

- **Captured and sensed** (Blue circles) Sensors, cameras, and IoT devices detect the movement, position, and biometric signals of the technician. These inputs form the raw data stream that enters the system, connecting the real world to the digital domain.
- **Processed and rendered** (XR Fusion) The raw data is interpreted by AI engines and XR modules. Algorithms reconstruct the scene in 3D, simulate physical dynamics, and match viewpoints. The system identifies objects, tracks motion, and generates a digital twin of the environment. This enables real-time visualization and interaction, forming the immersive layer of XR (Augmented World and Interfaces).
- **Augmented, distributed, and secured** (Perception and Interaction) The reconstructed environment is enhanced with overlays, annotations, and AI-generated insights. These are distributed across devices (headsets, tablets, laptops) while ensuring privacy, trust, and synchronization. This layer allows users to collaborate remotely, interact with shared digital artefacts, and receive personalized feedback.
- **Actuated and fed back** (Actuating Robotics and changes into The World) The system responds by triggering haptic feedback, updating the digital twin, or instructing a robotic actuator to adjust the physical valve. The loop closes as the digital decision leads to a real-world action, which is again sensed and re-entered into the system.

Together, these four stages form a cyber-physical feedback loop that enables real-time interaction, decision-making, and adaptation. It's not just about visualization but it's about creating a responsive, intelligent interface between humans, machines, and environments. This architecture underpins applications in industrial automation, healthcare, education, urban planning, and beyond. This bidirectional flow also works in reverse. A design change made in the virtual layer can propagate outward. The system simulates the change, validates it with AI, and then instructs a robot or technician to implement the modification in the physical world.

## ***Transitional potential***

Sweden stands at the cusp of a technological renaissance, as XR drastically can redefine innovation and use across diverse sectors and areas. This technological development can have significant societal and economic transition potential, and even though a technological area is at the centre, it is not mainly technology push, but rather pull from users and society. Sweden has a leading international research position in human-centred approaches to XR, visualization, image analysis, and related fields. Within both large and small companies there are impressive technological development, products and services, as well as experimentation with business models and diffusion.

XR is predicted to see a lowering of cost of both hardware for consumers and development costs (e.g. given the introduction of generative AI for content creation). As a global leader, Sweden can leverage XR to transform the pervasive infrastructures for information and communication technology as well as education and training, and be influential in the areas of societal applications, industrial manufacturing, healthcare, and games and culture. These fields, integral to the nation's identity and economy, hold immense potential to pioneer immersive solutions that enhance connectivity, preserve heritage, and take advantage of the gaming industry, streamline industry, revolutionize care, empower communities, and elevate learning. By embracing XR, Sweden can inspire the world, driving progress and shaping a future where imagination meets reality. We see two sectors or knowledge areas that are prerequisite for XR to become transitional, and these are ICT and education.

### ***ICT and XR: A symbiotic engine for digital transformation***

Information and Communication Technology (ICT) encompasses technologies and products for transmitting, storing, and exchanging information, including mobile devices, computers, networks, software, middleware, and the internet. ICT is both an enabler of XR and a sector transformed by it. It provides the infrastructure, hardware, software, cloud services, and security necessary for XR systems to function reliably and at scale.

XR, in turn, generates new business opportunities, drives demand for specialized ICT skills, reshapes digital services, and challenges traditional modes of user interaction. It introduces spatial computing, multimodal interfaces, and real-time collaboration environments that redefine how users engage with data, systems, and each other. The convergence of XR with ICT also accelerates the development of adjacent technologies (such as edge computing, 5G/6G connectivity, generative AI, and digital twins). These components enhance XR's responsiveness, scalability, and intelligence, enabling immersive experiences that are distributed, personalized, and secure.

In this way, ICT and XR are closely intertwined, mutually driving innovation and growth. Together, they form the backbone of Sweden's digital transformation, supporting new forms of communication, collaboration, and cognition across sectors. As XR becomes a pervasive interface layer, ICT evolves from a transmission medium into a dynamic infrastructure for extended human experience.

### ***Immersive education: How XR reshapes learning and training***

XR can revolutionize Sweden's education and training sector, with universities at the forefront. VR classrooms and interactive objects create immersive learning environments that enhance student engagement, comprehension, and retention. AR and VR technologies enable interactive vocational training (virtual welding, medical simulations, equipment handling, etc.) preparing workers for high-demand industries either on-site or through distributed remote platforms. For vocational education, technicians and trainees rehearse advanced procedures in risk-free virtual environments, improving safety, confidence, and operational readiness. XR also supports lifelong learning by offering accessible, scalable

training platforms that align with Sweden's national focus on digital skills development and inclusive education.

By integrating XR, educational institutions can improve learning outcomes, bridge skill gaps, and prepare a workforce for the digital economy strengthening Sweden's innovation ecosystem. Distributed XR training helps overcome geographic barriers, making high-quality education available in sparsely populated regions and supporting regional resilience. Beyond formal education, XR introduces new pedagogical models. Adaptive learning systems respond to individual performance, while AI agents act as mentors or collaborators in immersive scenarios. These tools support differentiated instruction, identity exploration, and confidence-building particularly for learners who struggle in traditional settings. XR also enables cross-disciplinary learning and collaborative research. Students and researchers interact with complex data sets, simulations, and digital twins in shared immersive environments. Platforms such as WISDOME and Wadströms Explorations Laboratory demonstrate how XR can accelerate STEM outreach and national competence development.

### **Leading application fields and sectors**

The possibilities are seemingly endless, and the development based on XR is expected to have a significant impact on several sectors and fields of application. XR is not only a technological innovation but also a platform for reimagining workflows, collaboration, and user experience. Given the competence and experience of Swedish actors, and the strength of the national industrial landscape, our discussion centres on four key domains where XR is poised to deliver transformative value: a) industrial manufacturing, b) health care, c) games and culture, and d) applications for society & public organisations.

These sectors are not isolated, but advances in one domain often catalyses innovation in others. For example, immersive training developed for manufacturing may inform healthcare simulations, while artistic experimentation in XR can influence user experience design in public services.

#### **Industrial manufacturing**

Sweden's manufacturing sector, with leaders like Volvo and Sandvik, can leverage XR to enhance efficiency and innovation. XR enables **virtual prototyping**, allowing engineers to test designs in immersive environments, reducing development costs, shortening time-to-market, and minimizing material waste. **AR guided assembly** can improve precision on factory floors by overlaying step-by-step instructions directly onto physical components. **VR training simulations** can upskill workers for complex machinery, as seen in ABB's automation advancements, and Volvo Trucks' training for battery electric vehicles. XR also supports **remote maintenance and diagnostics**, allowing experts to guide repairs or inspections without being physically present. This reduces downtime, lowers travel emissions, and improves responsiveness. **Digital twins** enable predictive maintenance, performance monitoring, and scenario testing, aligning with Sweden's Industry 4.0 and 5.0 ambitions.

Looking ahead, XR can facilitate **human-robot collaboration**, where immersive interfaces allow operators to supervise and interact with autonomous systems intuitively. It also opens pathways for **mass customization**, where customers co-design products in XR environments, feeding directly into agile manufacturing pipelines. By developing and adopting XR, Swedish manufacturers can maintain global competitiveness, streamline operations, and lead in sustainable, human-centred industrial transformation.

## **Healthcare**

XR technologies hold transformative potential for Sweden's advanced healthcare system, exemplified by institutions such as CMIV, Karolinska Institutet, and companies like Sectra. These technologies can reshape how care is delivered, how professionals are trained, and how patients engage with their own health. By integrating XR across clinical, educational, and research domains, Sweden can enhance outcomes, reduce costs, and expand access to innovative treatments. This positions the country not only as a leader in medical technology, but as a pioneer in human-centred, immersive healthcare innovation. XR enables **collaborative research and innovation**. Medical researchers can explore complex datasets in 3D, simulate biological processes, and co-design interventions with patients and clinicians. Platforms such as Wadströms Explorations Laboratory and AI Impact Lab demonstrate how XR can accelerate translational research and public health outreach.

**VR-based medical training** allows practitioners to simulate complex surgeries, rehearse emergency scenarios, and refine procedural skills without risk. Nurses can train in patient assessment, surgical assistance, and interprofessional collaboration through immersive modules that replicate real-world dynamics. These simulations improve confidence, reduce errors, and accelerate readiness. **AR-assisted surgical navigation** overlays critical anatomical data in real time, enhancing precision and reducing invasiveness. Surgeons can visualize internal structures during procedures, improving outcomes and minimizing recovery time. XR also supports preoperative planning and postoperative review, enabling more personalized and data-driven care.

**XR-based therapies** are gaining traction in mental health and rehabilitation. VR environments can be used to treat anxiety, PTSD, and phobias through exposure therapy and cognitive behavioral interventions. In physiotherapy, immersive programs guide patients through exercises, track progress, and provide motivational feedback, supporting Sweden's commitment to patient-centered care and digital health equity. Beyond clinical applications, XR enhances **healthcare accessibility and inclusion**. Remote consultations in immersive environments allow specialists to interact with patients across distances, while XR interfaces can support communication for individuals with cognitive or sensory impairments. These tools help bridge gaps in rural and underserved communities, aligning with Sweden's goals for equitable healthcare delivery.

## **Games and culture**

XR opens vast possibilities for more immersive and interactive experiences across games, film, music, live performance, and digital art. It enables users not just to observe, but to inhabit stories, environments, and emotions—blurring the boundaries between audience and performer, player and creator. As XR matures, it is poised to evolve into a recognized artform and medium in its own right, with its own dramaturgy, aesthetics, and expressive grammar.

In the gaming sector, XR is **redefining how games are designed, played, and experienced**. Traditional screen-based gameplay is giving way to spatial, embodied interaction where players move through environments, manipulate objects with gestures, and engage with characters through voice and gaze. Multiplayer XR games allow users to collaborate or compete in shared physical-digital spaces, merging social interaction with immersive storytelling. AI integration further expands the creative canvas: intelligent agents act as dynamic protagonists, antagonists, or collaborators, responding to user behavior, adapting narratives in real time, and creating emotionally resonant interactions. These systems enable emergent storytelling, where each experience is shaped by the user's choices, movements, and expressions.

Sweden is uniquely positioned to lead this cultural transformation. It hosts one of the world's most renowned gaming industries, with globally successful AAA studios and a vibrant indie developer scene. The country also supports a thriving ecosystem of artists, curators, and technologists exploring XR for creative expression, social commentary, and cultural preservation. Initiatives such as Wisdome demonstrate how immersive technologies can engage diverse audiences, preserve heritage, and foster dialogue. These platforms also support accessibility, remote participation, multilingual interaction, and inclusive design for neurodiverse users.

The cultural sector also serves as a **catalyst for innovation** in other domains. Avant-garde XR experiences developed by artists and game designers often pioneer new interaction models, interface paradigms, and content formats that later influence industrial design, education, and healthcare. For example, narrative techniques from immersive theatre may inform patient engagement strategies, while game mechanics can enhance motivation in training simulations.

In **industrial manufacturing**, game-based XR environments are increasingly used to simulate complex workflows, train workers, and optimize human-machine interaction. Gamified training modules allow technicians to practice assembly procedures, troubleshoot equipment, and respond to emergency scenarios in a risk-free, engaging format. XR games can also be used to teach safety protocols, reinforce compliance, and improve retention through repetition and reward systems. In collaborative design, game engines power real-time co-creation spaces where engineers and operators manipulate virtual prototypes together, testing ergonomics, performance, and feasibility. These applications not only improve efficiency and safety, but they also make industrial training more intuitive, inclusive, and enjoyable.

