eXperiential Technologies in India

A WHITE PAPER AND SKILL GAP ANALYSIS
OF EXPERIENTIAL TECHNOLOGIES IN INDIA (2024)

A REPORT
OF THE INDUSTRIAL CONSORTIUM FOR XR IN INDIA
CAVE (CONSORTIUM FOR AR AND VR ENGINEERING)
AT IIT MADRAS

IoE Research Center on VR and Haptics
eXperiential Technology Innovation Center (XTIC),
IIT Madras

THIS PAGE
INTENTIONALLY
LEFT BLANK

Indian Institute of Technology Madras
Chennai – 600 036

Phone : 0091-44-2257 0694 / 0091-44-2257 8001
Fax : 0091-44-2257 8003 / 0091-44-2257 0509

भारतीय प्रौद्योगिकी संस्थान मद्रास
चेन्नै – ६०० ०३६

Email : kama@cse.iitm.ac.in / director@iitm.ac.in
Web : http://www.iitm.ac.in

प्रो. वी. कामकोटि
Prof. V. Kamakoti
निदेशक
Director

Foreword

DIR.2024
29th February 2024

While Artificial Intelligence and Machine Learning have rightfully captured the spotlight, there exists another realm of innovation known as eXperiential Technologies (XT) or Spatial Technologies (ST), poised to revolutionize our interactions with the digital world. This report serves as a comprehensive overview of XT and its implications within the Indian context.

Also known as immersive technologies, XT encompasses a spectrum of innovations, including Virtual Reality (VR), Augmented Reality (AR), Mixed Reality (MR), Extended Reality (XR), Metaverse, Web 3.0, and Haptics. These technologies, collectively, represent a fundamental aspect of the ambitious Digital India initiative, promising transformative applications across various sectors such as healthcare, retail, manufacturing, real estate, tourism, education, and more.

A critical analysis of India's systemic competencies reveals areas ripe for development to establish global leadership in XT/ST. This report underscores the urgent need for advanced education in Perception Engineering, as well as R&D initiatives to propel our XR community towards greater value creation. To this end, the whitepaper proposes the establishment of an XR-Superhighway—a comprehensive network comprising innovation centers, skill training facilities, experience spaces, and manufacturing hubs—designed to empower individuals and drive multi-sectoral advancements in XT/ST.

Central to the XR/ST is the concept of the metaverse. As the whitepaper correctly noted, the development and governance of the metaverse must prioritize privacy, security, accessibility, and inclusivity, laying the foundation for a collaborative and equitable digital ecosystem. To this end, I am happy that the Metaverse India Policy and Standards (MIPS) forum has been established, dedicated to fostering an open and inclusive metaverse on a global scale.

In our pursuit of excellence, it is essential to leverage open-source technologies to foster standardization, interoperability, and scalability. Furthermore, investment in advanced education, research, and infrastructure is paramount to establishing India as a global leader in experiential technologies.

This report represents a collective effort led by IIT Madras team, drawing insights from diverse stakeholders, including members of the Consortium of Virtual Reality Engineering (CAVE) and esteemed committee members. It is our hope that this white paper will serve as a guiding light, informing policy decisions and driving India's successful exploitation and growth in the realm of experiential technologies.

Together, let us embark on this journey towards a future where experiential technologies empower us to transcend boundaries and unlock endless possibilities.

V. Kamakoti

V. Kamakoti

एस. कृष्णन, आई.ए.एस.
सचिव
S. Krishnan, I.A.S.
Secretary

सत्यमेव जयते

इलेक्ट्रॉनिकी और सूचना प्रौद्योगिकी मंत्रालय
भारत सरकार
Ministry of Electronics &
Information Technology (MeitY)
Government of India

FOREWORD

As we stand at the brink of the Fifth Industrial Revolution, characterized by the convergence of digital, physical, and biological spheres, it is imperative for nations to embrace and harness transformative technologies that propel us forward. This White Paper, presented by IIT Madras, serves as a crucial guide for India's journey towards leadership in the realm of eXperiential Technologies (XT) or Spatial Technologies (ST).

To harness the full potential of eXperiential Technologies (XT). "immersive technologies", we need a clear vision and forward-thinking measures that foster innovation and accelerate growth. This White Paper acts as a roadmap for India's XT journey, outlining crucial initiatives in education and training to cultivate a skilled workforce for this technological revolution. It emphasizes the need for supportive frameworks that empower businesses and entrepreneurs in the XT landscape. Additionally, it underscores the significance of a robust digital infrastructure to ensure XT's accessibility for all.

This report also offers a comprehensive overview of XT, encompassing a wide range of immersive technologies like Virtual Reality (VR) and Augmented Reality (AR), besides Mixed Reality (MR) – a combination of VR & AR; and also eXtended Reality (XR) – an umbrella term encompassing all technologies that create immersive experiences, including haptics. These technologies hold the potential to revolutionize healthcare, manufacturing, education, and defense, ultimately fostering economic and societal development.

Notably, XT presents a catalytic force in India's digital transformation journey, not just complementing but also elevating existing initiatives like 'Digital India'. The proposed XR-Superhighway, XR Innovation Centers, and XR Skill Training Centers outlined in this report exemplify the commitment to nurturing a vibrant XT ecosystem in India. This report is a valuable resource for shaping policy interventions that promote innovation, foster entrepreneurship, and propel India towards becoming a global hub for XT.

I congratulate IIT Madras for this insightful report. By fostering collaboration between academia, industry, and government, we can accelerate research, development, and adoption of XT, positioning India as a global leader in this burgeoning field.

(S. Krishnan)

Place: New Delhi
Dated: 28th February, 2024

आज़ादी का अमृत महोत्सव

Digital India
Power To Empower

इलेक्ट्रॉनिक्स निकेतन, 6, सी.जी.ओ. कॉम्प्लेक्स, नई दिल्ली–110003 / Electronics Niketan, 6, C.G.O. Complex, New Delhi-110003
Tel. : 011-24364041 • email : secretary@meity.gov.in

PREFACE

In an era marked by rapid technological advancements and digital transformation, the landscape of eXperiential technologies is evolving at an unprecedented pace. As “Digital India” is emerging, it is essential to assess the current state of experiential technologies and identify the existing skill gaps to foster sustainable growth and innovation.

This white paper serves as a comprehensive analysis/study of the ecosystem surrounding experiential technologies in India. Through data analysis, and collaboration with industry experts, academia, and policymakers, we endeavor to shed light on the opportunities, challenges, and future prospects within this rapidly evolving domain.

Moreover, this white paper conducts an in-depth XR (Extended Reality) skill gap analysis to evaluate the preparedness of India's workforce to meet the demands of the experiential technology landscape. Through the identification of critical proficiency areas and areas requiring enhancement, we aim to release a draft policy in the near future. This policy will serve as a guiding framework for stakeholders in academia, industry, and government, directing strategic investments towards education, training, and skill development initiatives.

In preparation for this Whitepaper, we convened a committee comprising seasoned industrialists and startup founders representing diverse sectors. These individuals were selected from among the members of the Consortium of Virtual Reality Engineering (CAVE) at IIT Madras, which stands as a unique consortium dedicated to XR in India.

This white paper aims to act as a foundation for fostering informed decision-making, collaboration, and concerted action to unlock the full potential of experiential technologies in India. Through a shared dedication to innovation, inclusivity, and excellence, we envision India assuming a leadership role in the global arena of eXperiential technologies. By doing so, we anticipate driving economic growth, facilitating societal transformation, and promoting human empowerment.

We extend our gratitude to all the individuals, organizations, and institutions whose contributions have made this white paper possible. May this document inspire dialogue, inspire action, and pave the path forward where eXperiential technologies enrich lives, empower communities, and unlock informal possibilities.

Sincerely,
Dr.M. Manivannan
Professor, IIT Madras

THIS PAGE
INTENTIONALLY
LEFT BLANK

EXECUTIVE SUMMARY

While the world is riding the technology wave of Artificial Intelligence and Machine Learning, eXperiential Technologies (XT) or Spatial Technologies (ST) holds promise as an emerging technology in the near future. This report presents an overview of XT and the prevailing climate and potential in India around this emerging technology. Also called immersive technologies, this suite of technologies collectively encompasses Virtual Reality (VR), Augmented Reality (AR), Mixed Reality (MR), Extended Reality (XR), Metaverse, Web 3.0 and Haptics (definitions provided in the report), all of which together can be considered to form a part of the ambitious Digital India initiative. The technology has a wide range of applications in healthcare, retail, manufacturing, real estate, tourism, architecture, product/service/experience/system design, construction, information, media and mass communication, education and training and skill development among others, with implications on the entire workforce and economy of a nation including defense and specialized task forces. From a very rudimentary beginning in the 1950-s, XT are gradually becoming all pervasive and are beginning to affect all walks of human life. Although a majority of current applications are in the gaming and multimedia industry, which saw the earliest adoption, applications in other areas are fast gaining momentum. Experiential technologies are complemented and enhanced by allied technologies, popularly referred to as exponential technologies – AI, Blockchain, Robotics, IoT and 5G; and XT/ST serves to integrate all of these to make them human-centric.

A gap analysis was conducted to assess the systemic competencies in India, similar to the initiatives in the Northern America, Europe, and China, to become a global leader in XT/ST, through widespread research, development, and implementation of these technologies in products, services, processes, and business models, resulting in profound economic, societal, and administrative impact. This white paper describes the gaps in India's XT hardware, software, and systemic competencies. The majority of India’s XR community is still at basic applications levels, highlighting an urgent need for advanced education in Perception Engineering as well as R&D and innovative approaches to take the community up the value chain. Towards this goal, this white paper proposes an XR-Superhighway - a global network to Vasudeiva Kutumbakam, an XR-Corridor - a national and regional corridor, XR Innovation Centers, XR Skill Training Centers, XR Experience Spaces, XR Manufacturing Centers and XR Education Centers to enable XR/XT empowerment that drive advanced education and skilling for multi-sectoral applications of XT/ST accelerated by global and local cooperative networks and communities of knowledge and practice that aim for shared

resources and shared progress.

The metaverse is the universe of XT/ST and its proper development and governance with due consideration for privacy, security, monetization, fairness, availability, accessibility, affordability, content moderation, inter-operability, trustability, etc. is critical to the growth of this technology in India. A Metaverse India Policy and Standards (MIPS) forum has been created. The objective of this forum is to build an open, inclusive and pervasive metaverse on a global scale through internal collaboration. Accordingly, the technology mission adopted by this forum serves to:

(i) Create the foundational elements of experiential technologies and provide a strong theoretical and mathematical foundation to the discipline,
(ii) Develop fundamental understanding of human embodiment in the virtual space and of human and manual interactions with the outside and virtual worlds in the context of perception engineering,
(iii) Foster R&D and play a vital role in the engineering of perceptual realities and creation of commercial and social applications of the technology that greatly impact human life, and
(iv) Leverage our country's position in the thriving IT and cyberspace sector as a catalyst for substantial and rapid growth of immersive technologies in the country's economy, resulting in India being the preferred and leading XR corridor of the world.

Open-source technologies offer several advantages such as standardization and interoperability, an interconnected digital ecosystem, adaptability, scalability, inclusivity and cost-effectiveness. Open-source frameworks are also crucial for small and startup businesses, which would otherwise find entry and initial operating costs to be prohibitively high and an insurmountable entry barrier.

The current scenario is that new-age technology providers such as Google, Microsoft, Apple and Meta are leading players and India needs to establish technology leadership in this domain to gain macro-economic stronghold over the current economic superpowers of the world. Unlike in the case of IT, where the India play was almost solely in the services sector, India needs to take significant ownership in technology and IP, which can bring far greater economic gains than merely being a services player. This requires substantial investment in higher education, advanced research, skill development, robust manufacturing system, valuable innovation, and fostering policies by the government. Further, since this technology has an associated hardware component, it would do well for the nation and established organizations to invest in hardware and manufacturing infrastructure, thus bringing about Industrial development on a large scale, along

with digital growth.

In line with the above, it is envisioned that India will be a global leader of XT through focussed research, development and implementation of these technologies in the form of products, services, processes and business models, resulting in profound economic, societal and administrative impact. Therefore, developing an ecosystem for investments in XR - enabling technology development, research, innovation, deployment, integration, and scaling up is both a prerogative and obligation of the Government. Hence policy-making should focus on all the above aspects for India's successful exploitation and growth of this industry.

This white paper has been prepared by gathering the response from a number of public audiences, members from the Consortium of Virtual Reality Engineering (CAVE) and committee members who volunteered to be part of this initiative in recommending an XR policy framework for the central government.