### **Applications for society and public organisations**

XR is important for **research**. Swedish research organisations are increasingly adopting XR to simulate complex systems, visualize data, and foster interdisciplinary collaboration. In fields such as climate science, medicine, behavioural studies, and urban development, XR enables researchers to interact with digital twins, test scenarios, and communicate findings in intuitive, spatial formats. These tools also support participatory research, allowing citizens to engage with scientific data and contribute to knowledge creation. Platforms like CMIV and AI Impact Lab exemplify how XR can accelerate innovation and public outreach.

Across Sweden's **public organisations and services**, XR is adopted to improve efficiency, accessibility, and engagement. In healthcare, XR supports patient education, rehabilitation, and mental health therapy, while enabling remote consultations and immersive training for medical staff. The police use XR simulations for tactical training, de-escalation practice, and forensic reconstruction, enhancing preparedness and reducing risk. The Swedish Transport Administration applies XR to visualize infrastructure projects, simulate traffic flows, and train personnel in safety protocols, supporting smart mobility and citizen engagement.

In **education**, XR enables immersive learning environments, vocational training, and inclusive education for neurodiverse students and those in remote areas. **Museums and cultural venues** use XR to enhance exhibitions, enable virtual access, and support multilingual and accessible experiences for diverse audiences. XR also promotes social inclusion and equality by fostering empathy, simulating lived experiences, and providing safe spaces for identity exploration and dialogue. In the **broader public sector**, XR supports digital transformation, service design, and citizen engagement across municipalities and agencies. It also strengthens societal security by enhancing preparedness for crises through immersive simulations and inter-agency coordination.

XR is transforming **infrastructure and city planning** and governance. Urban planners use AR to overlay infrastructure projects onto real environments, enabling stakeholders to assess designs interactively and improve decision-making. VR platforms allow citizens to explore proposed urban changes virtually, fostering inclusive public dialogue. XR also enhances accessibility by helping individuals with disabilities plan city visits and navigate public spaces remotely. These capabilities align with smart city initiatives in e.g. Kista, Hammarby Sjöstad, Norrköping, and Gothenburg, where immersive technologies support transparency, sustainability, and civic participation.

In the **civil-military interface** XR plays a vital role in Sweden's preparedness. Defence and emergency services use immersive simulations for mission rehearsal, equipment maintenance, and strategic planning. These tools improve situational awareness, reduce training costs, and enhance coordination. In civilian contexts, XR supports disaster response training, first aid education, and collaboration between organisations—boosting safety and resilience across both military and civil domains.

XR supports Sweden within **sustainability and green transition** by visualizing climate data, modelling environmental change, and educating citizens on biodiversity and ecological systems. These immersive tools enable storytelling around planetary stewardship and help foster behavioural change. Policymakers and stakeholders use XR to test interventions, simulate future scenarios, and engage the public in climate and biodiversity governance. As environmental challenges grow more complex, XR offers a powerful interface for aligning societal goals with ecological action.

### 3. Trends

In order to guide Sweden on how to reap opportunities and lead the development within XR, we need to anticipate technological advances, shifts in consumer preferences, or demographic and environmental pressures.

The overall key enablers and accelerators for the field may be expressed as:

- **Development of XR Technology:** The rapid evolution of XR hardware includes advanced devices (headsets, etc.) and collaborative immersive environments (high quality displays, sensors, controllers). Software development involves creating robust, user-friendly applications and operating systems that can seamlessly integrate hardware components.
- **XR in AI Driven Workflows:** AI-driven solutions can dramatically simplify complex workflow tasks, reducing human cognitive load and freeing up human affordances for higher level tasks. This trend calls for a new generation of visual metaphors with higher levels of abstraction. XR approaches will be instrumental as interfaces, and XR in itself will have to be reengineered to support the future human/AI workflow.
- **Multimodal Sensors and Interaction:** Visual, auditory, verbal and haptic feedback can augment human capabilities within XR environments. This multimodality allows natural and intuitive interactions, and generative AI is an important amplifier.
- **Distributed Systems and Connectivity:** For XR to be delivered seamlessly across different devices and locations, it is essential to combine high bandwidth and low-latency connectivity.
- **Policy Making, Regulations and Laws:** Important aspects relate to privacy, security, ethical use, inclusivity and accessibility. To ensure that XR based applications are developed and deployed responsibly and foster trust, clear policies and standards are needed.

To further explore these, we rely on a solid strategic foresight to equip the nation and the organizations of the ecosystem to better navigate changing societal needs, research progress, technological landscapes, and business prospects. The goal is to attempt to foresee, evaluate, and respond to emerging trends proactively and ahead of rivals. Our strategic foresight first explores signals, drivers, trends and counter trends to understand the direction in which society and processes related to XR may be changing. We categorize the potential changes into five types of trends: social, technological, economic, ecological and political.<sup>1</sup>

#### Social trends

Social dynamics are rapidly evolving in ways that significantly influence the adoption and development of XR technologies. Social trends include evolving societal challenges, consumer behaviours, cultural shifts, demographics, geography, lifestyle changes, work and purchasing habits, communication styles, community dynamics, and attitudes toward health, safety, quality, luxury, education, and privacy.

There is a strong shift toward digital-first **and virtual interaction** and new ways to connect,<sup>2</sup> where especially younger generations have changed the way that they prefer to meet, socialise, learn and get entertained. A lower acceptance of travel is evident even post-COVID, supported by **remote work** and climate concerns. With air travel criticized for its environmental impact and ground transport often too time-consuming, digital presence is increasingly chosen for reasons of cost, convenience, and sustainability.

**Virtual communities** have become central to how people connect, collaborate, and share experiences. Unlike traditional communities bound by geography, these digital spaces form

around shared interests, values, or goals, and they offer support systems, especially for marginalized groups or niche interests. What began with early forums has expanded into rich, multi-platform ecosystems with real-time interaction and deep social ties. **Digital identities** are now an integral part of how individuals express themselves, interact, and build reputations online. These identities are shaped by social media profiles, avatars in virtual worlds, and curated content across platforms.<sup>3 4</sup> They enhance self-expression, community roles and play a role in activism, entertainment, and support structures. In essence, virtual communities and digital identities shape XR adoption driven by digitalization, giving implications for how XR can be used to foster community, collaboration, and entertainment.<sup>5</sup>

This fuels **demand** for immersive XR platforms that support community-building, remote collaboration, and virtual events. There is a broad cultural emphasis on human-centred technology, devices and experiences. As digital literacy grows, so too do expectations for user-friendly, seamless, low-friction, intuitive **XR interfaces** including portability and seamless UX. Consumers are seeking lightweight, portable XR devices that integrate easily with smartphones or other devices. There's a growing expectation for intuitive, low-friction interfaces that don't require technical expertise. This shift reflects a broader behavioural change in how users interact with technology, emphasizing the need for design that prioritizes accessibility, comfort, and minimal cognitive load.<sup>6</sup>

This trend pushes developers to prioritize accessibility and comfort in XR design. At the same time, companies are adapting their strategies in response to these social shifts, demanding XR solutions that align with hybrid work models, employee wellbeing, and sustainable operations. Businesses increasingly seek XR tools that enhance remote collaboration, reduce travel costs, and support training and onboarding in engaging, scalable formats. Corporate interest in XR is no longer driven solely by innovation, but by social expectations around **inclusivity, flexibility, and digital competence**.

The move towards engagement in social XR platforms is not without its challenges relating to **negative social patterns, privacy intrusion or health risks**. Bystander privacy is a major barrier to XR adoption. Many users feel uneasy about being scanned or recorded by AR devices in public, which has led to calls for clearer ethical standards and privacy protection. Such concerns over privacy of data and the nature of sensitive data being collected calls for guidelines.<sup>7</sup> There is growing concern about a **lack of social cohesion** with screen fatigue, and the psychological and social impacts of prolonged digital engagement and digital addiction.<sup>8 9 10 11</sup> Digital use or even addiction can be set towards wellbeing, where research, for example, shows that prolonged use risks leading to permanent changes in the brain.<sup>12</sup> Therefore, some actors try to diminish the risk of prolonged exposure to non-essential digital content.<sup>13</sup> Importantly, XR may sometimes help counter the negative effects through the controlled use of XR in mental health care, e.g. for PTSD treatment,<sup>14</sup> for CBT,<sup>15</sup> for assessment in physiotherapy, or as alternative pain relief.<sup>16</sup>

## **Technological trends**

Technological trends in XR encompass research breakthroughs, infrastructure development, hardware evolution, software innovation, and the growing potential for XR across products, services, and societal applications. These trends shape how XR is adopted and implemented globally.

**Convergence of XR, AI, and advanced computing** intertwines XR with AI, cloud computing, and sensor technologies. This convergence enables more personalized, adaptive, and context-aware experiences, while also lowering the threshold for content creation.<sup>18 19</sup> This convergence is particularly relevant for applications in healthcare, manufacturing, and education, where real-time data processing and intelligent interfaces can

significantly enhance outcomes. For example, intelligent XR interfaces can guide medical procedures, optimize factory workflows, or tailor learning experiences to individual students.

**Advancements in 5G, 6G, and network technologies** provide the robust infrastructure XR needs to function in real time. The rollout of 5G and the anticipated arrival of 6G act as critical enablers of high-fidelity, low-latency XR applications.<sup>20 21</sup> These technologies support immersive experiences that require real-time interaction, such as remote surgery, collaborative design, and live virtual events. Sweden plays a leading role in this space, with companies like Ericsson driving global research and development in next-generation connectivity.

**Rising possibilities due to data availability** turn real-time data into a catalyst for XR innovation. There is an abundance of real time data: Every municipal bus, factory robot and hospital bed emit real-time telemetry, public agencies release thousands of curated datasets via the national open-data hub, and companies such as Volvo, pump gigabytes per second from 5G-enabled digital-twin production lines. When fused with edge analytics and generative AI, XR can project context-aware overlays that predict machine failures, personalize workforce training, or simulate urban planning scenarios. In short, data abundance is no longer the bottleneck; the challenge is turning it into insight. Sweden's tradition of open public data and its strong industrial base give it a natural advantage in crafting these data-rich XR solutions. The EU's Data Act ensures fair, portable access to non-personal industrial data, while GDPR continues to safeguard citizen privacy.

**Spatial computing and 3D mapping** mature rapidly, allowing XR systems to understand and interact with physical environments in more precise ways. These capabilities increasingly support architecture, industrial planning, and urban development. The proliferation of open-source tools and a strong culture of experimentation, particularly among students, researchers, and startups, foster a vibrant, though fragmented, innovation ecosystem.

**Maturing portable hardware** and head-mounted displays (HMDs) evolved significantly over the past decade. Non-tethered HMDs like Meta's Quest series and Pico 4 Ultra now offer onboard computing and high-fidelity pass-through, enabling more immersive mixed reality experiences. The launch of Apple Vision Pro, despite criticism over ergonomics and commercial performance, showcases what's possible in optics and processing power. Meanwhile, tethered systems like MeganeX Superlight 8K deliver ultra-high resolution and low latency for professional use. The discontinuation of Microsoft HoloLens 2 and Google Glass marks a setback for AR, but new partnerships (such as Meta and Ray-Ban) point to a future of lightweight, designer-style AR glasses.<sup>22</sup>

**Growth of neural interfaces and brain-computer integration** emerges as a frontier in XR. Devices like OpenBCI Galea, which integrate with Varjo headsets, aim to personalize XR experiences by measuring cognitive load, arousal, and other neural signals.<sup>23 24</sup> These technologies support adaptive training and entertainment. However, challenges in signal quality, latency, and individual variability make widespread adoption a longer-term prospect, but investment in BCI still grows.<sup>25</sup>

**Generative AI for XR content creation** transforms how XR content is produced. Tools powered by large language and image models enable rapid prototyping of virtual environments, avatars, and interactive narratives. This diffuses and democratizes XR development, allowing small teams, educators, and public institutions to create immersive experiences without extensive technical expertise.

The shift of the internet toward closed platforms creates a challenge. During its first decades the internet flourished because every node spoke open protocols, but today's digital interactions often occur within vertically integrated "walled gardens" like Facebook, WeChat,

or the Apple App Store, where a single firm controls discovery, distribution, payment and data exhaust. XR risks amplifying this trend. Headsets increasingly ship with proprietary operating systems (e.g. RealityOS, Horizon OS, Windows MR) that restrict access to third-party content and sequester biometric data behind non-negotiable cloud terms. This raises concerns about competition, privacy, and innovation. Counter-pressures such as OpenXR, WebXR, glTF/USD, and the EU's Data & Digital Markets Acts exist, but require active support. Thus, the **rise of open source and developer ecosystems** becomes foundational to XR. Standards like OpenXR, glTF, and USD allow developers to build applications that run across multiple devices and platforms. Engines like Godot now offer native XR support, and AI-assisted coding tools like GitHub Copilot accelerate development. Large language models are trained on millions of public repositories, so the more widely used an open-source project is, the richer its examples and issue discussions, the better today's so called vibe coding tools become at suggesting clean, idiomatic contributions. Each merged pull-request feeds the very models that propose the next one, creating a compounding loop of quality and speed that closed stacks cannot replicate. This is also a super clear incentive for companies to keep open sourcing their platforms and will probably be even more true in the future.

**Metaverse and interoperability** redefine the spatial internet. The emerging metaverse should be understood not as a single platform, but as a federated spatial layer of the internet: a persistent, shared, real-time 3D information space accessible via any compliant device. Interoperability ensures public value. Open specifications like OpenXR, glTF, and USD provide a neutral technological basis to stand on, but identity, payment, and governance may require local adaptations.

### *Economic trends*

Economic trends shape how XR technologies evolve across industries, public services, and society. Shifts in market demand, cost structures, global economic health, and the behaviour of dominant firms influence adoption and innovation. XR's trajectory also depends on the strength of national innovation systems and the ability of diverse actors (firms, universities, users, and governments) to collaborate effectively. As XR development accelerates globally, the interplay between public investment, private platforms, and regulatory frameworks becomes increasingly central to shaping its future.

**Training and simulation applications** continue to drive **XR adoption** across industrial and public sectors. Immersive tools offer scalable, cost-effective solutions for complex or hazardous environments, particularly in manufacturing, logistics, and healthcare.<sup>26</sup> **Industry 5.0 reframes digital transformation** with a focus on human-centeredness, resilience, and sustainability.<sup>27</sup> Digital twins and adaptive simulations support workforce development and operational efficiency, while XR-enabled human-machine interaction helps industries transition toward renewable energy and more resilient operations. These capabilities are amplified when combined with generative AI and autonomous agents, allowing operators to input data, receive contextual feedback, and collaborate with machines in real time.<sup>28</sup> There is an increase of niched XR for **digital twins** and **industrial applications** (e.g. immersive simulations, support tools for operators in production environments), enhancing productivity and innovation.<sup>29</sup> Globally, specialized XR solutions are gaining traction in sectors like automotive, energy, and logistics, though adoption remains concentrated among large firms. SMEs face barriers in cost and integration, prompting efforts to develop platform-based XR tools that lower entry thresholds. In Sweden and the Nordics, sectors such as maritime, advanced manufacturing, and public health have shown early success, supported by regional expertise and targeted pilot programs.<sup>30</sup>

**Healthcare and gaming** are at the forefront of **XR's economic relevance**. In healthcare, XR is used for diagnostics, therapy, rehabilitation, and medical education, improving patient engagement, supporting remote care, and enabling personalized treatment. These applications align with global trends in digital health and aging populations. In Sweden, hospitals and research institutions are piloting XR for cognitive training, pain management, and surgical planning, backed by a strong public healthcare infrastructure. Meanwhile, the gaming industry remains a major engine of XR market growth, especially in Europe, North America, and East Asia. As the largest audio-visual sector, gaming offers a natural entry point for immersive technologies. Yet XR must evolve beyond game mechanics to establish its own narrative logic and experiential grammar. Without this, it risks being perceived as a mere extension of existing formats. Sweden's vibrant gaming sector contributes to XR experimentation, and broader cultural adoption will depend on new storytelling paradigms.<sup>31</sup>

**Blockchain-based monetization models** introduce new revenue streams for XR. NFTs and crypto-assets embed scarcity and royalty logic into virtual goods, enabling creators to sell, rent, or license immersive assets across platforms. Indeed, by writing scarcity and royalty logic directly into the token, creators can sell a virtual drill bit for an industrial twin, rent out stage designs for a live concert in VR, or receive a micro-payment every time their asset is reskinned by another user. Because the ledger is public, the same token can, in principle, cross from one world engine to the next, letting value move as freely as the underlying 3-D file. This is how big-tech reasons on the possibilities and given the revenue opportunities it is easy to see why they are all moving into a position to control monetary streams (e.g. Apple Pay). While promising, these models require oversight to avoid speculation and misuse. The EU's MiCA regulation and similar frameworks worldwide now impose capital and consumer-protection rules. Sweden's financial authority has begun licensing intermediaries to ensure XR-native transactions remain traceable and integrated with the national economy.

**Security threats** in immersive environments escalate, bringing **new vulnerabilities and governance challenges**. Indeed, the fraud risks that accompanied email and social media do not disappear in XR but multiply. Realistic avatars, spatial audio, and biometric feedback can be exploited for fraud, impersonation, and social engineering: A well-crafted avatar that tracks eye-movements, lip-sync and spatial audio can evoke the same subconscious trust signals we rely on in face-to-face meetings. If a malicious actor controls those signals, scams gain a new persuasive layer: you are not just reading forged text, you are *standing in the same room* with a convincingly rendered impostor who can point to documents floating between you and respond to your body language in real time. As more of our workspaces, classrooms and marketplaces migrate into persistent 3-D environments, every additional sense that XR engages (voice, gesture, even haptic touch) becomes a fresh surface for social-engineering. The result is a spectrum of speculative but credible attack scenarios: deep-fake business meetings that reroute payments; phishing pop-ups that masquerade as system-level overlays; or "drop-in" agents that tailgate private virtual offices when access control is lax. Addressing these threats will demand multimodal authentication, runtime anomaly detection and user education that evolves as quickly as the medium itself, but the first step is recognizing that the immersive power that makes XR compelling for collaboration equally amplifies the confidence tricks of tomorrow's fraudsters. Swedish cybersecurity researchers and public agencies are beginning to explore safeguards tailored to immersive media.

Digitalization continues to drive **winner-takes-all dynamics**, where dominant platforms capture vast market share through scale, network effects, and data feedback loops. Search is monopolized by Google; online retail is led by Amazon; and streaming giants like Apple and Netflix have displaced local media and distribution. App stores impose steep tolls on developers, reinforcing platform control. XR inherits this structure but with even stickier

switching costs, volumetric assets, biometric data, and spatial maps are harder to transfer than traditional content. As XR systems collect increasingly granular data, including biometric and behavioural information concerns intensify around monetization of user data within XR environments, including privacy, consent, and ethical use. These risks intersect with broader debates about platform economies and the concentration of power among a few dominant firms. Without active support for interoperability, open procurement, and robust data governance, the spatial internet could consolidate even faster than the web. Swedish firms already face constraints as early digital enterprises are absorbed by global players, limiting local innovation unless safeguards are introduced.

**Ecosystems, regional hubs and innovation platforms** are essential to XR's long-term development. Around the world, geographically focused clusters are often anchored by universities, incubators, and public investment and foster experimentation, talent development, and cross-sector collaboration. Regional specialization, whether in industrial XR, immersive storytelling, or healthcare, helps diversify the national portfolio and build exportable solutions. Continued support for academic research, early-stage ventures, and open standards will be key to sustaining momentum and ensuring XR's economic potential is widely shared.

### *Ecological trends*

Ecological trends shape the development and use of XR technologies, aligning with global sustainability efforts such as the UN's 17 Global Goals and national climate strategies. As XR becomes more embedded across sectors, its environmental footprint—both in terms of energy and materials—requires careful consideration. The ecological implications of XR are not limited to its direct use but extend to how it transforms work, education, and infrastructure.

**Sustainability** is an increasingly important concern in XR, particularly due to the computational demands of real-time rendering, cloud processing, and data transmission. These processes consume significant energy and contribute to carbon emissions, especially in Metaverse environments that rely heavily on XR infrastructure. To address this, researchers have proposed frameworks like C3Meta (Context-aware Cloud-edge-end Collaboration), which aim to create energy-efficient XR systems while maintaining performance.<sup>32</sup> Alongside energy use, the rapid obsolescence of XR hardware contributes to growing electronic waste, prompting calls for longer product lifecycles and more recyclable components.

**Industrial green transition** is supported by XR through competence development and energy optimization. XR tools are being used to reskill and upskill workers transitioning from fossil-based systems to electrified powertrains. They also support remanufacturing processes by guiding operators in dismantling, inspecting, refurbishing, and reassembling products.<sup>33</sup> When integrated with Digital Twin technologies, XR helps manage energy consumption in buildings and industrial systems, reducing emissions and enhancing sustainability.<sup>34</sup> These applications are particularly relevant in regions facing demographic shifts and workforce transformation challenges.

XR contributes to **environmental awareness and education**, offering immersive experiences that communicate the impacts of climate change and promote sustainable behaviours. These applications are being used in schools, museums, and public campaigns to make ecological issues more tangible and emotionally resonant. XR also plays a role in urban planning and architectural education, helping optimize green spaces and visualize sustainable design choices in real time.<sup>35</sup>

**Remote work** supported by XR aligns with broader ecological goals, reducing the need for travel and physical infrastructure.<sup>36</sup> Immersive collaboration tools allow teams to meet, design, and operate across distances, lowering carbon footprints and supporting corporate sustainability commitments. This shift also contributes to national climate targets, positioning XR as a strategic enabler of low-carbon workflows across sectors.

## *Political trends*

Political trends shape the governance, regulation, and strategic direction of XR across national and global contexts. Laws, policy initiatives, and geopolitical ambitions influence how XR is developed, deployed, and integrated into society. As immersive technologies become more central to public services, industry, and citizen engagement, political frameworks increasingly determine their trajectory.

**Data privacy and security regulations** are reshaping XR development. Governments are responding to the risks of immersive environments with new legislation, including the EU's Digital Services Act and the Web 4.0 and virtual world initiative.<sup>37</sup> These aim to protect users through stronger data protection rules and sustainable strategies for citizen engagement in virtual spaces. XR-specific challenges include content moderation, biometric data handling, and the need for general security measures tailored to immersive systems.<sup>38</sup> These regulations influence how XR platforms are designed, governed, and accessed across jurisdictions.

**Ethical AI** and the threat of **deepfakes** are gaining political urgency.<sup>39</sup> As XR becomes increasingly integrated with generative AI, the potential for misinformation, identity manipulation, and erosion of anonymity grows. This has prompted calls for transparency, accountability, and ethical standards. The IEEE has published eight thematic white papers addressing XR ethics across domains such as education, medicine, finance, diversity, and governance.<sup>40</sup> These papers explore critical issues including virtual identity ownership, trolling and harassment in multi-user spaces, and the ethical implications of immersive environments in professional and educational contexts.

**Regional disparities in XR governance** complicate international collaboration and market access. Regulatory approaches vary widely, and while the reinstatement of the PCLOB agreement between the USA and EU has created temporary alignment, the landscape remains volatile.<sup>41</sup> Standardization and interoperability are critical to bridging these divides. Governments and industry bodies are advocating for open protocols to ensure cross-platform compatibility and prevent vendor lock-in. In Europe, there is growing momentum behind "EU-first" policies aimed at asserting digital sovereignty and balancing influence with the USA and China in the global tech arena.