CONTRIBUTORS

1. Dr. M. Manivannan, Professor in-charge of Experiential Technology Innovation Center, IIT – Madras
2. Raghavendra Achari, Experiential Technology Innovation Center, IIT – Madras
3. Dr. A. Damodaran, Distinguished Professor, ICRIER
4. Jayashree Parthasarathy, National Informatics Centre, Chennai
5. Ashok Maharaj, Head of XR Labs, Tata Consultancy Services
6. Chitra Chandrashekhar, Creative Founder-Visual Story Designpreneur, Mographies
7. Rabindra Sah, Chief Engineer, Tata Technologies
8. Avi Dwivedi, Founder, XRDI
9. M. Sreenath, Founder, Busifrog Tech Pvt. Ltd.
10. Ganesh S, Vice President, ICT Academy
11. Keyur Bhalavat, CEO, Plutomen Technologies Pvt. Ltd.
12. Suhas P. Bhagwat, Founder, Avroglide Consultants
13. Suneel Sharma, SKYZ Hotech Solutions Pvt. Ltd.
14. Dr. A. Paventhan, Director, ERNET
15. Dr. Jayanth Murali, DGP (Retired)
16. Rohit Singh, Product Manager, Trezi
17. Pravin Hungund, Indian Administrative Fellow, The Nudge Institute, RDPR, GoK
18. Kuldeep Singh, Technology Director, Thoughtworks
19. Milind Manoj, Founder, PupilMesh

CONTENTS

THIS PAGE
INTENTIONALLY
LEFT BLANK

Chapter - 1

INTRODUCTION

The landscape of work is evolving rapidly. Technology is not only empowering individuals in their daily lives and professions, but it is also introducing a plethora of new avenues for efficiency and productivity. Digital technologies have now pervaded the everyday life of all social classes and we are well poised to leverage this for the next phase of economic and social development. We are experiencing a major shift in the way we learn, train, work and communicate. We have evolved from text and images to video and now to a world where immersive media and immersive technology content is slowly becoming the norm.

Technology driven "Digital India" is an ambitious program launched by the Government of India in 2015 with a vision to transform the country into a knowledge society empowered by a digital economy. This initiative aims to leverage technology to enhance governance, empower citizens, and drive overall economic growth. The Digital India program encompasses a wide range of projects and policies, focusing on various sectors to bring about a comprehensive digital transformation. Digital Yoga can be a feather in the cap of these initiatives such as Infrastructure Development (e.g., BharatNet), E-Governance, Digital Literacy (e.g., Pradhan Mantri Gramin Digital Saksharta Abhiyan (PMGDISHA)), Mobile Connectivity (National Optical Fiber Network (NOFN)), Digital Payments (Unified Payments Interface (UPI)), Skill Development (Digital India Internship Scheme), Cybersecurity, Digital India Start-up Hub, Digital Healthcare (National Digital Health Mission (NDHM)), Digital Inclusion (Common Service Centers (CSCs)). This white-paper aims to add Immersive Technologies as one of the Digital India initiatives.

Over the years, Immersive Technology has evolved multifold and has become affordable for the common end user. Immersive technology that employs but is not limited to 3D digital imagery, Artificial Intelligence (AI), Machine Learning (ML), Internet of Things (IoT) and haptics technology are attempting to provide an alternative or augmented experience to the real world in a meaningful way. The current immersive technology market size was estimated to be around USD 22.5 billion globally, and is projected to reach USD 167.75 billion by 2032 [1] implying a CAGR of about 22%. Other reports [2] suggest this at USD 1.35 trillion by 2030.

Immersive technology is developing and diversifying at a rapid pace, and

commercial applications of Immersive Technology are being deployed in manufacturing and retail, real estate and tourism, architecture, product/service/experience/system design, construction, information, Media and mass communication, healthcare, education, training and skill development. Not surprisingly, Immersive Technology is increasingly becoming the focus of huge multinational corporations and tech start-ups in the world. Hence, there is a fast-growing market demand for professionals. (There were about 300,000 premium Immersive Technology job postings across the world in 2019-2020 alone! - a number which is only set to increase many-fold in the coming decade.)

This is the opportune moment to frame a nation-wide policy for Immersive Technologies which will position India as one of the world leaders in the area of Virtual Reality, Augmented Reality, Mixed Reality, eXtended Reality and haptics - collectively called Immersive or eXperiential Technologies (XT), also sometimes referred to as Spatial Computing. Throughout this document, the term 'eXperiential Technology' or 'eXperiential Technologies', abbreviated to XT, will be used in preference to 'Immersive Technology' or 'Immersive Technologies'.

Chapter - 2

DEFINITIONS

The umbrella term '**Immersive Technologies**' or '**eXperiential Technologies (XT)**' or '**Spatial Technologies (ST)**' covers several types of technologies, the chief of which include (Refer Figure 1 and 2) [3]:

2.1 **Virtual Reality (VR)** refers to a fully immersive, computer-generated environment that users can interact with entirely.

2.2 **Augmented Reality (AR)** overlays digital information or objects onto the real-world environment, enhancing the user's perception of foreseeing the reality.

2.3 **Mixed reality (MR)**, combines elements of both VR and AR, allowing users to interact with both digital and physical objects in real-time. MR systems can understand and respond to the user's environment.

2.4 **Haptics (HT)Haptics**, the science of touch, refers to the technology that involves the sense of touch, particularly in the context of computing and electronic devices. Haptic technology aims to recreate the sense of touch or tactile sensations through the use of vibrations, force feedback, and other mechanisms.

2.5. **Extended Reality (XR)** is an umbrella term that encompasses various immersive technologies, including VR, AR, and MR. XR combines real and virtual environments to produce new environments and visualizations, where physical and digital objects coexist and interact in real-time. This term is often used to describe experiences that blend elements of the physical and digital worlds, providing users with enhanced sensory experiences and interactions beyond what is possible in traditional reality.

2.6. **Mobile XR** refers to delivery of XR content through smartphones or tablets, enabling users to interact with virtual, augmented, or mixed reality content on-the-go.

2.7. **WebXR** refers to an open standard that enables immersive experiences to be accessed and interacted with through web browsers, without the need for additional software or applications, allowing for widespread accessibility and adoption of XR technologies.

Other sensory perceptions such as olfactions [5] and gustations which naturally prompts one to wonder if perception of smell and taste could also be conquered by XR technologies of the future.

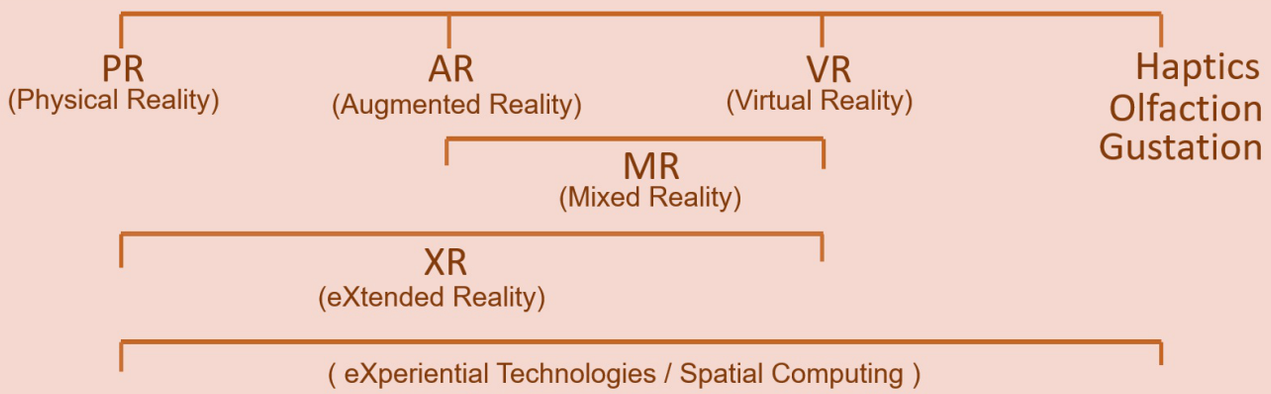


Figure 1. Landscape of Experiential Technologies and Spatial Computing

2.8 **Spatial Mapping** involves the process of creating a digital representation of physical environments for use in XR applications, facilitating interaction with virtual objects within real-world spaces.

2.9 **Spatial Awareness** refers to a system's ability to perceive and understand its surroundings in three dimensions, enabling more immersive and contextually aware experiences in XR environments.

2.10. **Spatial Interaction** encompasses the ways users engage with virtual objects or environments within a physical space, often using gestures, voice commands, or motion controllers to manipulate digital content.

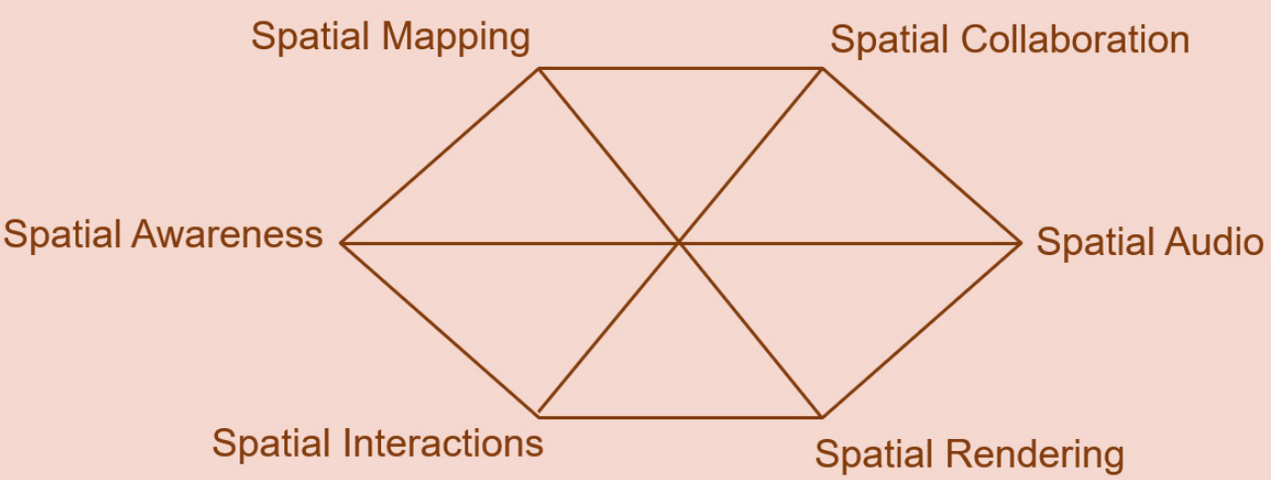


Figure 2. Dimensions of Spatial Computing

2.11. **Spatial Rendering** involves the generation and display of virtual objects or environments in a manner that accurately reflects their spatial relationships and interactions within the XR space.

2.12. **Spatial Audio** is a technique that creates three-dimensional soundscapes, enhancing immersion by accurately positioning audio sources within virtual environments to match their corresponding visual locations.

2.13. **Spatial Collaboration** refers to collaborative experiences that take place within shared virtual environments, allowing multiple users to interact and communicate with each other in real-time, regardless of their physical locations.

Chapter - 3

EXPERIENTIAL TECHNOLOGIES IN INDUSTRIES

3.1. History and evolution of eXperiential technologies

The history and evolution of eXperiential Technologies, including VR, AR and MR, have been marked by significant technological advancements and shifts in how we interact with and perceive digital information. Here's a brief overview of the key milestones in the development of eXperiential Technologies:

3.1.1. 1950s-1960s, Beginnings of Virtual Reality (VR): Morton Heilig, an American cinematographer, created the Sensorama in 1962, an immersive theater experience that stimulated multiple senses. Around the same time, computer scientist Ivan Sutherland from MIT developed the first head-mounted display (HMD) system, known as the 'Sword of Damocles'.

3.1.2. 1970s-1980s, Early VR Research: The term 'Virtual Reality' was coined by Jaron Lanier in the 1980s. VR systems were primarily used in academic and military settings during this period.

3.1.3. 1990s, Rise and Fall of VR: The 1990s saw increased interest in VR with the release of consumer-grade devices such as the Virtual Boy by Nintendo. However, the technology faced challenges, including limited computing power and graphics capabilities. Interest waned, which is often referred to as the 'VR Winter'.

3.1.4. 2000s, Augmented Reality Emerges: While VR faced challenges, augmented reality began to gain traction. One notable development was the AR Toolkit, an open-source tracking library for AR applications, created by Hirokazu Kato in 1999.

3.1.5. 2010s, Resurgence of VR and Proliferation of Mobile AR: The 2010s marked the resurgence of VR with the development of more powerful and affordable VR headsets, such as the Oculus Rift. Mobile AR also gained popularity with the introduction of smartphones equipped with AR capabilities. Pokémon Go, released in 2016, became a global phenomenon and showcased the potential of mobile AR.

3.1.6. 2016-Present, Mainstream Adoption and Mixed Reality: In 2016, VR gained mainstream attention with the commercial release of high-quality VR headsets like the Oculus Rift and HTC Vive. Major tech companies including Google, Microsoft, and Apple, invested in AR technologies. Microsoft introduced the HoloLens, a mixed reality headset that combines aspects of both VR and AR.

3.1.7. 2020s, Continued Innovation and Integration: The 2020s have seen ongoing innovation in eXperiential Technologies. Advances in hardware, such as more compact and powerful VR headsets, and improvements in AR applications continue to shape the landscape.

3.1.8. Current Status: Figure 3 reproduced from [4] shows the current landscape of XT/ST hardware, platforms, tools and apps and provides a comprehensive picture of the major players in the industry.

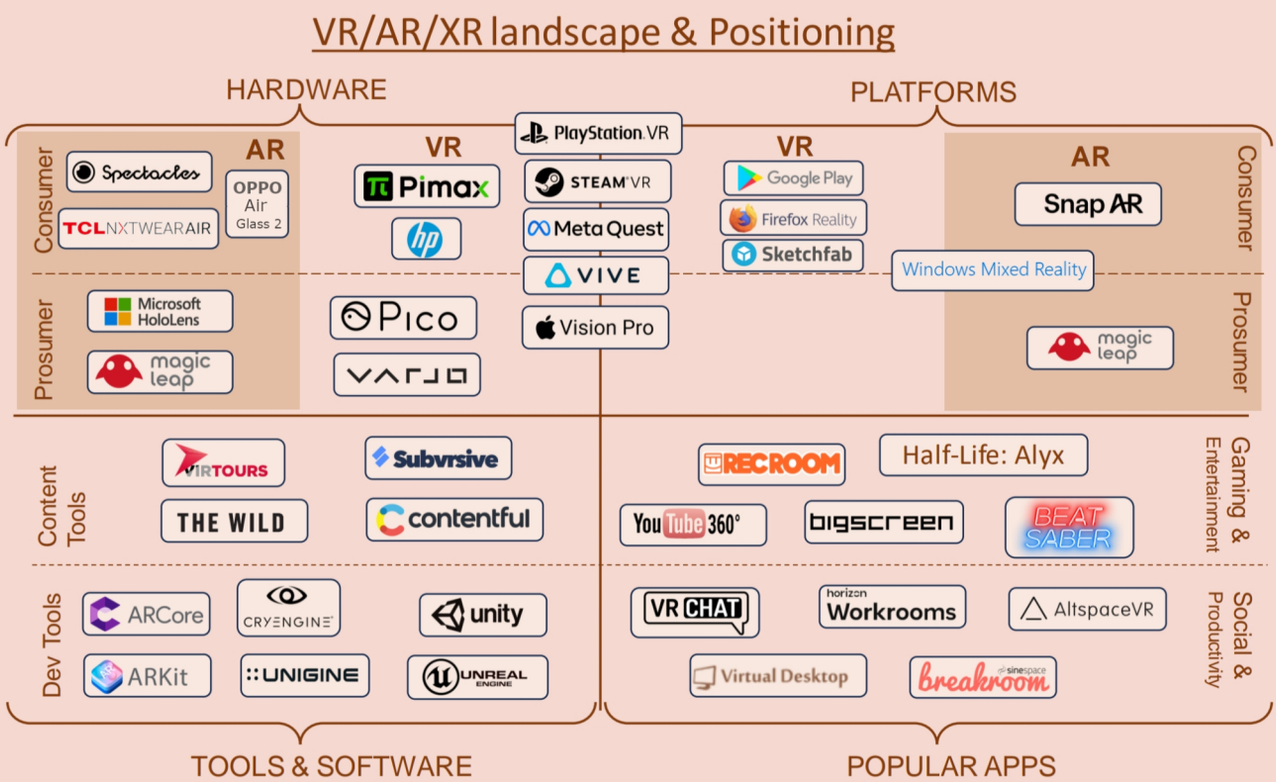


Figure 3. Current landscape of XT/ST hardware, platforms, tools and apps

3.2. Technology overview

3.2.1. Hardware Technologies and Components Across XR

Headsets: Devices such as VR headsets (Oculus Rift, HTC Vive, etc.), AR glasses (Microsoft HoloLens, Google Glass, Apple Vision Pro, etc.), and MR devices (e.g., Magic Leap) are key components for delivering immersive experiences. Heads-up display (HUD) is content projected using specific devices — the most common

consumer versions of these are for cars.

Sensors: : XR Sensor are components or devices integrated XR hardware systems that capture and interpret various physical inputs from the user's environment. These sensors can include cameras, depth sensors, accelerometers, gyroscopes, magnetometers, and infrared sensors, among others. They enable the XR system to perceive and understand the user's movements, gestures, surroundings, and interactions, facilitating the creation of immersive virtual environments or overlays in AR/MR experiences.

Input Devices: Input devices in XR are tools or interfaces that enable users to interact with virtual environments or objects within AR/VR/MR settings. These devices include controllers, motion trackers, hand gestures, voice commands, eye-tracking systems, and haptic feedback devices, allowing users to navigate, manipulate, and engage with digital content in immersive XR experiences.

Recent advancements include Spacetop's augmented reality laptop, which operates without a conventional display and instead provides an expanded display space through a headset.

XR Chipsets: Custom XR chipsets such as the Snapdragon XR2+ chip are at the heart of bringing XR technology to life, since they are custom designed to provide high performance and on-demand computing as well as storage requirements required for XR and MR applications.

3.2.2. Perception Engineering: Perception engineering forms the foundation of XR, representing a new engineering discipline that leverages insights into human perception to design XR hardware and software. This novel field merges traditional engineering methodologies with an understanding of human perception, harnessing these insights to innovate in XR development. Central to perception engineering is the consideration of sensory perception, cognitive load, motion sickness, and other dimensions of human perception, ensuring that XR technologies are not only functional but also ergonomic and user-friendly. XR designers strive to minimize sensory and cognitive conflict, fostering natural and intuitive interactions by drawing from diverse fields such as sensory perception, physiology, psychology, cognitive science, and human behavior.

3.2.3. Perception Algebra: Perception Algebra is an emerging mathematical field that applies algebraic principles to analyze the interactions of different perceptual systems at sensory, perceptual, and cognitive levels. In situations where users are presented with multiple stimuli across various modalities, Perception Algebra suggests mathematical operations at the perceptual level, including addition, subtraction, differentiation, or integration, which can impact

overall cognitive processing. This discipline directly applies mathematical operations and structures, utilizing algebraic principles to study perceptual systems, sensory interactions, and cognitive processes.

3.2.4. Perception Physiology: Perception Physiology represents a novel domain within XR, delving into the intricate interplay between human perception and human physiology. While human perception concerns the subjective interpretation of sensory input, shaped by psychological and cognitive factors, human physiology entails the objective study of the biological processes enabling bodily functions. While perception delves into the psychological and experiential dimensions of sensory input, physiology offers a broader and more objective examination of the underlying mechanisms within the body. As such, Perception Physiology investigates the bidirectional relationship between perception and physiology, exploring how each influences the other.

3.3. Applications in industries

XR, including both AR/VR, has found widespread applications across diverse industries such as gaming, healthcare, education, architecture, manufacturing, and entertainment. In these sectors, XR is utilized for interactive design, collaborative endeavors, navigation enhancement, real-time information delivery, and immersive training simulations.

Experiential Technologies are fast gaining adoption in the following sectors [3, 6, 7]:

1) Advertisement and Mass Media; Marketing
2) Aerospace and Defense
3) Architecture, Engineering and Construction (AECO)
4) Automotive
5) Biomedical, Healthcare and Therapeutic Applications
6) Computer and Digital Technologies
7) Computer and Electronics Hardware
8) Product Development, Design, Manufacturing and Testing
9) Education and Research; Skill Development [8]
10) Energy - Nuclear, Solar and Wind Power Technologies
11) Electronics, Instrumentation and Telecom
12) Retail, FMCG and Durables
13) Gaming and Multimedia
14) GIS, GLAM and Culture Sectors, Travel, Tourism and Hospitality Industry
15) Urban Planning and Public Transportation
16) Marine and Naval Engineering
17) Mechatronics and Industry 4.0

18) Process Industry [9]
19) Psychology and Psychiatry
20) Robotics and UAVs
21) Professional and Workforce Training; Maintenance and Safety training [10-13]

EXperiential Technologies are being integrated with artificial intelligence (AI) and the Internet of Things (IoT) to create more intelligent and responsive immersive experiences. This convergence enhances the capabilities of XR applications in understanding user behavior and adapting to real-world contexts.

3.4. XT in Environmental, Social and Governance (ESG)

Climate change has been the center-stage of many social and political debates in recent years. Various organizations are resorting to immersive media to address and act on the issue of climate change [7, 14]. Geography modeling for Sea level change, for example is enhanced by VR [15], and can also integrate simulation of various solutions. The connect with reality offered by VR can impress upon more people the need for swift action and drive the right behavioral changes quickly and effectively. Similarly, for instance, it can help city planners to test their plans in a virtual avatar of the city, as Autodesk (an architecture and construction software company) has done for San Francisco [16]. In this way, city planners can, for example, develop a better understanding of what needs to be built where and how the original plans need to be adapted to be implemented more efficiently.

Chapter - 4

BENEFITS, CHALLENGES, and BEST PRACTICES

AR and VR are revolutionizing how people interact digitally. This is possible because XT extend conventional digital experiences by the following ways [6]:

(i) Creating extremely realistic experiences by making people feel genuinely part of the digital world.
(ii) Revolutionizing hardware and software interfaces by allowing natural interaction through gestures, voice, eye movements, etc.
(iii) Simulating realistic situations for learning, practice and skill development, thereby making learning more engaging, interactive and effective.
(iv) Providing realistic visualizations of products to enhance the shopping experience.
(v) Improving technology accessibility for people with visual, hearing and other disabilities and providing simulated experiences as effective substitutes for real life experiences.

In academics [17], learning, training and skill development, XT can:

(i) Provide a customized one-on-one learning experience
(ii) Personalize the learning curve to suit the needs of the individual
(iii) Provide a platform to showcase the results or effectiveness of an individual's learning.

Thus, XT have the potential to transform technological, business, economic and social models in unimaginable ways. Therefore, organizations across sectors need to leverage and harness the power of XT and the associated exponential technologies like Blockchain Technology, AI, Big Data, IoT and Industry 4.0 in order to gain competitive advantage. In doing so, they must leverage the elements of pervasive IT and the emerging 5G technology.

However, some challenges and concerns remain and are actively addressed by the industry. The prominent ones are [6]:

Motion Sickness: Some users may experience discomfort or motion sickness in VR environments, particularly if there is a disconnect between visual and physical

movements.

Hardware Constraints: High-quality XR experiences often require powerful hardware – processing power, display technology, device compatibility, etc. - and achieving widespread adoption may depend on advancements in affordability and accessibility. Current AR and VR devices have limitations in battery life and field of view. Overcoming these requires advancements in hardware design and energy-efficient software solutions.

Software Challenges: Software development for AR and VR requires specialized programming skills and is often resource-intensive. Compatibility issues across different platforms has to be addressed during software development through effective cross-platform development strategies.

Ethical and Privacy Concerns: The collection and use of personal data in XR applications raise ethical and privacy considerations, requiring careful consideration and regulation. End-to-end encryption and secure data storage solutions are critical to protect user privacy.

Mass-market vs. Personalized Solutions: XR technologies for the mass-market vis-a-vis tailor-made solutions for individual customers reveal distinct challenges and considerations in their adoption, despite their interlinked nature. The contrast lies in the divergent needs and environments each caters to. Enterprise solutions demand stringent standards and practices. They are typically implemented in controlled and well-trained environments. The focus is on reliability, security, and integration with existing systems. Interoperability becomes crucial, requiring adherence to specific standards to ensure seamless operation within the enterprise ecosystem. The deployment of enterprise solutions often involves thorough training for users, and updates must be carefully managed to minimize disruptions in these controlled environments. On the other hand, consumer-focused solutions require a more user-centric approach. Accessibility, ease of use, and a seamless user experience are paramount. Consumer internet solutions are designed for a diverse user base with varying levels of technological proficiency. This demands intuitive interfaces, clear documentation, and a focus on user feedback for continuous improvement. Unlike enterprise solutions, consumer applications may be subject to more diverse and dynamic usage scenarios, necessitating a greater emphasis on adaptability and user-friendliness. However, the interlinkage between enterprise and consumer internet is evident. Advances in consumer technology often influence expectations in the enterprise space. User experiences in consumer applications set benchmarks for what is deemed acceptable and efficient, prompting enterprises to incorporate similar principles. Despite these interconnections, the security landscape differs significantly. While enterprises prioritize robust security measures due to the sensitivity of corporate data, consumer applications must balance security with usability. Consumer-

focused solutions are potentially more vulnerable to exploitation as they are accessible to a broader and less-controlled user base. In conclusion, the debate between enterprise and consumer internet underscores the need for tailored approaches. Enterprises prioritize standards, security, and controlled environments, whereas consumer solutions prioritize user-centricity and adaptability. Yet, the evolving landscape demands a nuanced understanding, recognizing the symbiotic relationship between the two and the potential for cross-pollination of best practices.

These challenges can be mitigated using some of the following best practices as put forth in [6]:

(i) Adopting effective user-centric design methodologies
(ii) Streamlining the development process using established frameworks and tools
(iii) Learning from and adopting best practices from successful AR and VR projects
(iv) Employing effective network protocols, data compression techniques and data transmission efficiencies for providing real-time interaction.
(v) Robust data encryption for safety and protecting user-privacy
(vi) Using motion tracking to reduce lag and prevent motion sickness.
(vii) Incorporating reminders for taking breaks directly into applications can promote safe usage durations and encourage users to take regular breaks to avoid fatique.

Chapter - 5

XR INTEGRATING OTHER EMERGING TECHNOLOGIES

Future technologies are anticipated to be increasingly human-centric, with industries moving towards a more people-focused approach, exemplified by the emergence of Industry 5.0. The integration of exponential technologies is poised to facilitate businesses in becoming more human-centric, prioritizing the needs and experiences of individuals. It means, the workforce would be given a lot more importance than present their mental wellbeing, their family would be cared more than the present. For example, AI/ML technologies are becoming responsible-AI, they are explainable-AI, they are ethical-AI (transparent-AI and trustworthy-AI), they are more human centric. Other exponential technologies would follow the same human-centric approach.

Among various exponential technologies, XR stands out as a horizontal exponential technology, unlike others that are vertical in nature, as illustrated in Figure 4. This distinction implies that XR is inherently more human-centric, as it integrates multiple exponential technologies to enhance human experiences, thereby fostering human-centric businesses and societies.