**Standardization and interoperability** are advancing rapidly and support innovation. Global standards such as OpenXR enable cross-platform compatibility, while frameworks like Khronos Group's glTF streamline 3D asset sharing. These tools support real-time, multi-user VR applications and cloud-based platforms that enhance accessibility. In Sweden, companies like Ericsson and a growing ecosystem of XR startups benefit from these developments, helping position the country as a leader in immersive technology. Emerging APIs and shared protocols are lowering costs and enabling more seamless collaboration across platforms.

**Public investment** in XR is shifting toward strategic capital allocation. Traditionally, digital projects were treated as operating costs—licences, IT staff, incremental upgrades—because digitalisation supported rather than transformed workflows. With AI, that premise changes: language models draft case files, vision models triage radiology, and chatbots resolve citizen queries. These systems behave like industrial automation, unlocking labour savings and

faster service. XR technologies follow the same logic. Headsets, spatial cameras, and shared 3D twins reduce travel, physical prototyping, and instructor time. For municipalities and agencies recalibrating budgets around AI automation, allocating capital expenditure to immersive systems becomes a fiscally responsible step rather than an experimental indulgence.

## *Conclusions on the future of XR*

Extended Reality is evolving within a dynamic landscape shaped by five interdependent trend domains: social, technological, economic, ecological, and political. Together, these forces define the opportunities, risks, and strategic choices that will determine Sweden's position in the global XR ecosystem.

**Social trends** highlight a cultural shift toward **digital-first lifestyles, virtual communities, and human-centered design**. Younger generations increasingly prefer virtual interaction for work, learning, and entertainment, driving demand for immersive platforms that support collaboration, identity expression, and community-building. Expectations for intuitive, portable, and accessible XR devices are rising, while concerns around privacy, mental health, and digital addiction call for ethical design and responsible use. XR's potential to support mental health care and inclusive digital spaces offers a counterbalance to these risks and positions it as a tool for wellbeing and social cohesion.

**Technological trends** accelerate XR's capabilities through **convergence with AI, advanced computing, and real-time data**. Breakthroughs in 5G/6G, spatial computing, and generative AI enable more adaptive, personalized, and scalable XR experiences. Sweden's leadership in connectivity and open data infrastructure provides a strong foundation for innovation. However, the rise of proprietary platforms and closed ecosystems threatens openness, competition, and developer autonomy. The future of XR depends on sustained support for open standards, cross-platform interoperability, and vibrant open-source communities. Globally, Sweden has a leading research position especially related to human centred approaches and has strong development within companies.

**Economic trends** reveal that XR-hardware has become easier to use and more cost-effective, which boosts uptake and deployment, but in many areas it is still niche. Albeit still not for everyone, XR is becoming a more commonly used medium for virtual communities, with its possibility to express and explore different virtual identities. XR has an expanding role in **industrial productivity**; training, simulation, and digital twins drive adoption in manufacturing, logistics, and public services; healthcare and gaming remain high-impact sectors with XR supporting diagnostics, therapy, and immersive storytelling. Blockchain-based **monetization models** offer creators new revenue streams, but also raise regulatory and ethical questions. There are still challenges with both more large-scale deployment, reaching higher TRL and being able to reach the critical mass in number of users to gain enough traction. Meanwhile, **security threats** and platform consolidation pose risks to trust and innovation. **Regional hubs** and public-private collaborations are key to ensuring inclusive growth and exportable solutions.

**Ecological trends** underscore the need to **embed sustainability** into XR's design and deployment. Energy consumption, e-waste, and hardware obsolescence are pressing concerns, especially in Metaverse-scale environments. Yet XR also supports the **green transition** by enabling remote work, optimizing energy use through digital twins, and promoting environmental education. Sweden's climate commitments and industrial transformation goals align well with XR's ecological applications, provided sustainability is prioritized from the outset.

**Political trends** shape XR through **regulation, governance, and strategic investment**. Data privacy, ethical AI, and platform accountability are central to emerging policy frameworks. Regional disparities in regulation complicate global collaboration, while standardization efforts like OpenXR and glTF offer pathways to interoperability. Public investment is shifting toward capital assets that deliver long-term savings, positioning XR as a fiscally responsible tool for municipalities and agencies. Sweden's proactive stance on digital sovereignty and innovation policy will be critical in navigating geopolitical tensions and platform dependencies.

### ***Strategic conclusions***

- XR is no longer a niche technology but is becoming a foundational layer of digital society. Its relevance spans ICT, industry, education, healthcare, culture, and much more.
- Human-centred design and ethical safeguards are essential. Trust, wellbeing, and inclusion must be built into XR systems from the start.
- Open standards and interoperability are strategic imperatives. Without them, XR risks fragmentation and monopolization.
- Sustainability must be embedded early. XR can support climate goals, but only if energy use, hardware lifecycle, and ecological impact are actively managed.
- Public-private collaboration is key to national leadership. Sweden's innovation system must continue to support experimentation, regional hubs, and exportable solutions.
- Regulatory foresight and digital sovereignty will shape Sweden's global position. Active engagement in international standards and governance frameworks is necessary to protect national interests and democratic values.

## 4. Scenarios

As reflected by the trends in the previous section, the development in extended reality (XR) can be expected to have a significant impact on many large sectors and societal areas. Using the trends, we have opted to in some detail dwell on six scenarios, each outlining how XR will influence various areas, contexts or sectors. These scenarios were constructed not as an attempt to predict the future to full certainty, but more to act as *plausible* or *desirable* scenarios. The scenarios thus act as an aid in visualising a desired future state for XR in Sweden, what effects that would have on the XR-ecosystem, other stakeholders, different sectors, policy, governance, etc.

In the following sections, we will map out scenarios and what these may imply for Sweden. The first two scenarios are for the pervasive infrastructures *ICT* versus *Education and Training*. Thereafter we present scenarios for four focused areas: industrial manufacturing, health care, games and culture, and societal applications.

### *XR as a backbone of ICT infrastructure*

In this scenario, XR becomes a foundational layer of Sweden's digital infrastructure. It integrates seamlessly with cloud platforms, edge networks, and public data systems. XR interfaces are used for system monitoring, urban planning, and real-time decision-making across sectors. The spatial internet emerges as a civic utility, where immersive environments support public services, industrial operations, and democratic engagement. XR is no longer a peripheral tool but becomes the interface through which Sweden governs, collaborates, and innovates.

#### ***A fictive scenario for XR & ICT***

XR, empowered by ICT, is used for real-time data visualization, virtual prototyping, predictive maintenance, and collaborative design across telecommunications, automotive, and smart city applications. It supports remote diagnostics, immersive planning, and adaptive training. ICT giants like Ericsson and META, automotive leaders like Volvo, and innovative startups across Sweden are key developers and users. Academic organisations such as Linköping University deploy XR in research and education, while municipalities use XR dashboards to manage transport, energy, and public services. XR is deployed in tech hubs like Linköping/Norrköping, Gothenburg, Malmö, and Stockholm, with cloud-based platforms enabling use in rural areas, ensuring nationwide connectivity and inclusive innovation.

XR also enables new forms of civic engagement. Citizens participate in virtual town halls, explore planning proposals in immersive environments, and contribute feedback through spatial interfaces. Public health agencies simulate outbreak scenarios, energy providers optimize grid performance, and transport authorities visualize traffic flows, all through XR-enabled systems.

The following fictional vignettes illustrate how a fully realized scenario could empower diverse actors across Sweden. Each group contributes to and benefits from the ecosystem in distinct ways, reinforcing the need for inclusive design, open standards, and coordinated governance. A fictive scenario is that in 2035, Sweden's XR infrastructure is fully integrated into its digital backbone. Across sectors and regions, immersive technologies support real-time decision-making, collaboration, and public engagement.

- *Universities and research groups:* At Linköping University, a multidisciplinary research team uses XR to visualize how different materials and layouts influence city temperatures. Students navigate immersive models of city blocks, adjusting green space layouts and building materials to reduce temperature spikes. The XR lab collaborates with municipal planners, feeding real-time data into the city's spatial

dashboard. Meanwhile, KTH's ethics and AI group uses XR to test public reactions to biometric data collection in virtual environments, informing national policy on immersive privacy standards.

- *Large established firms:* At Volvo's innovation centre, engineers use XR overlays to monitor autonomous vehicle fleets in real time. Maintenance teams receive alerts through head-mounted displays, guiding them to specific components with predictive diagnostics. Ericsson's global operations group meets daily in a persistent XR workspace, where avatars interact with spatial models of network traffic. Algorithms are tested collaboratively with partners in Seoul and Toronto, optimizing 6G bandwidth allocation across continents.
- *New innovative firms and startups:* In Malmö, a startup called XGrid develops XR tools for energy grid visualization. Their platform allows utility companies to simulate outages, reroute power, and train technicians in immersive environments. The company accesses public datasets through Sweden's open data portal and tests its product in Norrköping's XR testbed. XGrid wins a Vinnova grant to expand its platform to rural municipalities, enabling decentralized energy management.
- *Traditional SMEs:* A mid-sized construction firm in Västra Götaland adopts XR for site planning and safety training. Workers use lightweight AR glasses to visualize underground utilities and receive step-by-step guidance during excavation. The firm partners with a local integrator to retrofit its legacy systems with XR interfaces. Though initially hesitant, the SME sees reduced errors and improved compliance, prompting further investment in immersive workflows.
- *Professional users:* A regional water utility in Skåne uses XR to monitor and manage its underground pipe network. Engineers walk through immersive replicas of the system, identifying leaks and planning maintenance without disrupting service. A research institute in Uppsala uses XR to visualize climate models, collaborating with international partners in real time to simulate flood risks and mitigation strategies. A public health agency in Västerbotten deploys XR for training emergency responders, integrating biometric feedback and spatial simulations to improve coordination during crisis scenarios.
- *End users:* A high school student in Kiruna attends a virtual field trip to the Luleå harbour, exploring logistics operations through XR. Her class collaborates with students in Hamburg, comparing port infrastructure and environmental strategies. A nurse in Umeå uses XR to train on emergency procedures, guided by real-time feedback from biometric sensors. A retiree in Örebro joins a virtual town hall to discuss local park renovations, walking through proposed designs and leaving comments via spatial markers.
- *Public organisations:* The Swedish Transport Administration uses XR to monitor national rail infrastructure. Inspectors walk through virtual replicas of tunnels and bridges, identifying stress points and coordinating repairs with remote teams. In Stockholm, the city council hosts monthly planning sessions in an XR forum where citizens explore proposed developments in immersive 3D. Feedback is collected spatially, allowing planners to adjust designs based on public sentiment and accessibility concerns.
- *Policy makers and financiers:* At the Ministry of Infrastructure, policymakers use XR simulations to evaluate the impact of new zoning laws. A spatial model of Västerås shows how traffic, emissions, and housing density shift under different regulatory scenarios. Meanwhile, a national investment bank uses XR to assess the viability of infrastructure projects, visualizing cost-benefit analyses in immersive dashboards. These tools help align funding decisions with climate goals and regional equity.

## Key drivers

- **Social:** Shift toward digital-first lifestyles and remote collaboration; Demand for intuitive, low-friction interfaces across generations; Rise of virtual communities and immersive civic participation.
- **Technological:** Expansion of 5G and 6G networks enabling low-latency XR; Convergence with AI, edge computing, and spatial mapping; Growth of open standards and developer ecosystems.
- **Economic:** XR adoption in industrial productivity and public services; Cost-saving potential through remote operations and digital twins; Emergence of new monetization models for immersive assets.
- **Ecological:** XR-enabled remote work reducing travel emissions; Digital twins optimizing energy use in infrastructure; Pressure to reduce e-waste and improve hardware sustainability.
- **Political:** Public investment in digital infrastructure and innovation platforms; Regulatory momentum around data governance and ethical AI; Strategic ambition for digital sovereignty and exportable civic tech.