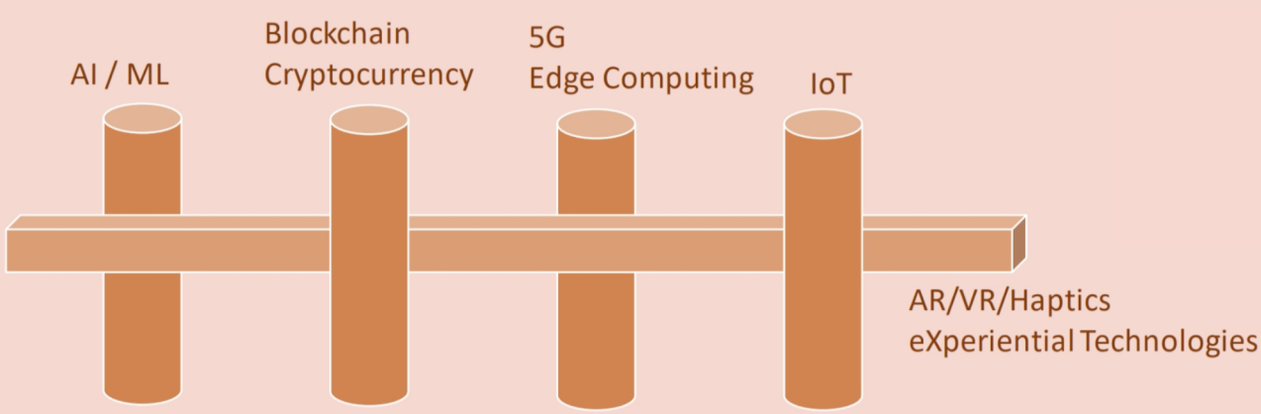


Figure 4. Landscape of Emerging Technologies and XR Will be Integrating other Exponential Technologies for Human Centered Industry 5.0

5.1. Role of AI in XR

AI is an essential component of XR technologies and powers many of the core features of XR technologies. For example, AI is used for object recognition, tracking and spatial mapping, which are essential for creating immersive and

realistic XR experiences. AI is also used for natural language processing, which allows users to interact with XR environments using voice commands. AI algorithms can analyze user data and provide personalized recommendations, adapt content to individual preferences, and tailor XR experiences to specific needs or interests. This can make XR experiences more engaging, effective and accessible. Thus, AI can personalize XR experiences. AI can enhance the safety and security of XR environments. AI can be used to detect and prevent potential hazards, monitor user behavior, and enforce security protocols. This can help make XR environments safer and more secure for users. AI can help regulate and manage XR content. AI algorithms can be used to identify and filter out inappropriate or harmful content, ensuring that XR environments are safe and appropriate for all users. AI can help to dynamically generate content within XR environments based on user interactions and preferences. This ensures that the experience remains fresh and engaging over time. AI holds the potential to propel innovation within XR technologies, with AI researchers continually exploring novel applications of AI in XR. This ongoing exploration is driving the development of increasingly advanced XR experiences, opening up new possibilities for immersive and interactive environments.

5.2. Role of robotics in XR

Robotics, when combined with XR, creates a powerful synergy that enhances user experiences and enables new possibilities.

Advanced Robotics in XR allows for realistic physical interaction within virtual environments. Haptic feedback systems, often integrated with robotic devices, provide users with a sense of touch, enabling them to feel and manipulate virtual objects.

Robotics enables telepresence in XR, allowing users to remotely control robotic devices and experience a sense of presence in a different location. This has applications in fields such as healthcare, where surgeons can perform remote surgeries through robotic systems controlled via XR interfaces.

Collaborative robots, or cobots, can be integrated into XR environments to facilitate teamwork and collaboration. Users from different physical locations can share a virtual space and collaborate on tasks using robotic avatars, enhancing communication and productivity.

Robotics algorithms are at the core of creating immersive and interactive XR environments. Algorithms such as Motion Planning and Control, Pathfinding in Virtual and Physical Spaces, Simultaneous Localization and Mapping (SLAM), Inverse Kinematics, Collision Detection and Avoidance, Grasping and Manipulation play a critical role in the development of XR. They enable precise

control, realistic interactions, and dynamic adaptations within virtual and augmented realities, making XR experiences more compelling and sophisticated. As XR continues to evolve, the synergy between robotics and algorithms will play a pivotal role in shaping the future of immersive technologies.

5.3. Role of IoT in XR

The integration of IoT with XR creates a synergistic relationship, opening up new possibilities for immersive experiences and expanding the range of applications.

IoT devices generate vast amounts of real-world data, such as sensor readings, environmental data, and user interactions. Integrating this data into XR environments enhances realism and context, providing users with more accurate and dynamic virtual experiences.

IoT sensors contribute to spatial understanding and mapping in XR. By leveraging data from sensors embedded in the physical environment, XR applications can create more accurate and responsive virtual overlays, aligning virtual content with the real world in a more precise manner.

IoT enables remote monitoring and control of devices within XR environments. Users can interact with and control IoT-enabled devices in the physical world through XR interfaces, opening up opportunities for remote operation, monitoring, and control in various industries.

Digital Twins are virtual replicas of physical objects or systems. The real-time data from IoT devices allows Digital Twins to stay synchronized with their real-world counterparts, providing an accurate and up-to-date representation of the physical environment. IoT data enhances the fidelity of Digital Twins by contributing to the creation of accurate spatial models. This is particularly valuable in industries such as manufacturing and smart cities, where Digital Twins rely on precise spatial data for simulation and analysis. Digital Twins, enriched by IoT, have potential applications in smart cities, industrial IoT, and predictive maintenance across various industries.

5.4. Role of 5G in XR

5G plays a transformative and pivotal role in unlocking the full potential of immersive technologies in terms of low latency, high bandwidth, mobility and ubiquity (Figure 5 and 6).

Low latency is crucial for a seamless and responsive XR experience. In VR and AR applications, delays in the transmission of data can lead to disorientation and discomfort. 5G networks provide ultra-low latency of the order of 1ms, reducing

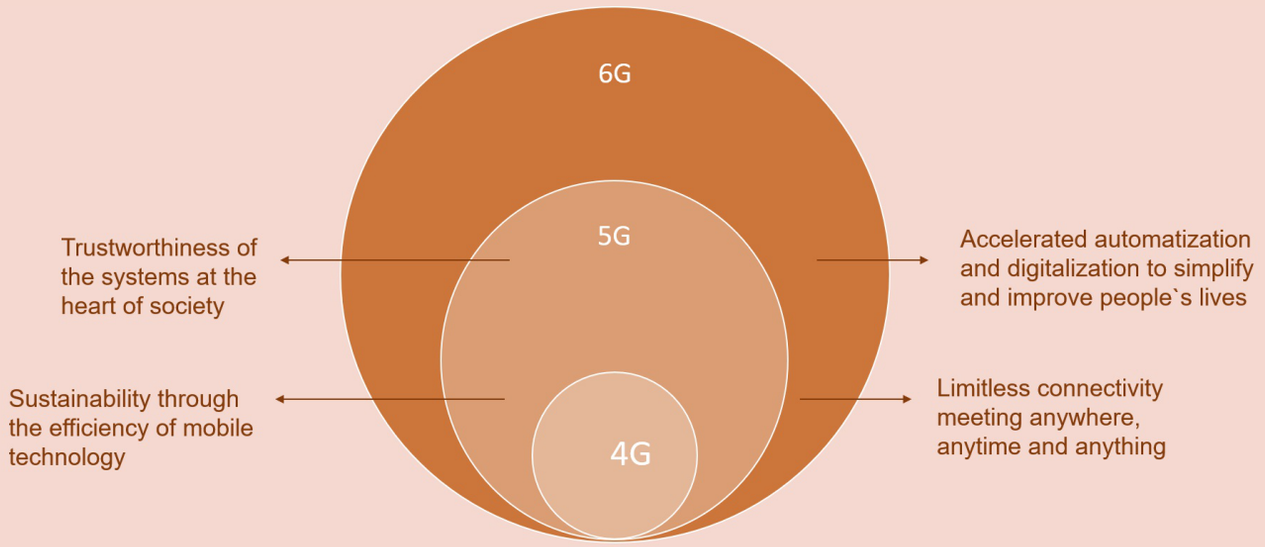


Figure 5. Four main drivers - emerging for the 6G era

the delay between user actions and the corresponding changes in XR environments. This instantaneous responsiveness significantly enhances the overall user experience, making XR applications more immersive and comfortable.

High-quality XR experiences require large amounts of data, especially for high-resolution visuals, complex simulations, and realistic graphics. 5G networks offer

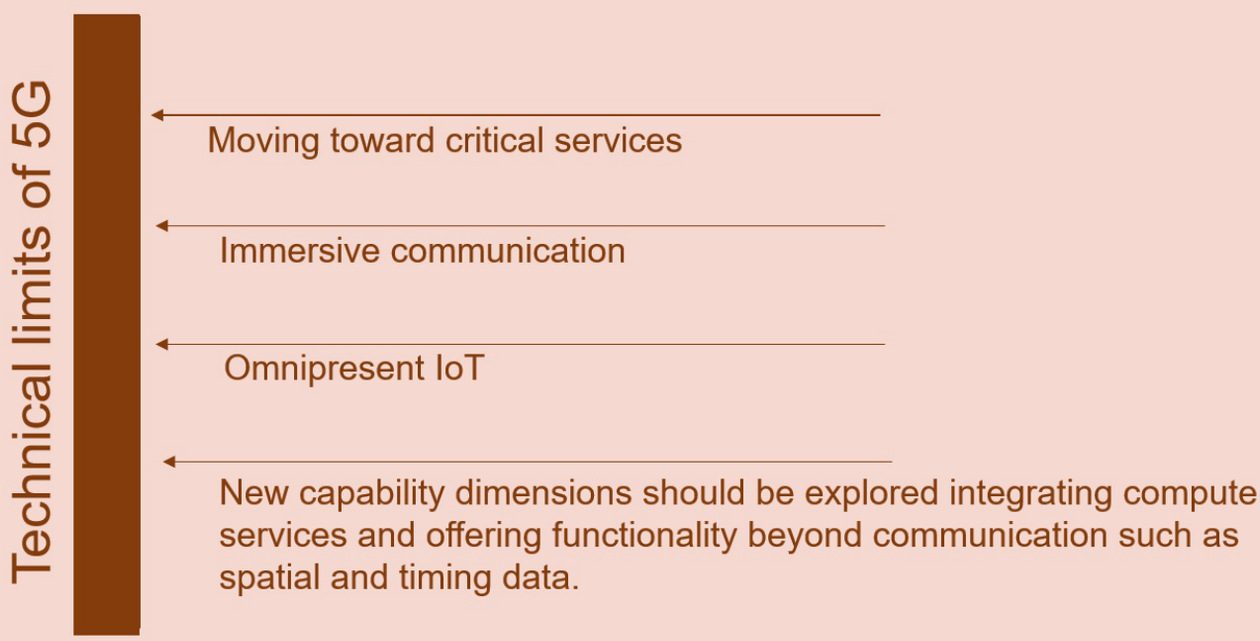


Figure 6: Challenges that push beyond Technical limits of 5G

significantly higher bandwidth compared to those of previous generations. This enables the streaming of high-definition content, large-scale data transfers, and complex simulations in XR without compromising on quality. Users can access more detailed and sophisticated XR environments.

Processing power is a critical factor in rendering realistic XR environments. Centralized cloud computing can introduce delays in data processing. 5G facilitates edge computing, bringing computational resources closer to the user. This reduces latency and enables real-time processing, enhancing the rendering of complex XR scenarios. Edge computing in 5G is particularly beneficial for AR applications that rely on rapid environmental understanding.

5.5. Role of Blockchain in XR

The integration of Blockchain technology with XR holds significant potential in addressing various challenges and unlocking new opportunities.

Virtual assets and items within XR environments often lack true ownership, and interoperability between different XR platforms can be limited. Blockchain provides a secure and transparent way to establish ownership of digital assets within XR. Through blockchain-based tokens and smart contracts, users can own, trade, and transfer virtual assets across different XR platforms, fostering interoperability and creating a genuine digital ownership ecosystem.

Content distribution in XR often involves centralized platforms, leading to issues such as censorship, control, and ownership concerns. Blockchain enables decentralized content distribution. XR content creators can use blockchain to distribute and monetize their creations directly to users, eliminating the need for intermediaries and ensuring more equitable compensation for their work.

Privacy and security concerns arise when users engage in immersive XR experiences, particularly when personal data is involved. Blockchain's decentralized and cryptographic nature enhances security and privacy in XR. Users can have greater control over their personal data, and transactions within XR environments can be securely recorded on the blockchain, reducing the risk of unauthorized access and data breaches.

Traditional payment models for XR transactions can involve multiple intermediaries, leading to delays and additional costs. Smart contracts on blockchain automate and execute transactions within XR environments. This enables seamless, trustless, and programmable transactions, reducing friction and costs associated with traditional payment systems.

5.6. Metaverse

The term 'metaverse' refers to a virtual reality space that exists parallel to the physical world. It is a collective virtual shared space that is created by the convergence of physical and virtual reality, including augmented reality (AR) and

virtual reality (VR), as well as various other immersive technologies. In the metaverse, users can interact with computer-generated environments and other users in real-time. It goes beyond traditional online spaces and social media by creating a more immersive and interconnected digital universe. Users can access the metaverse through various devices such as VR headsets, augmented reality glasses, or even standard computers and smartphones. For a detailed overview of Metaverse and its application in various sectors, the reader is referred to [18].

Web 3.0 is a fusion of decentralized digital identity, decomposable digital assets and automated ecosystems enabled by smart contracts that void the need of a central authority. At its core, a decentralized internet means that technology companies that mediate services may no longer own or govern the web. Using this privacy-first construct, users may bypass these central authorities that store their personal data [18].

The stake-holders of the Metaverse ecosystem are shown in Figure 7. The figure shows the use-cases of Metaverse across manufacturing, telecom, finance and retail industries. The metaverse is gaining significant attention in recent years, driven by advancements in technology, increased interest in virtual reality, and the development of online platforms that aim to create more interactive and immersive digital experiences. Companies in the tech and gaming industries are actively exploring and investing in the development of the metaverse, envisioning it as a next-generation internet where people can work, socialize, play, and create in a seamless digital environment. Thus, the metaverse is an emerging computing paradigm with transformative potential for digital experiences and socio-economic opportunities. The projected social and economic benefits of the metaverse is estimated to be in the trillions in revenue by 2030 and beyond.

In the Metaverse, other than the regular B2B and B2C, many different models of engagement would emerge in the future - such as D2C (Direct to Customers) bypassing retail channels and building direct relationships, Consumer to Consumer (C2C) and Consumer to Business (C2B).

The new startup culture along with digital transactions like USSD, UPI, and AEPS will propel India's Metaverse economy. Metaverse will enhance gaming, education, e-commerce, and virtual real estate, creating new business prospects and revenue streams. India's IT specialists may discover new metaverse uses that are truly global for their expertise. Communication with the global customers, either B2B, or B2C, will take priorities.

5.6.1. Barriers and Challenges to Metaverse Adoption

Privacy Concerns and Monetization: Identification of privacy concerns and the monetization of personal information is a key barrier to metaverse adoption.

Technical Challenges: These include technical hurdles like developing a seamless user experience and the slow progress of metaverse technology.
Technological Dependencies: There is heavy interdependence of metaverse progress on various technological components, including infrastructure, graphics engines, and user-level adoption.

Technological Dependencies: There is heavy interdependence of metaverse progress on various technological components, including infrastructure, graphics engines, and user-level adoption.

Funding Limitations: Constraints exist due to limited funding for hardware start-ups, hindering the advancement of metaverse technologies.

5.6.2. Diverse Pathways and Global Contributions

Unique Pathways: Each country's journey towards metaverse maturity will differ based on sectoral mix, development level, and national priorities, offering unique contributions to the global ecosystem.

International Leadership: China, the US, and the EU are the potentially leading international platforms due to innovative technology ecosystems, research investments, and favorable attitudes towards extended reality in certain regions.
Regional Strategies: Here is a summary of the strategies adopted by the leading global players:

- China's Advancements: China's positive views on extended reality and ongoing hardware and content development efforts.
- US Big Tech's Role: Silicon Valley's initiatives in developing large-scale immersive technology platforms.
- EU's Governance Structures: Potential development of governance structures in the EU and adoption of strategies related to Web 4.0 and virtual worlds by the European Commission.

5.6.3. Role of Inclusive Metaverse Index Framework Structure

Measuring Progress: The Inclusive Metaverse Index is a measure for countries to capture value and drive progress within the developing metaverse ecosystem.

The index is composed of two pillars – Access and Engagement:

- Access: Access refers to the fundamental availability of underlying and key technologies and their affordability.
- Availability: This category measures the existence and maturity of the physical

and digital infrastructure required for a metaverse ecosystem to develop in any given country. Sub-components are digital infrastructure, internet quality and user hardware.

- **Affordability:** This category measures the costs incurred by consumers, firms and governments to access the metaverse ecosystem. Sub-components include internet cost and user hardware cost.
- **Engagement:** Engagement comprises the relevance of the emerging metaverse ecosystem for current and potential users, as well as the readiness of countries to engage with it in a safe and secure manner.
- **Relevance:** This category explores the extent to which individuals are aware of the metaverse, and how much the emerging metaverse ecosystem holds current and potential value for individuals and organizations within a country, which is critical for stimulating interest and adoption. Sub-components include awareness, value proposition, and usage.
- **Readiness:** This category measures the ability of individuals and organizations to engage with and contribute to the emerging metaverse ecosystem in a safe and responsible manner. Sub-components include digital literacy, talent, trust and safety, and cybersecurity.

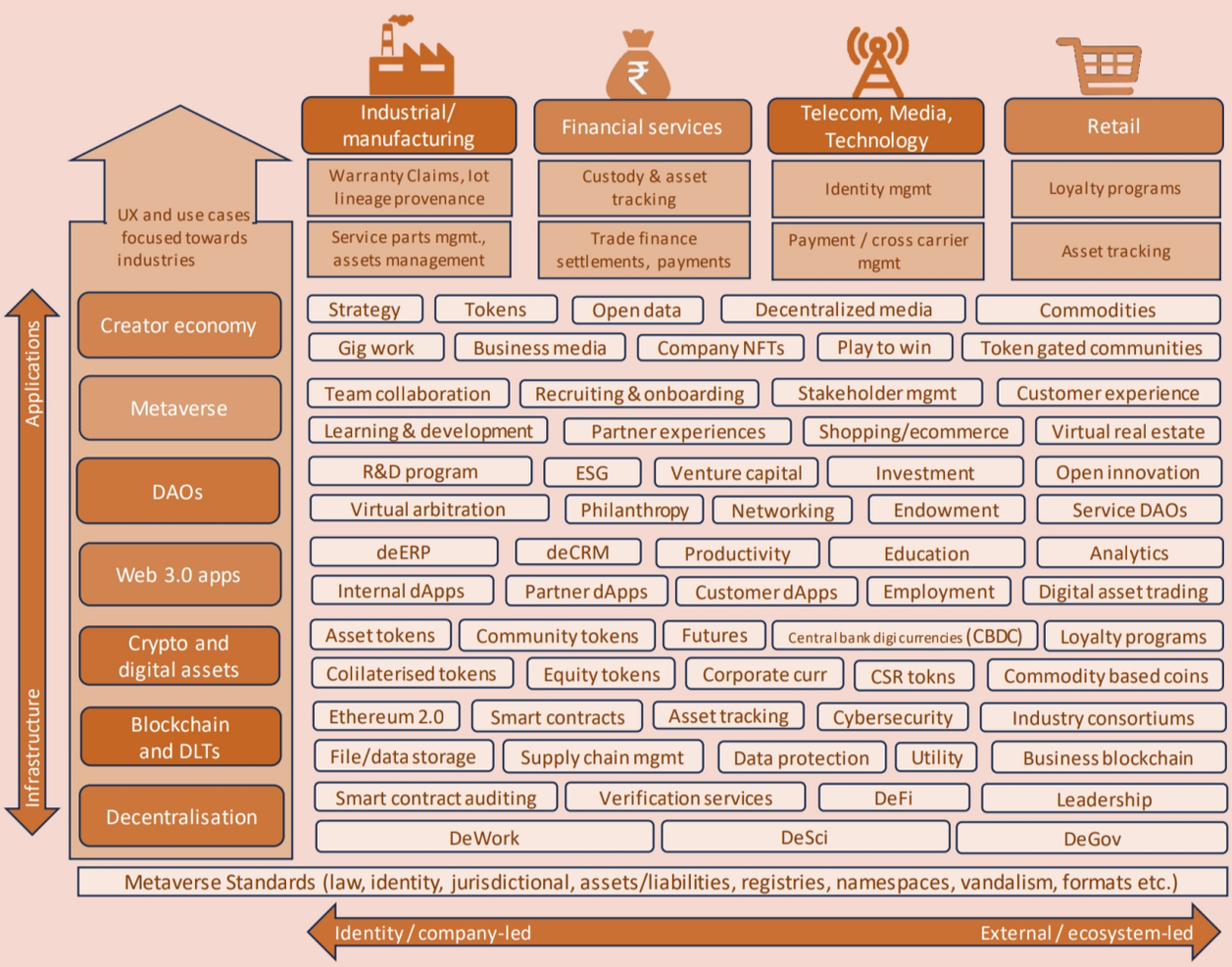


Figure 7. Use Cases of Metaverse and Web 3.0 [19]

5.6.4. Metaverse Index Framework Structure: The index is composed of three pillars of metrics:

Ethical Metaverse Index:

- Interoperability: Measures the compatibility of the Metaverse platforms ensuring seamless experience for users and fostering collaboration between virtual worlds.
- Privacy: Measures the protection of users' privacy within metaverse, including data handling practices, user consent mechanisms, and adherence to privacy regulations.
- Content Moderation: Evaluates the effectiveness of content moderation mechanisms to ensure a safe and responsible virtual environment, preventing harmful or inappropriate content.
-

Responsible Metaverse Index:

- Global Connectivity: Measures how well the metaverse facilitates global connectivity, allowing users from different regions to interact seamlessly and promoting cross-cultural experiences.
- Innovation and Creativity: Measures the degree of innovation and creativity within the metaverse ecosystem, assessing the development of new technologies, applications, and user-generated content.
- Diversity and Inclusion: Measures the inclusivity of the metaverse, looking at how well it accommodates a diverse range of users in terms of gender, age, ethnicity, and abilities.
- Sustainability: Measures the environmental impact of the metaverse ecosystem, considering factors such as energy consumption, carbon footprint, and the use of eco-friendly technologies.

Transparent Metaverse Index:

- Trustability: Measures how well the metaverse fosters trust among users. When users have clear information about how their data is collected, used, and protected, they are more likely to trust the metaverse platform and its operators.
- Platform Governance: Measures how well the users know the governance structures and decision-making processes, and how policies are developed and enforced.

5.6.5. Considerations for Policymakers and Stakeholders

- Inclusive Policies: Encouragement for policy-makers to create inclusive policies supporting affordable internet access, digital literacy, privacy, safety,

and cybersecurity.

- Industry and Consumer Demand: Acknowledgment of the crucial role of local industry and consumer demand in influencing adoption rates and economic value creation through immersive experiences.

5.7. Yogaverse: Yoga diplomacy in the Metaverse

Yoga is the India's gift to the world. The Prime Minister of India has transformed yoga into a hugely potent tool for global public diplomacy by announcing June 21st as the International Yoga Day. As said by a famous Yogi, "Yoga has a complete message for humanity. It has a message for the human body, it has a message for the human mind and it also has a message for the human soul. Will youth come forward to carry this message, not only in India but in every corner of the world?"

Although Yoga has its home in India, America seems to be the leading practitioner, with thousands of yoga studios in big cities and small towns. Yoga is as American as apple pie with many different yoga styles and millions of practitioners. XR and Metaverse could change this perception. Yoga in Metaverse could be taken to every corner of the world to ensure wellness - towards Vasudeiva Kutumbakam.

Metaverse might unite Vasudeiva Kutumbakam across languages. Companies operating in India need to choose a language from among 122 recognized languages and a few hundred dialects, with even minority languages being spoken by millions of people. This is the same with companies that have a presence in Metaverse. They have to reach more people in many different languages.

In the Metaverse, other than the regular B2B and B2C, many different models of engagement would emerge in the future such as D2C (Direct to Customers), bypassing retail channels and building direct relationships - Consumer to Consumer (C2C) and Consumer to Business (C2B).

Chapter - 6

OPEN-SOURCE FRAMEWORKS

6.1. Introduction

Open-source frameworks are critical for rapid development at scale, especially at the intersection of Open Source and XR, where they serve as a catalyst for innovation in shaping the future development of Internet 3.0. In this evolving digital landscape, characterized by blurred boundaries between physical and artificial realities, fostering openness, independence, interoperability, and accessibility through initiatives like open-source becomes paramount, ensuring inclusive and adaptable development reflective of diverse perspectives, thus unlocking the full potential of Internet 3.0.

6.2. Role of open-source frameworks in XR development

Open-source has been a driving force in enhancing the scalability and accessibility of XR technologies, empowering developers to create impactful solutions.

The collective and collaborative nature of open-source provides more than just a solution to a specific problem; it offers an environment where developers can actively contribute by addressing challenges within the open-source community itself.

6.2. Open-source vs. Proprietary IP

In fostering innovation and sustainable development, a balanced approach is needed to protect proprietary information while also encouraging the development and monetization of such assets. While proprietary solutions drive innovation and scalability, open-source solutions foster collaboration and universal practices.

Achieving the right mix of proprietary and open-source solutions is crucial for establishing standards, frameworks, and a strong foundation for innovation. Successful models like UPI, ONDC, and Beckn demonstrate the effectiveness of

open ecosystems in enabling various proprietary solutions to flourish.

By open-sourcing certain components while generating IP for specific implementations, a dynamic synergy can be achieved, ensuring a robust foundation for sustainable businesses within the evolving landscape of Internet 3.0.

6.4. Influence of open-source frameworks on XT

The collaboration with open-source communities has significantly shaped the development of XR solutions, leading to profound impacts on the trajectory towards Web 3.0.

Rooted in decentralization, open-source communities epitomize the ethos of Web 3.0, driving innovation through collective effort. Initiatives like XROS, OpenXR, OpenBCI, and OpenAI exemplify this collaborative spirit, championed by diverse groups and consortiums. These initiatives are poised to redefine the future of technology, with OpenXR emerging as a pivotal component in the XR domain. Its widespread adoption, coupled with the support from tech giants like Google and Apple, signifies a fundamental shift in XR device development and user experience. By democratizing access to XR devices and fostering a culture of experimentation and shared innovation.

OpenXR embodies a departure from traditional models of proprietary control. This collaborative approach not only accelerates development but also promotes accessibility to technology, heralding a decentralized and inclusive digital landscape aligned with the principles of openness and shared innovation.

As we transition into the Web 3.0 era, this collaborative ethos promises a vibrant ecosystem where diverse contributors collectively drive technological advancements towards a common goal of human progress.