## Opportunities and risks for developers

	<b>Opportunities</b>	<b>Risks</b>
<i>Hardware Developers</i>	Demand for portable, energy-efficient devices; integration with public infrastructure	Rapid obsolescence; e-waste; ergonomic limitations
<i>Software Developers</i>	Build civic apps, spatial dashboards, and AI-driven XR tools	Platform dependency; data compliance burdens; fragmentation
<i>System Integrators</i>	Lead deployment across sectors; bridge legacy systems with XR	Complexity of integration; lack of standards; high cost of customization
<i>Content Creators &amp; Designers</i>	Develop immersive narratives for public engagement and education	Limited monetization models; IP protection challenges
<i>Data Scientists &amp; AI Engineers</i>	Use spatial data for predictive analytics and decision support	Ethical risks in biometric data; bias in AI-driven interfaces

## Implications, opportunities, and pathways for Swedish society

As XR becomes a backbone of Sweden’s digital infrastructure, municipalities begin using immersive dashboards to manage transport, energy, and public services. National agencies adopt XR for infrastructure oversight, emergency response, and environmental monitoring. Public data is spatially visualized, improving transparency, civic engagement, and trust in governance. Remote collaboration across regions becomes the norm, reducing travel and enabling inclusive participation in planning and decision-making. These developments make Sweden’s infrastructure more resilient, adaptive, and accessible.

To fully realize this potential, Sweden must accelerate the deployment of 5G and 6G networks to support high-fidelity XR, while investing in edge computing and cloud platforms optimized for spatial data. Equal access to immersive connectivity must be ensured across rural and urban regions. Promoting the adoption of open standards such as OpenXR, glTF, USD, and WebXR is essential across both public and private sectors. Open-source

contributions and modular XR architectures should be encouraged to avoid vendor lock-in and foster long-term flexibility.

Education and workforce development will play a critical role. Universities and technical institutes must integrate XR and spatial computing into curricula, while interdisciplinary programs should combine ICT, design, ethics, and governance. Funding XR fellowships and internships will help build robust talent pipelines. Regional XR testbeds, developed through public-private partnerships, can foster experimentation and cross-sector collaboration. These testbeds should be used to address public-sector challenges such as energy, transport, and health, serving as launchpads for scalable immersive solutions.

### **Opportunities and risks for the ecosystem**

<b>Actor Group</b>	<b>Opportunities</b>	<b>Risks</b>
<i>Universities &amp; Research Groups</i>	Advance spatial computing, AI-XR integration, and civic tech; attract funding and talent	Fragmented research agendas; lack of applied testbeds; limited industry collaboration
<i>Large Firms</i>	Scale XR across operations; shape standards; lead global exports	High integration costs; risk of closed ecosystems; regulatory scrutiny
<i>Innovative Firms &amp; Startups</i>	Build modular XR services; access public data; partner with municipalities	Limited access to infrastructure; dependency on dominant platforms; IP vulnerability
<i>Traditional SMEs</i>	Use XR for training, planning, and remote operations	Lack of technical capacity; high onboarding costs; unclear ROI
<i>Professional users</i>	Apply XR to optimize workflows, simulate systems, and visualize data; collaborate across sectors; drive innovation in applied contexts	High dependency on stable infrastructure; need for cross-sector standards; risk of siloed development without coordination
<i>End users</i>	Access immersive public services; participate in planning; benefit from remote collaboration	Privacy concerns; digital fatigue; unequal access and literacy gaps
<i>Public Organisations</i>	Improve service delivery, transparency, and civic engagement	Procurement complexity; data governance challenges; risk of exclusion
<i>Policy Makers &amp; Financiers</i>	Shape ethical frameworks; fund strategic infrastructure; support open innovation	Regulatory lag; misaligned incentives; risk of over-centralization

### **XR in education and training: Transforming learning across Sweden**

In this scenario, XR becomes a foundational part of Sweden’s educational infrastructure. It enhances proven aspects of learning across elementary, secondary, and higher education, while expanding access to vocational and lifelong training. XR enables distributed learning of complex and embodied concepts, offering new ways to visualize, interact with, and understand content. From geometry and molecular chemistry to historical re-enactments and emergency simulations, immersive technologies make difficult subjects more accessible and engaging.

### ***A fictive scenario for XR & education***

Remote XR-based training transforms vocational education, especially in sparsely populated areas. Students rehearse procedures, operate virtual machinery, and interact with simulated patients or clients before engaging in real-life practice. Dangerous or rare scenarios, such as chemical spills or reactor emergencies, can be safely explored in immersive environments. AR and MR strengthen on-the-job training and continuous competence development. These shifts challenge traditional pedagogical models and raise new questions about the role of XR in learning design, such as whether immersive tools should be used for short sessions or integrated into everyday learning.

The immersive nature of XR also supports identity exploration and confidence-building. This helps school refusers re-engage with learning and supports vocational learners in high-pressure environments. New forms of pedagogy emerge, influenced by live-action roleplay and adaptive learning systems. AI agents act as mentors, while human teachers design and control immersive scenarios. Platforms like WISDOME and Wadströms Exploration Laboratory support STEM outreach and national competence acceleration. Organisations such as Modda Sörmland help schools integrate immersive technologies into everyday education.

By 2035, XR is embedded across Sweden's education system. It supports real-time learning, adaptive training, and inclusive access to knowledge. Students engage with immersive content both synchronously and asynchronously, at home, in classrooms, in simulation labs, and on the job. AI-driven tutoring systems complement human-led instruction, while teachers orchestrate immersive learning environments tailored to individual needs. Vocational learners train on virtual machines, rehearse emergency protocols, and interact with simulated patients. Higher education institutions use XR for collaborative research and interdisciplinary teaching. Municipalities deploy XR for lifelong learning and workforce development. Immersive platforms connect learners across regions, enabling shared experiences and scalable education.

- *Universities and research institutes:* At Linköping University, education researchers use XR to study how immersive geometry lessons improve spatial reasoning. Students explore mathematical concepts by manipulating three-dimensional shapes in virtual classrooms. At Umeå University, nursing students train on emergency procedures using XR simulations of hospital environments. KTH's pedagogy lab experiments with adaptive XR scenarios that adjust difficulty based on biometric feedback.
- *Large established firms:* A national education publisher develops XR modules aligned with Sweden's curriculum standards. These modules are deployed in schools across the country, enabling interactive history lessons and science experiments. A major healthcare provider uses XR to train staff on patient interaction and crisis response, integrating simulations into onboarding programs.
- *New innovative firms and startups:* A startup in Lund creates immersive chemistry labs for secondary schools, allowing students to conduct virtual experiments with real-time feedback. Another firm develops AI-driven XR tutors that adapt to each learner's pace and style. These startups collaborate with municipalities and universities to pilot their tools in diverse learning environments.
- *Traditional SMEs:* A vocational training centre in Umeå uses XR to teach welding and machinery operation. Trainees practice in virtual workshops before handling physical equipment. The centre partners with a local integrator to ensure compatibility with legacy systems and national certification standards.

- *Professional users:* Teachers use XR to design interactive lessons and monitor student progress in real time. Vocational instructors simulate workplace scenarios to prepare learners for complex tasks. Educational technologists develop modular XR environments for cross-disciplinary learning and assessment.
- *End users:* A student in Skåne studies biology by exploring virtual ecosystems. A nursing trainee in Sundsvall practices patient care in immersive hospital simulations. A teacher in Västerbotten uses XR to guide students through historical events, allowing them to interact with virtual figures and artifacts.
- *Public organisations:* The Swedish National Agency for Education supports XR adoption by funding pilot programs and developing guidelines for immersive learning. Municipal education offices use XR to deliver inclusive training for adult learners and newcomers. Public libraries host XR learning stations for community access to STEM content.
- *Policy makers and financiers:* The Ministry of Education funds research into XR pedagogy and supports infrastructure grants for immersive classrooms. A national innovation fund backs startups developing educational XR content. Policymakers collaborate with researchers to ensure ethical use of biometric data and equitable access to immersive learning.

### Key drivers

- **Social:** Demand for inclusive and engaging learning tools; rise of remote and hybrid education; evolving role of teachers and mentors
- **Technological:** Convergence of XR, AI, and biometric feedback; expansion of immersive platforms; growth of adaptive learning systems
- **Economic:** Cost-effective training for vocational skills; new markets for educational content; increased demand for XR-compatible infrastructure
- **Ecological:** Reduced travel for training; virtual labs minimizing material waste, sustainable access to high-quality education
- **Political:** National strategies for digital education, funding for immersive infrastructure, development of standards and ethical frameworks

### Opportunities and risks for the ecosystem

	<b>Opportunities</b>	<b>Risks</b>
<i>Universities and research groups</i>	Advance XR pedagogy and adaptive learning, attract funding and talent	Limited access to infrastructure, fragmented research agendas
<i>Large established firms</i>	Scale immersive content, shape curriculum standards	High development costs, risk of monopolization
<i>Innovative firms and startups</i>	Build adaptive XR tools, partner with schools and municipalities	Limited market access, dependency on dominant platforms
<i>Traditional SMEs</i>	Use XR for vocational training and upskilling	Lack of technical capacity, unclear return on investment
<i>Professional users</i>	Design immersive lessons, monitor progress in real time	Need for training, risk of overreliance on automation
<i>End users</i>	Access personalized learning, engage with content interactively	Privacy concerns, unequal access and digital literacy gaps
<i>Public organisations</i>	Support inclusive education, deliver scalable training	Procurement complexity, content quality assurance challenges

<i>Policy makers and financiers</i>	Fund infrastructure and research, shape ethical standards	Regulatory lag, misaligned incentives
-------------------------------------	---	---------------------------------------

### ***Implications, opportunities, and pathways for Swedish society***

XR transforms Sweden's education system by making learning more interactive, inclusive, and scalable. Students across regions access immersive content tailored to their needs. Vocational learners rehearse complex tasks in safe environments. Teachers evolve into designers of adaptive learning experiences. Public organisations use XR to support lifelong learning and workforce development.

To reach this future, Sweden must invest in pedagogical and didactical research to validate XR's effectiveness. Infrastructure must be expanded to ensure access to hardware and software across institutions. Centralized hubs can provide shared resources and support procurement. Quality assurance mechanisms are needed to evaluate content and guide implementation. Policy frameworks must address standards, ethics, and equity in immersive learning.

### ***Opportunities and risks for developers***

	<b><i>Opportunities</i></b>	<b><i>Risks</i></b>
<i>Hardware developers</i>	Demand for portable, classroom-ready devices, integration with school infrastructure	Rapid obsolescence, ergonomic limitations, e-waste
<i>Software developers</i>	Build adaptive learning platforms and immersive content tools	Platform dependency, compliance burdens, fragmentation
<i>System integrators</i>	Deploy XR across schools and training centres, bridge legacy systems	High cost of customization, lack of standards
<i>Content creators and designers</i>	Develop curriculum-aligned immersive experiences	Limited monetization models, IP protection challenges
<i>Data scientists and AI engineers</i>	Use biometric and learning data for adaptive feedback	Ethical risks, bias in AI-driven tutoring systems

## ***XR in industrial manufacturing: Enabling a smarter, safer, and more agile production ecosystem***

In the envisioned future, XR is a foundational technology across Sweden's industrial manufacturing landscape. It supports workforce training, product design, factory layout planning, testing, and sales, integrating seamlessly with digital twins, AI, and Industry 5.0 principles. XR enables immersive, distributed collaboration, reduces physical risk and travel, and enhances productivity across large firms, SMEs, and startups. It becomes a strategic tool for innovation, competence development, and sustainability in Sweden's globally competitive manufacturing sector.

### ***A fictive scenario for XR & industrial manufacturing***

In 2035, XR is embedded across the entire industrial value chain. Operators and technicians train in immersive simulations that replicate hazardous or complex tasks guided by AI agents that adapt to individual skill levels. Recruitment processes include remote XR assessments, allowing candidates to demonstrate capabilities from home or at job fairs. Onboarding and continuous learning are supported by modular XR platforms developed in-house or by third-party providers.