6.5. Promotion of open-source frameworks in XT

Promoting open-source principles within XR development offers significant opportunities to address unique challenges such as spatial user experience design and security.

By leveraging open-source solutions, particularly in areas like automation testing for XR applications, developers can enhance interoperability, standardize development practices, and accelerate innovation.

Championing open-source within the XR community fosters collaboration,

knowledge-sharing, and the development of tools tailored to the specific demands of spatial and immersive experiences, ultimately leading to more robust and effective XR solutions.

6.6. Benefits of adopting open-source frameworks

Open-source practices, epitomized by the adoption of OpenXR, are reshaping XR technologies, democratizing access beyond the control of a select few tech giants.

The integration of OpenXR into smart glasses and future devices is diversifying the XR landscape, fostering innovation and providing alternatives. This collaborative approach extends across industries like TV manufacturing and automotive, accelerating the evolution of XR while ensuring accessibility and democratization of technology.

Moreover, open-source enables quick evaluation and customization of multiple use cases of XR solutions, empowering companies and startups to scale efficiently based on customer needs, despite resource constraints.

6.7. Challenges in standardization and interoperability

In XR development, open-source collaboration is pivotal for addressing standardization and interoperability challenges, fostering a robust digital ecosystem.

Open-source frameworks facilitate collaboration among diverse stakeholders, allowing for the collective shaping of standards and specifications essential for a resilient XR landscape.

6.8. Challenges in commercialization and IP protection

Balancing open collaboration with financial sustainability and IP protection in XR and emerging technologies requires strategic decision-making around licensing and business models.

Historical examples demonstrate that open-source projects can be monetized effectively without sacrificing IP protection, with diverse monetization strategies emerging, such as offering proprietary services on open-source foundations.

6.9. Suitability for small businesses

In the context of XR and emerging technologies, open-source offers significant viability for small businesses, allowing them to build sustainable solutions through community support and scalability within a collaborative ecosystem.

This model attracts investors due to its potential for flexible and scalable ventures, providing an appealing pathway for small enterprises to innovate and thrive.

6.10. Open-source frameworks in public health

XR applications, developed through open-source collaboration, improve patient engagement and rehabilitation with features like immersive-therapy environments, gamification, personalized treatment plans, real-time feedback, remote rehabilitation, and social engagement.

Evidence from studies such as those published in the Journal of NeuroEngineering and Rehabilitation [20] and the Journal of Pain Research [21] supports their effectiveness in areas like motor skills improvement and pain management.

6.11. Open-source frameworks in medical diagnostics

Open-source principles enable healthcare providers to ensure accessibility and inclusivity in XR applications by collaborating openly with communities and adhering to standards like WCAG, while also prioritizing user-centric design and conducting regular accessibility audits for ongoing improvements.

· This collaborative approach fosters a diverse and inclusive healthcare ecosystem, where XR applications meet a variety of patient needs inclusively.

Collaborative development of open-source XR technologies in medical imaging enables accurate visualization of patient records, enhancing diagnostic speed and precision.

Thus, open-source XR will lead to customized and finely tuned medical solutions from the ground up (i.e., from hardware to software stack).

6.12. Open-source and XR hardware

OpenXR based chipset and reference architectures are being built by Qualcomm (Qualcomm Snapdragon SDK) and followed by others, such as the OpenXR chipsets and open-source smart glasses [22].

These initiatives, along with reference devices, serve as examples where vendors follow specifications and build hardware compliant with the reference device architecture. However, it is essential to note that while adherence to open standards is widespread, the realization of true open hardware success in the XR domain is still an ongoing process.

6.13. Recommendations for open-source

To promote open-source in India, it is essential to raise awareness through workshops and campaigns, emphasizing global success stories. Integrating open-source technologies into academic curricula encourages early collaboration.

Government support in the form of incentives and funding for open-source initiatives is crucial, along with promoting open-source in government projects. Skill development programs, including hackathons, engage the developer community, while corporate involvement encourages businesses to contribute and showcases long-term benefits. Supporting open-source startups through mentorship and resources fosters growth.

Industry-academia collaboration addresses real-world issues, making open-source practical. Online learning platforms can disseminate knowledge, and emphasizing clear documentation and localization efforts ensures accessibility. This multifaceted approach will cultivate a thriving open-source ecosystem in India, fostering innovation and collaboration.

Chapter - 7

INDIA XR SKILLS SPECTRUM

Excelling in XR requires two categories of skills:

- Digital spatial development skills
- Strategic prowess, legal acuity with entrepreneurial flair

7.1. Digital XR development skills

XR Digital Skills in-turn involves three different kinds of skills as depicted in Figure 8:

- Spatial Technology Artistic Skills
    - 3D Modelling and Animation: Skills in creating 3D models and animations using tools like Blender, Maya, or 3DS Max, or creating new tools.
    - Programming: Proficiency in languages such as C#, C++, and Unity or Unreal Engine for VR/AR application development.
    - AI and Machine Learning: AI Integration with XR.
    - Computer Vision: Understanding computer vision concepts for AR applications.
    - Hardware Knowledge: Familiarity with XR hardware devices and their specifications.

- Spatial Design skills
    - Storytelling: Crafting compelling narratives that enhance the immersive experience,
    - 3D Content Conceptualization: Creating engaging 3D content for VR and AR experienc-es, and creating animations that enhance realism
    - Engagement and Interaction Design: This includes 3D UI/UX design, and understanding how to design for a three-dimensional, immersive space.

- Efficiently managing XR projects from conception to delivery

These three skills can be considered as three different dimensions that are orthogonal to each other.

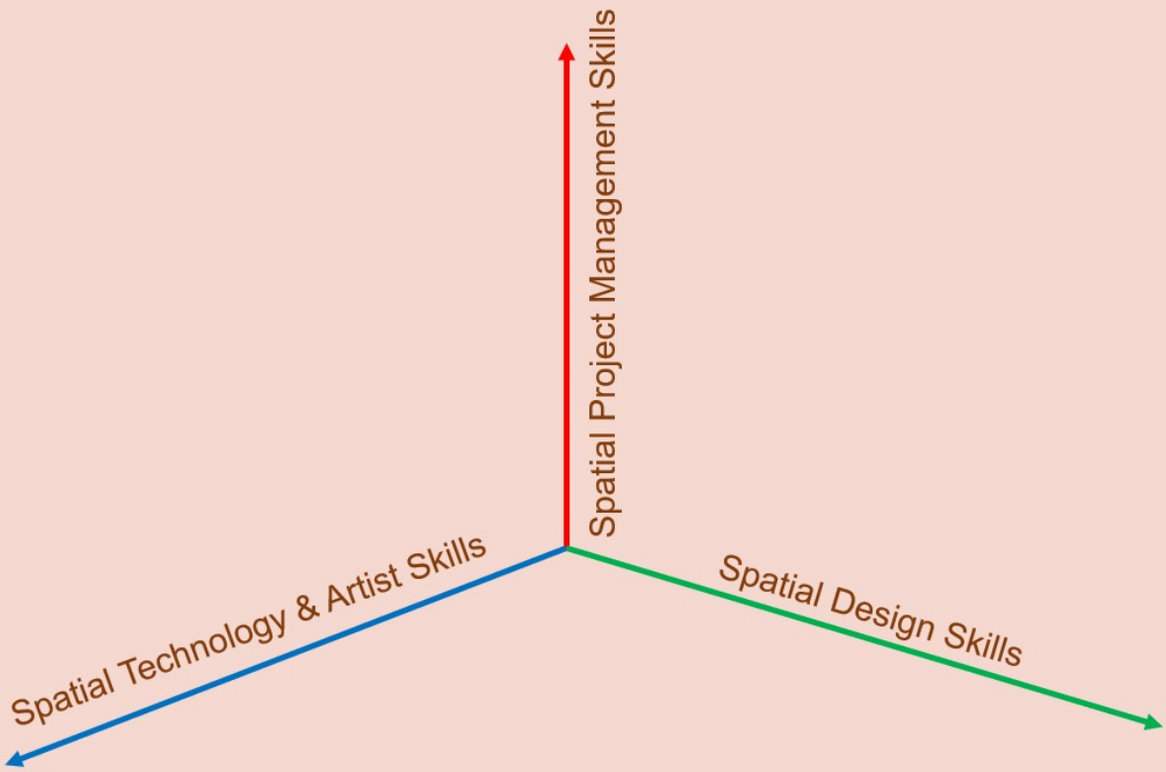


Figure 8: Dimensions of XR Development Skills

7.2. Business skills: Strategic prowess, legal acuity with entrepreneurial flair

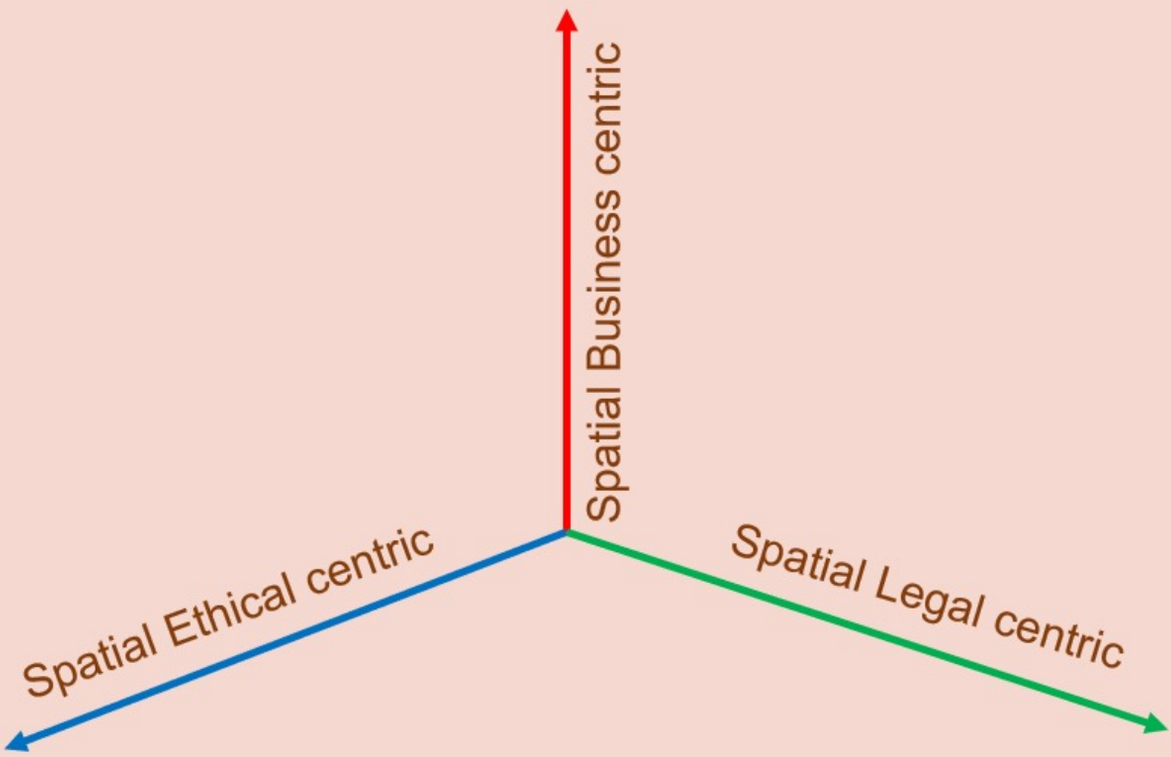
This includes three different skills (Figure 9):

- Business and Strategic Acumen:
- Market Research: Staying informed about market trends, user preferences and emerg-ing technologies in XR.
- Business Development: Identifying opportunities for XR applications across industries.
- Entrepreneurial Mindset: Cultivating a mindset that encourages innovation and the ex-ploration of new ideas within the XR space, and
- Risk-Taking: Willingness to take calculated risks in pursuing new XR ventures.

- Ethical Considerations: Consideration of the ethical implications of XR technologies, includ-ing privacy, accessibility, and inclusivity; user Safety - ensuring XR experiences prioritize user safety and well-being.

- Legal and Regulatory Awareness: Understanding Regulations related to XR, such as data protection laws and safety standards.

These three skills can be considered as three different dimensions that are



orthogonal to each other.

Figure 9. Dimensions of XR Business Skills

7.3. XR skills gap analysis

Table 1 provides an overview of the competency spectrum in India in hardware, software and applications. With the exception of optics, there is moderate to high level of expertise in hardware. Similarly, except in VR OS where skills are virtually non-existent, there is only a modest prevalence of expertise in software. It is apparent that the XR community in the country is focused predominantly on applications with a large number lingering at basic levels of skill. The vision is to move the practitioners up the value chain by focusing on advanced education, R&D and innovation. This will enable the country to be become an XR superpower and knowledge powerhouse and reap massive financial gains. Details of how this can be achieved follow.

While the Hardware and Software components of XR are driven by R&D, XR 'Application Development' is devoid of research content. XR Application Development skills can be categorized into three levels.

Basic Level:

- Software:
  - Use of existing Game Engines: UNITY3D, Unreal Engine.

- Use of existing 3D-Modeling Tools: Blender, Maya, 3ds Max.
- Use of existing WebVR: Three.js

- Hardware:
  - Use of existing Hardware: IoT

- Advanced Level: Shipped Titles

- Software:
  - Asset creation (modelling and animation).
  - Game engine integration and app development.
  - User Interface (UI) and User Experience (UX): 3D UI/UX.
  - AI tools for XR.
  - Cloud Servers for 3D.
  - 3D Project Management.
  - Project Design and Estimation.
  - Project Management with Developer Team.
  - Project Milestones Customer Collaboration.
  - Project Delivery

Table 1. XR Competency Spectrum in India with current Skill Level in %

Hardware			
#	Category	Skill Level %	No. of Groups
1	Display	50	2
2	Sensors	70	5
3	Optics	20	3
4	Connectivity	60	20
5	Battery	90	30
6	SoC	80	20
7	Haptics	95	1

Software			
#	Category	Skill Level %	No. of Groups
1	VR OS	5	3
2	AR OS	50	3
3	SDK	50	10

Applications			
#	Skill Level	Skill Level %	No. of Groups
1	Basic	90	> 1 million
2	Advanced	90	~ 10000
3	Expert	90	~ 1000

- Hardware:
  - IT Infrastructure 3D.
  - Project Management Tools.
  - Version Control System.
  - Learning Management Systems.
  - Servers.
  - Use of existing Hardware: 5G

Expert Level

- Software: Software as Service (SaaS)
  - Design and Develop new Platform
  - Design and Develop Solution/Technical Architecture
  - Design and Develop New Game
  - Develop Guidelines and Best Practices
  - Developing Plugin for the existing Game Engines
  - Developing Tools to automate XR Development process

- Hardware:
  - Designing and Developing Gaming Hardware
  - Use of existing Hardware: Robotics
  - Use of existing Hardware: Edge Computing
  - Use of existing Hardware: Blockchain
  - Use of existing Hardware: 5G

Some observations on the current state of XR skills in India

- India has a vast majority of digitally skilled 3D professionals. These professionals learn either UNITY3D or UNREAL Engine and remain as developers. They do not grow to become experts in a chosen field.
- There is a dearth of 3D artists in India.
- Similarly, there is a dearth of 3D project management skills.
- Research and Development in XR hardware and software is largely absent.
- Optical systems, particularly photonic systems, that are crucial for XR hardware are a conspiciously missing technology component.

7.4. Recommendations

In order to elevate the professionals at the basic level to the advanced or expert level, and then to R&D level, fundamentals of XT/St should be emphasized. Theoretical concepts such as Perception Engineering, Computational Imaging, Computer Graphics, Sensors and Actuators and 3D interfaces could be emphasized along with practicals. Unfortunately, most of the VR courses in India

only provide training to use some game engines such as UNITY3D or Unreal Engine. Seldom do the trainers emphasize the basic principles of VR design.

While the infrastructure such as Semiconductor and Optical systems needed to support in India is scanty and is still evolving, the professional should be trained for designing Very Large Scale Integration (VLSI) systems and Pho-tonic systems for XR at least.

3D UI/UX design involves collaboration between designers, developers, engineers, and content creators from various disciplines. Investing in skill development in this area fosters cross-disciplinary collaboration and knowledge-sharing, leading to the development of holistic and im-pactful solutions. India has the potential to establish itself as a hub for 3D UI/UX design talent on the global stage. By nurturing and showcasing expertise in this field, Indian professionals and companies can gain recognition and contribute to shaping the future of user interfaces and expe-riences worldwide.

Developing skills in Metaverse Frameworks encourages collaboration across sectors, bringing to-gether experts from technology, entertainment, education, healthcare, and other domains. This interdisciplinary approach fosters innovation and enables the creation of immersive experiences with real-world applications. Investing in skills development in Metaverse Frameworks helps fu-ture-proof India's workforce against technological disruptions. By equipping professionals with the knowledge and expertise to adapt to evolving digital landscapes, India can ensure its continued relevance and resilience in an increasingly digital world.

Chapter - 8

SUSTAINABLE DEVELOPMENT GOALS (SDG)s AND XR

Experiential Technologies have the potential to contribute significantly to india's efforts to achieve sustainable development goals.

8.1. Quality education (SDG4)

XR can revolutionize education by providing immersive and interactive learning experiences. Virtual classrooms, educational simulations, and virtual field trips can enhance access to quality education, especially in remote and underserved areas of india.

Immersive Education: According to a report by Allied Market Research [23], the global market for VR in education is projected to reach $3.8 billion by 2027, with a compound annual growth rate (CAGR) of 42.9% from 2020 to 2027. According to a report by Goldman Sachs [24], the global market for VR in education is projected to reach $700 million by 2025, with VR technology of-fering new opportunities for immersive learning experiences.

Distance Education: In India, where access to quality education is a challenge in rural areas, XR can play a crucial role. According to the World Bank, over 65% of India's population lives in rural areas, where access to educational resources may be limited. A survey by Deloitte [25] found that 58 % of K-12 educators in the United States were using AR/VR to support remote learning during the pandemic.

Experiential Learning: Research by the Stanford Virtual Human Interaction Lab [26] showed that students who learned through VR simulations were more likely to remember the information and apply it to real-world situations compared to those who learned through traditional methods.

Accessibility and Inclusivity: According to the World Health Organization [27], approximately 15 % of the world's population lives with some forms of disability, and XR can help ensure that education is accessible to all learners. A study published in the Journal of Educational Computing Research [28] found that AR-based learning experiences enhanced the engagement and motivation of

students with disabilities.

8.2. Good health and well-being (SDG 3)

XR technologies have numerous applications in healthcare, ranging from medical training and simulation to patient education and therapy. VR simulations can be used for medical training, allowing healthcare professionals to practice surgical procedures in a safe and controlled environ-ment. AR applications can assist in remote diagnosis and treatment, especially in rural areas with limited access to healthcare facilities.

Medical Training and Simulation: According to a study published in the Journal of Surgical Educa-tion, medical students who trained with VR simulation showed a 230 % improvement in perfor-mance compared to traditional methods [29].

Patient Education: A study published in the Journal of Medical Internet Research found that AR-based patient education improved patient satisfaction and comprehension compared to traditional methods [30].

Telemedicine: According to a report by Grand View Research, the global telemedicine market size is expected to reach $298.9 billion by 2028, with a compound annual growth rate (CAGR) of 22.4 % from 2021 to 2028 [31].

Pain Management: A study published in the Journal of Pain Research found that VR-based distrac-tion therapy reduced pain intensity by 38 % and pain unpleasantness by 60 % in hospitalized pa-tients [32].

Disease Prevention and Health Promotion: A study published in the International Journal of Envi-ronmental Research and Public Health found that VR-based health promotion interventions result-ed in significant improvements in physical activity levels and dietary behaviors [33].

8.3. Industry, innovation, and infrastructure (SDG 9)

XR technologies drive innovation and create opportunities for economic growth. India's growing XR ecosystem can foster entrepreneurship and technological innovation, contributing to job crea-tion and economic development. AR and VR can be utilized in infrastructure planning and design, urban development, and construction, improving efficiency and sustainability in infrastructure pro-jects.p

Innovation in Manufacturing and Design: XR technologies can revolutionize manufacturing pro-cesses by facilitating immersive design reviews, virtual

prototyping, and assembly simulations. AR-enabled maintenance and repair procedures can improve operational efficiency and reduce down-time in industrial settings. According to a report by Markets and Markets [34] , the global XR market size is expected to grow from $6.1 billion in 2021 to USD 51.7 billion by 2026, at a compound annual growth rate (CAGR) of 50.9 %.

Skills Training: XR technologies offer immersive training experiences for employees across vari-ous industries, from manufacturing and construction to healthcare and aerospace. VR simulations can provide hands-on training in hazardous environments, while AR applications can deliver on-the-job guidance and support. According to a report by PwC [35], 74 % of organizations using VR for training and simulation have seen quantifiable improvements, such as faster learning curves, increased retention rates, and fewer errors.

Remote Collaboration and Communication: XR technologies facilitate remote collaboration and communication among distributed teams, enabling real-time interaction and problem-solving. VR meetings and virtual workspaces create immersive environments for teams to collaborate on pro-jects regardless of geographical location. According to a report by Accenture [36], 82 % of executives believe that XR solutions will play a pivotal role in their organizations' digital transformation efforts, particularly in enabling remote work and collaboration.

8.4. Reduced inequalities (SDG 10)

XR can bridge geographical and socioeconomic divides by providing equal access to information and resources. Virtual meetings, conferences, and training sessions can connect people across regions, reducing inequalities in access to opportunities. AR applications can empower individuals with disabilities by providing augmented experiences tailored to their needs, promoting inclusivity and accessibility.

Cultural and Social Innovations: XR technologies can promote cultural diversity and social inclu-sion by providing immersive experiences that celebrate diverse perspectives and heritage. VR tours of museums and historical sites allow users to explore cultural artifacts and landmarks from around the world, fostering empathy and understanding. According to a study published in the Journal of Computer-Mediated Communication [37], VR-based simulations have been shown to enhance intercultural communication and empathy, facilitating meaningful interactions among individuals from different backgrounds.

Community Engagement and Advocacy: XR technologies can amplify the voices of marginalized communities and facilitate advocacy efforts for social justice and

equality. VR documentaries and immersive storytelling experiences can raise awareness about pressing social issues and mobilize support for positive change. According to a report by Amnesty International [38], VR-based advocacy campaigns have been successful in raising awareness about human rights abuses and engag-ing audiences in advocacy actions.

Chapter - 9

XR REVOLUTION AND EVOLUTION

As we advance, an increasing number of technologies will converge to prioritize human connection, with a particular focus on human-centeredness. XR will take the lead in integrating various technologies to ensure a more human-centered approach.

9.1. In 2030:

In 2030, the landscape of Extended Reality (XR) experiences would undergo a significant revolution and evolution, driven by experential technologies.

Computing Power and Miniaturization: By 2030, Moore's Law would continue to hold true, resulting in exponential growth in computing power. This would lead to the development of highly compact and powerful XR devices that are accessible to a wide range of users. These devices would be capable of rendering complex virtual environments with photorealistic graphics and advanced physics simulations, providing users with immersive experiences that rival the real world. Indian market would demand a complete customization of XR hardware similar to the mobile revolution during the last decade.

Advancements in AI: AI driven XR content would play a pivotal role in shaping the evolution of XR experiences. By 2030, AI algorithms would have become integral components of XR platforms, enabling advanced features such as AI generated 3D virtual contents seemingly integrated with real world contents, intelligent object recognition, natural language processing in local languages, and predictive analytics. In India particularly AI driven XR based education content would likely be the economic driving force for XR adaptation.

Sensor Technologies and Spatial Mapping: Unique and customized interactive XR experiences would require innovations in sensor technologies to accurately track user movements and accurate hand gestures, as well as capture and interpret spatial data in real-time. This would seamlessly blend virtual and physical elements. Spatial mapping technologies allow users to overlay digital content onto their surroundings, creating immersive augmented reality experiences.

5G Connectivity and Edge Computing: The rollout of 5G networks and

advancements in edge computing would have significantly improved the connectivity and responsiveness of XR devices. By leveraging low-latency, high-bandwidth networks, users can stream high-definition XR content in real-time, participate in multiplayer experiences, and collaborate with others remotely. Edge computing capabilities would enable XR devices to offload processing tasks to nearby servers, reducing latency and improving overall performance. The next phase of development is currently occurring with 5G-Advanced, featuring greater capabilities in enhanced Mobile Broadband (eMBB), ultra-reliable low latency communication (URLLC), and massive Machine Type Communication (mMTC). By 2030, society will have been influenced by XR-5G technology for a decade, incorporating insights gained from its implementation and adapting to emerging needs and services. Despite the inherent flexibility of 5G, there will be a requirement to develop new capabilities for XR. This necessitates continued development in response to societal demands and the availability of more sophisticated technological resources, which must be prepared for the evolving 6G-XR era.

Convergence with Other Technologies: XR would have converged with other exponential technologies, such as blockchain, robotics, Internet of Things (IoT), and biometrics, to create synergistic applications and experiences.

9.2. In 2047 – Vasudeiva Kudumbakam

By 2047, the XR landscape would have undergone further transformation, driven by continued advancements in exponential technologies. These developments would have propelled XR into new frontiers, shaping the way we interact with the world and each other in profound ways, particularly towards Vasudeiva Kudumbakam with our own BharatVerse and VIdyaVerse.

Holographic Displays and Light Field Technology: By 2047, live holographic displays and light field technology would have become ubiquitous, replacing traditional screens and monitors. These displays offer realtime and lifelike visuals with depth and parallax, enhancing immersion and presence in XR environments. Users can interact with virtual objects and environments as if they were tangible physical entities, blurring the lines between the virtual and the real. The future Prime Ministers would personally interact one-to-one, but remotely, with Indian Citizens through “Mann-ki baat” and “Pariksha pe Charcha” or similar programs using these AI enabled live holographic technologies and Light Field Technologies.

Neural Interfaces and Brain-Computer Interfaces (BCIs): Personalization and customization of XR environments would require Neural interfaces and BCIs. By directly interfacing with the brain, users can control virtual objects and

environments using their thoughts and intentions. This opens up new possibilities for people with disabilities, allowing them to navigate XR environments and communicate with others using only their minds.

Quantum Computing and Simulation: The advent of practical quantum computing would have enabled the creation of highly complex and realistic simulations within XR environments. Quantum algorithms can simulate the behavior of molecules, materials, and physical systems with unprecedented accuracy, revolutionizing scientific research, engineering design, and virtual prototyping.

Decentralized and Blockchain-Powered XR Platforms: Decentralized XR platforms built on blockchain technology have emerged as alternatives to centralized platforms. These platforms offer increased security, transparency, and ownership of digital assets, empowering users to monetize their creations and participate in virtual economies without intermediaries.