Design teams conduct distributed events, using XR to co-create and evaluate prototypes in real time. Engineers assess ergonomics and feasibility in immersive environments, reducing the need for travel and physical mock-ups. Factory layout planners use MR tools to visualize machinery placement and optimize workflows collaboratively across locations. Service personnel perform remote diagnostics and repairs using XR overlays and voice-guided AI support.

Sales groups use hyper-realistic XR renderings to showcase new product lines, especially those that are large, complex, or not yet physically available. Testing engineers simulate crash scenarios and performance benchmarks using XR combined with advanced computation. Operator-machine interaction evolves through LLM interfaces, where technicians reason aloud while the system guides and responds, creating a fluid, conversational troubleshooting process.

- ***Universities and research institutes:*** Chalmers and KTH lead collaborative projects with industrial partners and RISE to develop XR-based training modules tailored to the DICE paradigm, addressing tasks that are dangerous, invisible, counterintuitive, or expensive. Research groups investigate cognitive load, skill retention, and ergonomic impact in immersive environments, contributing to pedagogical standards and certification frameworks for industrial XR. These universities also host open innovation labs where students and companies co-create XR prototypes for factory layout planning and operator-machine interaction.
- ***Large established firms:*** Volvo and Sandvik have embedded XR into their core workflows. At Volvo, XR is used to pre-train technicians for battery electric vehicle maintenance, simulate crash testing, and conduct immersive design reviews across global settings. Sandvik uses XR for onboarding, continuous competence development, and remote diagnostics of mining equipment. Both firms maintain internal XR teams that co-develop scalable platforms with startups and academic labs, ensuring interoperability, safety compliance, and alignment with Industry 5.0 and digital twin strategies.
- ***New innovative firms and startups:*** A Gothenburg based startup develops AI-powered XR interfaces that allow operators to perform routine checks and maintenance through natural language interaction with large language models. Another startup offers plug-and-play XR modules for SMEs, enabling them to build

customized training scenarios without coding—dramatically lowering the barrier to entry. These firms also support remote events, helping distributed groups co-design components and assess production feasibility in immersive environments.

- *Traditional SMEs:* A mid-sized manufacturer adopts XR to onboard new assembly workers using interactive simulations that mirror real factory conditions. They use XR to conduct remote design reviews with suppliers, reducing travel and accelerating feedback loops. By implementing modular XR platforms, they improve training retention and reduce downtime, while also enabling technicians to perform remote equipment inspections and collaborate with external experts in real time.
- *Professional users:* Technicians use XR headsets and tablets to perform routine maintenance, guided by conversational AI agents that adapt to their skill level and provide real-time feedback. Designers work in shared virtual environments to iterate on parts and systems collaboratively, using MR tools to visualize prototypes and assess ergonomics. Factory layout planners use XR to test spatial configurations and optimize workflows before physical implementation.
- *End users:* Customers interact with new machinery through immersive XR demos at trade shows, showrooms, or online platforms. These experiences allow them to explore product features, configurations, and operational workflows in detail—especially for large or complex equipment that cannot be easily transported. XR enhances product understanding and supports informed purchasing decisions.
- *Public organisations:* Regional innovation hubs and vocational training centres deploy XR to support lifelong learning and industrial upskilling. XR modules are integrated into public training programs for technicians and assembly workers, often co-developed with industry partners. Public procurement includes XR-based safety and compliance training, and municipalities use XR to support inclusive employment initiatives and remote learning access.
- *Policy makers and financiers:* Vinnova and EU actors fund XR pilot projects focused on training efficiency, digital twin integration, and cross-sector collaboration. Policymakers work to remove regulatory barriers and establish standards for industrial XR deployment. National strategies promote XR adoption through incentives, public-private partnerships, and support for research and innovation platforms that connect academia, industry, and startups.

### **Key drivers**

- **Social:** Growing demand for safer, more inclusive training environments; generational shift toward immersive learning and collaboration
- **Technological:** Advances in XR hardware, AI integration, digital twins, and LLM interfaces; interoperability across platforms
- **Economic:** Need for cost-effective training, reduced travel, and faster prototyping; pressure to maintain global competitiveness
- **Ecological:** Reduced carbon footprint through remote collaboration and virtual prototyping; support for sustainable production practices
- **Political:** EU policy alignment on XR deployment; national strategies for Industry 5.0 and digital transformation

### ***Opportunities and risks for developers***

	<b><i>Opportunities</i></b>	<b><i>Risks</i></b>
<i>Startups building modular XR training platforms</i>	High demand from SMEs and vocational centres for customizable, low-code tools	High upfront development costs; long sales cycles; need for pedagogical validation
<i>AI-integrated XR interface developers</i>	Unique value in operator-machine interaction; potential for cross-sector use	Fragmented standards; LLM integration challenges; data privacy concerns
<i>Digital twin and simulation tool providers</i>	Strong alignment with Industry 5.0; partnerships with large firms and researchers	Complex integration requirements; dependency on client infrastructure
<i>Content creators for immersive design and prototyping</i>	Growing need for Virtual Build Events and ergonomic simulations	IP ownership disputes; difficulty scaling bespoke content across clients
<i>Sales and marketing XR solution firms</i>	Demand for hyper-realistic product visualization; trade show and remote demo use	High rendering costs; niche market size; limited repeatability across sectors
<i>XR integrators for SMEs and public organisations</i>	Expansion into underserved markets; public procurement opportunities	Limited internal capacity for support; need for localization and compliance
<i>Platform providers for multi-device XR environments</i>	Demand for cross-platform access (headsets, tablets, laptops); remote collaboration	Interoperability challenges; performance optimization across devices
<i>EU-funded innovation consortia and labs</i>	Access to research funding; ability to shape standards and policy	Regulatory uncertainty; administrative overhead; slow commercialization timelines

### ***Implications, opportunities, and pathways for Swedish society***

The widespread adoption of XR in industrial manufacturing strengthens Sweden's position as a global leader in advanced production. It supports safer, more efficient workplaces and enables lifelong learning across the workforce. SMEs gain access to scalable training and design tools, reducing barriers to innovation. Large firms benefit from streamlined operations and enhanced collaboration, while startups and researchers drive new interaction models and content formats. XR also contributes to sustainability by reducing travel, material waste, and energy use in prototyping and testing. It supports inclusive employment by enabling remote onboarding and adaptive training for diverse user groups. Public organisations play a key role in spreading best practices and ensuring equitable access to XR infrastructure.

To fully realize this scenario, Sweden must invest in empirical studies, implementation frameworks, and open platforms that allow industrial actors to develop and share XR content. Policy alignment, cross-sector collaboration, and targeted funding will be essential to scale adoption and unlock the full potential of XR in manufacturing.

### **Opportunities and risks for the ecosystem**

	<b>Opportunities</b>	<b>Risks</b>
<i>Universities &amp; research groups</i>	Research funding, industry collaboration, pedagogical leadership	Limited access to industrial data and deployment environments
<i>Large established firms</i>	Efficiency gains, global competitiveness, internal innovation	Integration complexity, high upfront investment
<i>Startups &amp; innovators</i>	Niche solutions, partnerships, rapid iteration	Market fragmentation, scaling challenges
<i>Traditional SMEs</i>	Affordable training, remote collaboration, reduced travel	Lack of internal expertise, dependence on external platforms
<i>Professional users</i>	Safer workflows, intuitive interfaces, continuous learning	Overreliance on tech, need for digital literacy
<i>End users</i>	Enhanced product understanding, immersive engagement	Privacy concerns, accessibility gaps
<i>Public organisations</i>	Workforce development, regional innovation, procurement leverage	Budget constraints, uneven adoption
<i>Policy makers &amp; financiers</i>	Strategic leadership, ecosystem coordination, funding impact	Regulatory lag, fragmented policy landscape

### **XR in healthcare: Enhancing care, competence, and access across Sweden**

In the envisioned future, XR is a foundational technology across Sweden’s healthcare system. It supports onboarding, continuous training, patient care, and public health outreach. XR enables immersive simulations for clinical education, real-time support for medical procedures, and remote treatment in underserved regions. It also empowers patients through pain relief, preparation for interventions, and rehabilitation. Integrated with AI and medical records, XR becomes a trusted interface for safer, more personalized, and more inclusive healthcare.

#### **A fictive scenario for XR & healthcare**

By 2035, XR is embedded in clinical workflows, education, and patient interaction. Nurses and assistant nurses train in immersive simulations that replicate ward procedures, equipment handling, and interprofessional teamwork. Specialized modules address rare events, complex machinery, and language barriers, supporting diverse groups and improving communication. VR is used off-site for theoretical and procedural training, while MR supports hands-on practice with real or mock equipment, reinforcing muscle memory and spatial awareness.

In surgery, XR assists specialists through intraoperative navigation, overlaying anatomical data and diagnostics in real time. During ward rounds, AR interfaces provide instant access to patient records, including medication history, lab results, and imaging, streamlining decision-making and reducing cognitive load. XR also supports remote care. Physiotherapists guide patients through rehabilitation exercises in immersive environments, while primary care providers conduct assessments and follow-ups in sparsely populated areas. In mental health, VR is used for cognitive behavioural therapy (CBT), exposure therapy, and emotional regulation. Patients use VR as a distraction technique during painful procedures or to prepare for surgery, reducing anxiety and improving outcomes.

- *Universities and research institutes:* Karolinska Institutet, Linköping University and RISE co-develop XR modules for nursing education and surgical training. Research units study the impact of immersive learning on clinical performance, empathy, and retention. XR labs collaborate with hospitals to prototype AR interfaces for ward rounds and diagnostics.
- *Large established firms:* Companies like Sectra and Elekta integrate XR into imaging systems and surgical platforms. They develop intraoperative AR tools and remote treatment modules for physiotherapy and oncology. Their R&D units work with clinicians to ensure compliance with medical standards and data security.
- *New innovative firms and startups:* A Stockholm-based startup builds AI-powered XR agents that guide nurses through procedures, adapting to skill level and language. Another develops VR environments for paediatric pain relief and pre-surgical preparation. These firms partner with hospitals and education providers to pilot and scale their solutions.
- *Traditional SMEs:* A regional care provider in Värmland adopts XR for onboarding assistant nurses and training in dementia care. They use shared XR platforms to reduce costs and collaborate with other municipalities on content development and procurement.
- *Professional users:* Doctors use AR glasses during ward rounds to access patient data hands-free. Nurses train in interprofessional simulations that include emergency scenarios and communication drills. Physiotherapists conduct remote sessions using XR to monitor movement and provide feedback.
- *End users:* Patients use VR to manage pain, reduce anxiety, and prepare for procedures. In rural areas, they receive remote assessments and follow-up care through XR platforms, improving access and continuity of care.
- *Public organisations:* Hospitals and vocational training centres deploy XR for continuous competence development. Municipalities collaborate on shared procurement and management of XR training modules. Public health agencies use XR to educate citizens on preventive care and mental health.
- *Policy makers and financiers:* Region Västra Götaland and national health authorities fund XR pilots and support standardization. Policymakers address GDPR and interoperability challenges, promoting secure integration with medical record systems. Innovation platforms help coordinate efforts and spread best practices.

### **Key drivers**

- **Social:** Need for inclusive training, improved patient experience, and equitable access to care across regions
- **Technological:** Advances in AR/VR hardware, AI-guided agents; integration with electronic health records
- **Economic:** Pressure to reduce training costs, improve efficiency, and expand care delivery without increasing staff burden
- **Ecological:** Reduced travel for training and care; support for remote services in sparsely populated areas
- **Political:** GDPR compliance, public sector procurement reform, and national strategies for digital health innovation

### ***Opportunities and risks for developers***

	<b><i>Opportunities</i></b>	<b><i>Risks</i></b>
<i>XR training platform providers</i>	High demand from hospitals and vocational schools	High development costs; need for pedagogical validation
<i>AR interface developers for clinical use</i>	Integration with patient records; real-time decision support	GDPR and data security challenges; system interoperability
<i>VR content creators for patient engagement</i>	Growing use in pain relief, mental health, and pre-op preparation	Limited clinical validation; niche use cases
<i>Startups focused on remote care and physiotherapy</i>	Expansion into rural and underserved regions	Reimbursement and regulatory hurdles
<i>Public sector integrators</i>	Shared procurement and training across municipalities	Budget constraints; slow adoption cycles

### ***Implications, opportunities, and pathways for Swedish society***

The integration of XR into healthcare strengthens Sweden's commitment to equitable, high-quality care. It supports lifelong learning for medical professionals, improves patient outcomes, and expands access in remote regions. XR reduces anxiety and pain, enhances communication, and fosters empathy, transforming both clinical practice and patient experience.

To reach this future, Sweden must address cost-sharing, procurement, and data integration challenges. Common platforms and shared management models can reduce duplication and accelerate adoption. Endorsement from top-level and middle management is essential, as is trust-building among staff and patients. An innovation platform can play a key role by identifying best practices, connecting partners, and supporting implementation. It can help overcome scepticism, promote secure and ethical use of XR, and ensure that public sector organisations benefit from scalable, validated solutions.

### ***Opportunities and risks for the ecosystem***

	<b><i>Opportunities</i></b>	<b><i>Risks</i></b>
<i>Universities &amp; research groups</i>	Research funding, pedagogical leadership, clinical validation	Limited access to deployment environments; slow translation to practice
<i>Large established firms</i>	Integration with existing systems, clinical partnerships	Regulatory complexity; data compliance burden
<i>Startups &amp; innovators</i>	Niche solutions, rapid iteration, patient-centred design	Fragmented market; reimbursement uncertainty
<i>Traditional SMEs</i>	Affordable training, shared procurement, regional collaboration	Lack of internal capacity; dependence on external platforms
<i>Professional users</i>	Safer workflows, adaptive learning, improved care delivery	Tech scepticism; need for digital literacy
<i>End users</i>	Reduced anxiety, better access, personalized care	Privacy concerns; accessibility gaps
<i>Public organisations</i>	Workforce development, procurement leverage, regional equity	Budget constraints; uneven adoption
<i>Policy makers &amp; financiers</i>	Strategic leadership, funding impact, regulatory reform	GDPR and interoperability barriers; slow consensus

## ***XR in games and culture: A maturing medium for collective creativity***

In the coming years, XR becomes a dynamic platform for artistic expression, storytelling, and entertainment across Europe. Despite recent economic challenges and slow adoption rates, the convergence of open-source platforms, generative AI, and multisensory technologies opens new creative possibilities. Indie studios, cultural institutions, and cross-disciplinary teams begin to shape XR into a collective medium, much like cinema and theatre before it. As XR gains its own narrative language and dramaturgical style, it evolves into a vibrant space for experimentation, community-building, and immersive cultural experiences.

### ***A fictive scenario for XR and the games and culture sector***

By the late 2020s, XR in games and culture has moved beyond its plateau. Indie developers, empowered by open-source platforms like Android XR and WebXR produce compelling XR-exclusive content. Generative AI helps streamline production and enhance visual fidelity, allowing small organisations to compete with larger studios. While some creatives remain sceptical of AI's impact on artistry, others embrace it as a tool for expanding narrative depth and visual experimentation. Lower equipment costs and more intuitive development tools make the medium accessible to a wider range of creators.

New forms of storytelling emerge, inspired by digital communities, user-generated identities, and Nordic LARP traditions. These immersive worlds blend game mechanics with live-action roleplay, creating hybrid formats that challenge conventional boundaries between audience and performer. Multisensory technologies such as haptic suits, olfactory devices, and full-body tracking become more affordable and widely adopted. Combined with cloud-rendered services and location-based XR venues, these tools allow audiences to experience high-fidelity content without expensive personal hardware. As XR becomes more collective and socially engaging, it attracts larger audiences and matures into a recognized cultural format.

- *Universities and research institutes:* Arts and media faculties at institutions like Lund University and Umeå Institute of Design collaborate with game labs to explore immersive dramaturgy, multisensory storytelling, and digital identity. Research units run experimental XR workshops that blend Nordic LARP traditions with interactive narrative design, contributing to new formats for cultural expression.
- *Large publishers and cultural institutions:* Major publishers cautiously invest in XR adaptations of classic IPs, while museums and performing arts venues pilot XR installations that combine archival material with interactive elements. Institutions like the Swedish Museum of Performing Arts use XR to reimagine exhibitions and reach younger audiences through gamified cultural experiences.
- *Startups and indie developers:* Small studios build AI-assisted XR tools that help creators generate environments, characters, and branching narratives. Others focus on multiplayer XR platforms that support digital communities and user-driven storytelling. These teams often operate with minimal resources but high creative autonomy, driving innovation in the medium.
- *Traditional SMEs:* Regional creative firms expand into XR by developing virtual gallery tours, interactive theatre productions, and local heritage experiences. They collaborate with developers to create content that reflects regional identity and engages local audiences, often supported by municipal grants or cultural funds.
- *Professional users:* Game designers, writers, and performers take on hybrid roles as immersive content directors, leading XR productions that combine visual art, sound design, and live interaction. They work across disciplines to shape new formats for collective storytelling and audience engagement.

- *End users*: Players engage with XR through multiplayer games, cultural experiences, and social platforms. They create avatars, participate in digital communities, and contribute to evolving storylines, blurring the line between audience and co-creator.
- *Public organisations*: Libraries, museums, and arts councils commission XR experiences for education, outreach, and inclusion. They support access through public venues and mobile platforms, and often partner with developers and artists to co-create content.
- *Policy makers and financiers*: Regional and EU-level actors fund XR pilots, support open-source infrastructure, and promote ethical standards for biometric data. They encourage cross-sector collaboration and invest in creative innovation to strengthen Europe's cultural and technological sovereignty.

### **Key drivers**

- **Social**: Growing demand for collective and community-driven experiences in digital spaces
- **Technological**: Advances in generative AI, open-source XR platforms, and multisensory interaction tools
- **Economic**: Need for cost-effective production tools and new revenue models for small studios
- **Ecological**: Reduced travel and material use through virtual cultural events and digital distribution
- **Political**: Support for European digital sovereignty, creative funding, and ethical data governance

### **Opportunities and risks for developers**

	<b>Opportunities</b>	<b>Risks</b>
<i>Indie studios creating XR-exclusive content</i>	Access to open platforms and AI tools for rapid development	Limited funding and market visibility
<i>Startups building generative XR tools</i>	Demand for creative automation and cross-platform support	Ethical concerns and resistance from traditional creatives
<i>Cultural institutions commissioning XR experiences</i>	New formats for outreach and education	High production costs and uncertain audience engagement
<i>Developers of multisensory hardware and interaction tech</i>	Integration into collective XR formats and public venues	Fragmented standards and slow adoption
<i>XR platform providers for social and community content</i>	Growth in digital identity and multiplayer storytelling	Moderation challenges and data privacy risks

### **Implications, opportunities, and pathways for Swedish society**

Sweden's creative sector stands to benefit from XR's evolution into a collective and expressive medium. Indie studios and artists gain new tools to tell stories, build communities, and reach audiences beyond traditional formats. Cultural organisations can expand access and engagement through immersive exhibitions and virtual performances. Public venues and mobile platforms help democratize XR, making it available to diverse groups across regions.

To realize this potential, Sweden must support cross-disciplinary collaboration, invest in open-source infrastructure, and promote ethical standards for biometric data. Educational institutions can lead the way by developing XR-focused curricula and training programs.

Innovation platforms play a key role in connecting creators, developers, and funders, helping to build a sustainable ecosystem for XR in games and culture.

***Opportunities and risks for the ecosystem***

	<b><i>Opportunities</i></b>	<b><i>Risks</i></b>
<i>Universities and research groups</i>	Curriculum development and artistic exploration	Limited funding and slow institutional adoption
<i>Large publishers and institutions</i>	Cultural innovation and audience expansion	High production costs and uncertain ROI
<i>Startups and indie developers</i>	Creative freedom and new storytelling formats	Market fragmentation and platform lock-in
<i>Traditional SMEs</i>	Regional relevance and expanded offerings	Lack of technical capacity and funding
<i>Professional users</i>	New roles and creative leadership	Need for upskilling and interdisciplinary fluency
<i>End users</i>	Richer experiences and community participation	Privacy concerns and content moderation
<i>Public organisations</i>	Educational outreach and cultural access	Budget constraints and uneven infrastructure
<i>Policy makers and financiers</i>	Strategic investment and digital sovereignty	Regulatory complexity and slow consensus

## ***XR in societal applications: Building inclusive, resilient, and data-driven communities***

In the envisioned future, XR becomes a central tool for shaping Sweden's cities, public services, and civil preparedness. Integrated with AI and digital twins, XR supports inclusive urban planning, immersive public engagement, and advanced crisis response. Citizens, planners, and public agencies collaborate in virtual environments to co-create sustainable and accessible communities. From traffic simulations to participatory design forums, XR helps Sweden lead the way in smart, resilient, and inclusive societal development.

### ***A fictive scenario for XR and societal transformation***

In Norrköping, city planners gather at Visualization Center C to explore a digital twin of the city. Augmented reality overlays machine learning insights, predicting traffic flows and environmental impacts for new districts like Ostlänken and Inre Hamnen. Residents, including those with disabilities, participate in virtual reality forums to experience and shape urban plans, ensuring inclusive decision-making through AI-analysed feedback.

In Malmö, the Swedish Civil Contingencies Agency (MSB) trains in immersive crisis simulations, using AI to model natural disasters, cyberattacks, and multi-agency coordination. Stockholm's traffic strategists use AR and digital twins to optimize flow and safety across the city. Cloud-based XR platforms allow remote access, enabling nationwide collaboration and participation.

This XR ecosystem transforms how Sweden designs, governs, and protects its communities. It supports real-time planning, inclusive consultation, and adaptive training—positioning XR as a foundational technology for public sector innovation.

- ***Universities and research institutes:*** Linköping University and KTH collaborate with municipalities to develop XR tools for urban analytics, citizen engagement, and crisis simulation. Students learn to build digital twins and design inclusive interfaces, while research teams explore how AI-enhanced XR can improve decision-making and public trust.
- ***Municipalities and public agencies:*** Cities like Norrköping, Gothenburg, and Umeå deploy XR for participatory planning, traffic modelling, and accessibility audits. Public forums allow residents to explore future neighbourhoods in VR and provide feedback that is analysed by AI to inform planning decisions. Agencies also use XR to visualize policy impacts and coordinate across departments.
- ***Startups and developers:*** Small firms create modular XR applications for environmental impact visualization, public consultation, and civil preparedness. Others focus on accessibility tools that allow users with disabilities to navigate and interact with virtual spaces. These startups often partner with municipalities or universities to pilot their solutions.
- ***Defence and civil protection org:*** MSB and regional emergency services use XR to simulate crisis scenarios such as floods, cyberattacks, and multi-agency coordination. These immersive environments improve preparedness and foster collaboration between civilian and military actors.
- ***Professional users:*** Urban planners, architects, and emergency responders use XR to simulate infrastructure changes, assess risks, and engage stakeholders. They rely on real-time data and AI-driven insights to guide decisions and communicate complex scenarios to non-experts.
- ***Citizens:*** Residents participate in virtual consultations, explore city plans, and contribute to community design. XR platforms offer accessible interfaces for remote users, elderly residents, and people with mobility challenges, ensuring broader inclusion in civic processes.

- *Policy makers and financiers:* Regional authorities and national funders like Vinnova support XR adoption through pilot programs, open standards, and strategic investments. They promote ethical frameworks for biometric data and encourage cross-sector collaboration to scale XR across public services.

**Key drivers**

- Social: Demand for inclusive public services, citizen participation, and accessible urban design
- Technological: Advances in AI, digital twins, cloud rendering, and multisensory XR interfaces
- Economic: Need for cost-effective planning tools, scalable training, and efficient infrastructure development
- Ecological: Support for sustainable urban growth, environmental modelling, and climate resilience
- Political: National strategies for smart cities, civil preparedness, and digital inclusion

**Opportunities and risks for developers**

	<b>Opportunities</b>	<b>Risks</b>
<i>XR platforms for urban planning and consultation</i>	High demand from municipalities and regional planners	Complex integration with legacy systems and data standards
<i>AI-enhanced simulation tools for crisis response</i>	Partnerships with defence and civil protection agencies	Regulatory constraints and high validation requirements
<i>Accessibility-focused XR developers</i>	Growing need for inclusive interfaces and remote participation	Limited funding and fragmented user needs
<i>Digital twin and visualization startups</i>	Alignment with smart city initiatives and public infrastructure projects	High technical complexity and data interoperability challenges
<i>Cloud-based XR service providers</i>	Nationwide scalability and remote access	Latency issues and dependence on robust ICT infrastructure

**Implications, opportunities, and pathways for Swedish society**

The integration of XR into societal applications strengthens Sweden’s capacity for inclusive governance, sustainable development, and civil resilience. Citizens gain new ways to engage with their communities, while planners and public agencies benefit from real-time insights and immersive collaboration. XR helps bridge gaps in accessibility, participation, and preparedness—supporting a more equitable and responsive public sector.

To reach this future, Sweden must invest in ICT infrastructure, open standards, and cross-sector collaboration. Universities can lead in training the next generation of XR and AI professionals. Public-private partnerships can create testbeds for innovation, while national funding bodies support scalable, interoperable solutions. An innovation platform can accelerate adoption by connecting municipalities, researchers, startups, and defence agencies. It can coordinate pilot projects, promote OpenXR standards, and support training in XR and deep learning. By fostering collaboration and building capacity, the platform helps Sweden realize a resilient, inclusive, and data-driven society.

### ***Opportunities and risks for the ecosystem***

	<b><i>Opportunities</i></b>	<b><i>Risks</i></b>
<i>Universities and research groups</i>	Curriculum development and applied research	Limited deployment environments and funding cycles
<i>Municipalities and public agencies</i>	Inclusive planning and citizen engagement	Integration challenges and uneven digital maturity
<i>Startups and developers</i>	Innovation in civic tech and accessibility tools	Market fragmentation and procurement barriers
<i>Defence and civil protection bodies</i>	Advanced training and scenario modelling	High compliance demands and data sensitivity
<i>Professional users</i>	Real-time decision support and collaborative workflows	Need for upskilling and system interoperability
<i>Citizens</i>	Participation in planning and access to public services	Digital divide and privacy concerns
<i>Policy makers and financiers</i>	Strategic investment and public trust	Regulatory complexity and slow consensus

- 
- <sup>1</sup> *Drivers* are something that creates the development or change and gives birth to trends. This could be e.g. technical developments, natural occurrences, or demographic shifts. *Trends* are developments, changes or shifts that occur through time. Trends have a direction and increase or decrease. *Signals* are signs of early change, also called “seeds of change”, which can be hard to interpret today but could nevertheless have a great importance in the future. These signals can be vague and ambiguous but could still give important information about the future.
- <sup>2</sup> Goodley, S. (2025, May 27). Tough times loom for night-time economy as young Britons opt to go out (and go home) early. *The Guardian*.
- <sup>3</sup> Maloney, D., Freeman, G., & Robb, A. (2021). Stay connected in an immersive world: Why teenagers engage in social virtual reality. In *Proceedings of the 20th ACM Interaction Design and Children Conference* (pp. 69–79). Association for Computing Machinery.
- <sup>4</sup> Eventmasterbook. (2023, April 18). Generation Z prefers entertainment and networking in virtual spaces. *Event Master Book Magazine*.
- <sup>5</sup> VIVERSE Team. (2024, December 17). The rise of virtual communities: How digital platforms unite people across the globe. *VIVERSE Blog*.
- <sup>6</sup> Gatsou, C., & Farrington, J. S. (2022). The evolution of the graphical user interface: From skeuomorphism to material design. *Design/Arts/Culture*, 2.
- <sup>7</sup> Lin, J., & Latoschik, M. E. (2022). Digital body, identity and privacy in social virtual reality: A systematic review. *Frontiers in Virtual Reality*, 3.
- <sup>8</sup> Sperling, J. (2024, March 29). Here’s how social media affects your mental health. *McLean Hospital*.
- <sup>9</sup> Nakshine, V. S., Thute, P., Khatib, M. N., & Sarkar, B. (2022). Increased screen time as a cause of declining physical, psychological health, and sleep patterns: A literary review. *Cureus*, 14(10).
- <sup>10</sup> Folkhälsomyndigheten. (2024). Digitala medier och barns och ungas hälsa: Kunskapssammanställning. Folkhälsomyndigheten.
- <sup>11</sup> Chotpitayasunondh, V., & Douglas, K. M. (2018). The effects of “phubbing” on social interaction. *Journal of Applied Social Psychology*, 48(6), 304–316.
- <sup>12</sup> Morrison, N. (2024, June 4). Too much internet use is changing teenage brains, study finds. *Forbes*.
- <sup>13</sup> Preston, D. (2025, February 4). Opera’s new browser might save you from doomscrolling. *The Verge*.
- <sup>14</sup> McLay, R. N., McBrien, C., Wiederhold, M. D., & Wiederhold, B. K. (2010). Exposure therapy with and without virtual reality to treat PTSD while in the combat theater: A parallel case series. *Cyberpsychology, Behavior, and Social Networking*, 13(1), 37–42.
- <sup>15</sup> Dilgul, M., Martinez, J., Laxhman, N., Priebe, S., & Bird, V. (2020). Cognitive behavioural therapy in virtual reality treatments across mental health conditions: A systematic review. *Consortium Psychiatricum*, 1(1), 30–46.
- <sup>16</sup> Hermander, K., Jildenstål, P., Erestam, S., Dahm, P., Lindgren, S., Strömberg, J., & Sjöberg, C. (2025). Healthcare professionals’ perceptions of pre-, peri-, and postoperative virtual reality immersion in elderly patients. *Healthcare*, 13(6), 669.
- <sup>17</sup> Region Stockholm – Astrid Lindgren’s Barnsjukhus. (2024, October 18). Implementation of eXtended Reality (XR) technology for painful procedures in pediatric healthcare, VINNOVA.
- <sup>18</sup> Wearable Devices Ltd. (2025). Wearable Devices Ltd. unveils next-generation AI-powered gesture personalization technology for XR and wearable markets. *Nasdaq*.
- <sup>19</sup> Financial News. (2024). Luminous XR unveils code-free VR content tool. *Financial News*.
- <sup>20</sup> Wang, E., Dohler, M., Phillips, G., & Karlsson, P. (2023, May 15). Five research insights on 6G and XR. *Ericsson*.
- <sup>21</sup> O’Halloran, J. (2024, January 25). Additional spectrum needed for 5G Advanced, 6G networks. *Computer Weekly*.
- <sup>22</sup> The Verge. (2024, October 1). Microsoft is discontinuing its HoloLens headsets; *The Verge*. (2023, March 15). Google Glass Enterprise Edition is no more; *Reuters*. (2024, September 17). EssilorLuxottica extends smart glasses partnership with Meta.

- 
- <sup>23</sup> OpenBCI. (n.d.). Galea: The world's most advanced biosensing headset. Retrieved April 10, 2025.
- <sup>24</sup> Research and Markets. (2025, February 6). Brain computer interface technology revolutionizing healthcare, communication, and gaming sectors. *GlobeNewswire*.
- <sup>25</sup> Mattsson, S., Partini, J., & Fast-Berglund, Å. (2016). Evaluating four devices that present operator emotions in real-time. *Procedia CIRP*, 50, 524–528.
- <sup>26</sup> Mickle, T. (2024, December 26). Companies finally find a use for virtual reality—at work. *The Wall Street Journal*. Luminous XR. (n.d.). VR safety skills app for workforce training.
- <sup>27</sup> European Commission: Directorate-General for Research and Innovation, Breque, M., De Nul, L., & Petridis, A. (2021). *Industry 5.0 – Towards a sustainable, human-centric and resilient European industry*. Publications Office of the European Union.
- <sup>28</sup> Romero, D., & Stahre, J. (2021). Towards the resilient operator 5.0: The future of work in smart resilient manufacturing systems. *Procedia CIRP*, 104, 1089–1094.
- <sup>29</sup> *IndustryWeek*. (2025, January 17). Immersive AR/VR technologies in manufacturing: Case studies, benefits. *IndustryWeek*.
- <sup>30</sup> Flintberg, B., Svenman Wiker, L., & Trella, F. (2024). *Möjligheter för användning av VR i lärande- och valideringskontext: En forskningsstudie om utmaningar och möjligheter att använda virtual reality för lärande och validering*. RISE Research Institutes of Sweden.
- <sup>31</sup> European Commission, Directorate-General for Communications Networks, Content and Technology, ECORYS, & KEA. (2023). *Understanding the value of a European video games society*. Publications Office of the European Union; Flintberg, B., & Nylander, J. (2023). *Kraftsamling Dataspelebranschen : En rapport om svensk spelindustri*. RISE Research Institutes of Sweden.
- <sup>32</sup> Wang, R., Wang, J., Hao, Y., Hu, L., Alqahtani, S. A., & Chen, M. (2023). A context-aware cloud-edge-end collaboration framework toward green metaverse. *IEEE Wireless Communications*, 30(5), 144–150.
- <sup>33</sup> de Giorgio, A., Monetti, F. M., Maffei, A., Romero, M., & Wang, L. (2023). Adopting extended reality? A systematic review of manufacturing training and teaching applications. *Journal of Manufacturing Systems*, 71, 645–663; Marino, E., Bevacqua, G., Drago, M. F., Barbieri, L., Bruno, F., & Muzzupappa, M. (2025). A collaborative XR platform for streamlining industrial maintenance activities. In *Lecture Notes in Mechanical Engineering* (pp. 303–310).
- <sup>34</sup> Yeom, S., Kim, J., Kang, H., Jung, S., & Hong, T. (2024). Digital twin (DT) and extended reality (XR) for building energy management. *Energy and Buildings*, 323, Article 114746.
- <sup>35</sup> *The Conversation*. (2025, January 9). How virtual reality technologies are shaping an inclusive future for architecture.
- <sup>36</sup> *Nextbrick*. (2024, December 25). How AR and VR are transforming remote work and virtual collaboration.
- <sup>37</sup> European Commission. (n.d.). *The Digital Services Act*. Retrieved April 10, 2025; European Commission. (2023, July 11). *An EU initiative on Web 4.0 and virtual worlds: A head start in the next technological transition*.
- <sup>38</sup> *Tech Policy Press*. (2024, May 9). *Physical solutions in virtual spaces: Challenges to content moderation in XR*.
- <sup>39</sup> *XR Today*. (2024, October 1). 7 reasons to invest in XR security and data privacy this year. *Biometric Update*. (2025, February 20). *DARPA continues work on technology to combat deepfakes*.
- <sup>40</sup> *IEEE Standards Association*. (n.d.). *The IEEE Global Initiative on Ethics of Extended Reality*. Retrieved April 10, 2025.
- <sup>41</sup> *Privacy & Information Security Law Blog*. (2025, May 22). *D.C. Federal Court rules termination of Democrat PCLOB members is unlawful*.