Global Collaboration and Telepresence: XR would have facilitated unprecedented levels of global collaboration and telepresence. Remote teams from Indian Villages can collaborate in virtual workspaces, conduct meetings and presentations, and socialize in virtual environments as if they were physically present globally. This could lead to a paradigm shift in the way we work, learn, and connect with others, transcending geographical boundaries and fostering a sense of global community. These developments would have propelled XR towards Vasudeiva Kudumbakam with our own BharatVerse and VidyaVerse and others.

Chapter - 10

TECHNOLOGY VISION AND MISSION

10.1. Vision

To be a global leader of eXperiential Technologies through widespread research, development and implementation of these technologies in the form of products, services, processes and business models, resulting in profound economic, societal and administrative impact.

9.1.1. The XR Super-Highway: A Global Network

The XR super-highway is to transform the XR technological landscape in India. India could be the XR super-highway for the world - similar to the phrase 'India is the IT corridor of the world'. India could realize 'India as the XR corridor of the world' in a reasonable timeframe, say 10 or 20 years. The XR super-highway takes the concept of XR connectivity to a global scale towards Vasudeiva Kutumbakam. It envisions a vast, interconnected network of XR experience centers, transcending geographical boundaries, and offering users a truly borderless metaverse. This super-highway could be characterized by several key differentiators:

Global Connectivity: The XR super-highway could connect users from different countries and continents seamlessly. It would allow individuals to interact with peers, engage in commerce, or access educational resources worldwide, transcending the limitations of traditional borders.

Interoperability: One of the defining features of the XR super-highway could be its ability to integrate various XR platforms, devices, and technologies, ensuring a cohesive user experience. Whether the user uses VR, AR glasses, or MR headsets, they can seamlessly interact with others in this interconnected metaverse.

Multilingual and Multicultural: The XR super-highway could accommodate diverse languages and cultures, making it an inclusive space for users from around the world. Translation services, cultural integration, and globalized content create a rich and immersive environment.

Global Commerce: E-commerce within the XR super-highway could enable users

to buy, sell, and trade products and services globally. Virtual showrooms, online marketplaces, and XR-enabled transactions open new avenues for global commerce.

Universal Experiences: XR super-highway users could participate in global events, conferences, and cultural festivals, offering a rich tapestry of universal experiences. Educational institutions, corporations, and cultural organizations can host events accessible to a global audience.

Cross-Sector Collaborations: The XR super-highway could foster cross-sector collaborations on a global scale. Researchers, innovators, and entrepreneurs can collaborate seamlessly, leveraging shared resources and global expertise.

10.1.2. XR-Corridor: National and Regional Network

The XR Corridor is a nationwide physical and virtual network of

1. XR innovation centers in different parts of India
2. XR skill training centers in different parts of India
3. XR experiential spaces in different parts of India
4. XR education centers
5. XR manufacturing units
6. One nation-wide consortium or community of faculty, students, researchers, developers, startups, government bodies, and industries.

This XR corridor could serve as a conduit for the exchange of XR experiences, XR knowledge, and XR opportunities.

10.1.3. XR Innovation Centers

XR innovation centers are dedicated hubs or facilities that focus on fostering innovation, research, development, and collaboration within the XR ecosystem. These centers play a crucial role in advancing the field of XR. A Hub and spoke model of networking several innovation centers in India is proposed.

1. Research and Development to bring together interdisciplinary teams of researchers, engineers, designers, and experts to explore new technologies, algorithms, and applications.
2. Technology incubation to offer resources, mentorship and access to state-of-the-art equipment.
3. Collaboration and networking to facilitate partnerships between academia, industry, and startups.
4. Prototyping and testing facilities to provide advanced prototyping and testing facilities equipped with the latest XR hardware, software, and development

tools. Specifically, XR test bed to assess the quality of XR systems before they are deployed.

5. Showcasing XR applications to raise awareness about the potential applications of XR across various industries, from healthcare and education to entertainment and manufacturing.
6. Access to funding in the form of grants, venture capital connections, or assistance in navigating funding avenues for XR ventures.
7. Industry partnerships to bridge the gap between research and commercialization, fostering the development of XR technologies with practical applications in the market.
8. Hackathons and competitions to encourage creativity and problem-solving within the XR community.

10.1.4. XR Skill Training Centers

XR training centers are specialized facilities focused on providing realistic, hands-on experiences to enhance learning across various industries. These centers offer courses, training programs, workshops, and other educational initiatives to support skill development in XR technologies.

1. Industry-specific training programs tailored to the needs of various sectors such as healthcare, manufacturing, aviation, and more.
2. Hands-on skill development focuses on hands-on skill development by providing trainees with opportunities to practice tasks and procedures in a risk-free virtual environment.
3. Safety training and emergency response where trainees can practice responding to emergencies, such as fires or medical crises, in a controlled and realistic virtual setting to improve their preparedness and decision-making skills.
4. Equipment operation and maintenance to learn how to operate and maintain equipment through virtual simulations across industries, including manufacturing, construction, and logistics, where hands-on experience is essential.
5. Medical simulation and surgical training where surgeons, medical professionals, and paramedics can practice procedures in a virtual environment, refining their techniques and decision-making skills.

10.1.5. XR Education Centers

XR education centers are specialized institutions or facilities dedicated to leveraging XR for educational purposes and to offer courses on designing and developing XR systems. These centers focus on transforming traditional learning methods by incorporating immersive experiences to enhance understanding, engagement, and skill acquisition. Also, these centers offer XR courses at different

levels

1. To design and develop XR systems for Engineering students.
2. To familiarize with the XR technologies for Engineering professionals.
3. To use XR systems for a) engineering graduates, b) medical and healthcare graduates and working professionals, c) architects, d) artists and game developers, e) others
4. To design and develop XR systems for working professionals.
5. To design and develop XR systems for artists.
6. To fix and maintain XR systems to Diploma students and IT students.
7. To teach XR theory and practicals, both online and offline.

10.1.6. XR Experiential Spaces

XR experiential spaces are physical centers designed to offer immersive and interactive experiences through the use of XR with the aim to transport users to digital realms, providing them with engaging and multisensory experiences.

1. Showcasing XR hardware along with demos to encourage the users to adapt XR for novel use-cases.
2. Showcasing XR applications in several domains, may separate XR eXperiential space for each of the specializations such as automotive, medical, architecture, construction, media and entertainment, defense, culture and heritage, space technologies, financial applications, environmental application and others.

10.1.7. XR Manufacturing Centers

These centers could focus on the production of XR hardware such as VR headsets, AR glasses, sensors, and other related devices.

India is already the world's second-largest manufacturing hub for mobile phones, with significant investments from Original Equipment Manufacturers (OEMs), Original Design Manufacturers (ODMs), and companies specializing in mobile components and parts. Similarly, we would expect that India manufactures XR devices and components and parts as well in the near future. We would expect that Meta and Apple headsets are manufactured in India. The establishment of XR manufacturing centers in India could bring several advantages:

1. Technology Adoption: XR technologies could aid Indian manufacturers in adopting advanced and efficient manufacturing practices.
2. Skill Development: Setting up manufacturing centers would necessitate the development of a skilled workforce capable of designing, developing, and maintaining XR technologies.
3. Global Competitiveness: Being at the forefront of XR manufacturing could

enhance India's global competitiveness in the technology sector.

4. Industry Applications: XR technologies can find applications in various industries, from automotive to healthcare, enhancing efficiency and improving outcomes.
5. Research and Development: These centers might also serve as hubs for research and development, fostering innovation in XR technologies for manufacturing processes.

10.2. Technology mission

9.2.1. To create the foundational elements of experiential technologies and provide a strong theoretical and mathematical foundation to the discipline.

9.2.2. To develop fundamental understanding of human embodiment in the virtual space and of human and manual interactions with the outside and virtual worlds in the context of perception engineering.

9.2.3. To foster R&D and play a vital role in the engineering of perceptual realities and creation of commercial and social applications of the technology that profoundly impact human life.

9.2.4. To leverage our country's position in the thriving IT and cyberspace sector as a catalyst for rapid and substantial growth of immersive technologies in the country's economy, resulting in India being the preferred XR corridor of the world.

10.3. Critical role of Metaverse in the technology mission

The Metaverse initiative is critical in empowering the people of the country to engage in a secure, inclusive and responsible Metaverse so that they benefit from virtual worlds which respect Indian values, way of living and rules, while providing them with a digital identity, data and assets and the means and freedom to use them. The initiative will put forward principles and actions for people's empowerment in virtual worlds, and for the promotion of diversity (cultural, linguistic, social, economic), equality and non-discrimination, reducing the physical distance and digital gap, towards Vasudeiva Kutumbakam. The initiative sets the following major expectations:

(i) Developing a favorable climate for investments in XR - enabling technology research, innovation, deployment, integration, and scale up.
(ii) Improving access to capital for small and medium-sized enterprises (SMEs) in India; and fostering the country's cultural and creative industries. Along with this, the initiative will investigate how to construct XR that is safe, sustainable, and fair; how it can increase the long-term competitiveness of our industries;

and how to encourage the public and private sectors in India to effectively adopt XR solutions.

Among the important cross-cutting enablers that could be part of this initiative are the following:

(i) the necessity for structured and sustained foresight of critical technologies.
(ii) the right governance models to guarantee Indian leadership in the development and standardization of virtual worlds.
(iii) the cultivation of the talent pool necessary, and
(iv) the support of skill development for technology specialists and creators.

By taking the lead in promoting openness, interoperability, and Indian values inside this new ecosystem, the project will give India a voice in its global development. The endeavor is being supported by concurrent efforts to develop a robust and efficient network infrastructure, which is essential for the launch of XR.

10.4. Vision for XR hardware in India

Major XR technology companies have not released XR hardware in India. These companies do not have any roadmap for releasing the hardware in India in the near future. The decision to release XR hardware in India can be influenced by several factors and therefore appropriate policies could make India an attractive market:

Indigenous Hardware: Although India has been encouraging local hardware development, this needs to be accelerated to keep up with the pace of XR development worldwide. The local hardware could include Shakti Processor and BharOS, along with collaboration with various stakeholders.

Semiconductor Mission of India: XR hardware requires several semiconductors sensors and actuators, such as high-resolution camera, precise inertia measurement units, and environmental sensors for enhanced spatial awareness, and optimized display technologies. India's semiconductor mission aiming to boost local manufacturing and reduce dependency on imports, especially in critical technology sectors could help in XR as well. The success of leveraging the semiconductor mission for XR hardware development depends on continuous government support, industry collaboration, and the ability to attract global talent and investments.

Photonics Mission of India: India is far behind in optical systems needed for XR. It needs a Photonics Mission similar to the Semiconductor Mission for the XR to flourish. XR hardware needs Waveguides and Beam Splitters to direct light into the

user's field of view, and to help merge digital images with the real-world view. Optical filters are utilized to control the wavelengths of light, enhancing color accuracy and contrast in XR displays. Diffractive optical elements are employed to manipulate and shape light waves in XR devices, contributing to the design of compact and lightweight optical systems.

Regulatory Compliance: The XR hardware, either locally developed or released by other multinationals, need to meet safety and privacy standards in India. Streamlining regulatory processes and providing clear guidelines can encourage companies to develop and release XR hardware in India.

Infrastructure Readiness: The success of XR devices can depend on the availability and quality of supporting infrastructure. High-speed internet connectivity and advanced computing capabilities can enhance the user experience and make India a more attractive market for XR hardware.

Cultural and Content Considerations: XR experiences often involve content creation and consumption. Companies may evaluate the cultural preferences and content ecosystem in a region to tailor their offerings accordingly. Developing region-specific content could be a factor in the decision-making process.

Economic Factors: Economic considerations, such as purchasing power and consumer spending habits, play a role in deciding where to release high-end technology products. Companies may prioritize markets where consumers have the financial capacity to adopt new and premium technologies.

10.5. Misconceptions - Integration of XR with AGCV sectors in India

While mainstream academic courses such as Computer Graphics, Computer Vision, and Human-Computer Interaction relevant to XR are already within Computer Science departments, the incorporation of XR into mainstream academics is gradually gaining traction. It is anticipated that XR will soon emerge as a major sector in academia, potentially surpassing even AI/ML. This projection stems from the recognition that XR applications will permeate various aspects of life and industry, becoming ubiquitous in their usage.

On the contrary, the AVGC (Animation, Visual Effects, Gaming, and Comics) sector has not achieved mainstream status in Indian academia, primarily due to the absence of major academic programs catering to AGCV. Several other factors contribute to this:

1. Catering to Specific Markets: AVGC predominantly serves specific industries

focused on entertainment through animation, VFX, gaming, and comics. In contrast, XR holds potential across all sectors, including healthcare, social services, and economics.

2. Perceived Non-Traditional Status: Academic institutions traditionally prioritize conventional fields like engineering, medicine, and business, which may overshadow perceived non-traditional or niche fields like AVGC.
3. Complex Skill Set: AVGC demands a diverse skill set spanning art, design, technology, storytelling, and project management. Developing comprehensive academic programs covering all aspects of AVGC poses challenges and necessitates interdisciplinary collaboration, which may not align with traditional academic structures.
4. Industry-Academia Divide: Misalignment between the needs of the AVGC industry and academic offerings is prevalent. The rapid evolution of the AVGC sector often outpaces academic programs' ability to keep pace with industry trends and technological advancements, resulting in a gap between academic theory and industry practice.

The misconception of adding XR with AVGC stems mostly from the utilization of game engines from the gaming industry and 3D resources from the animation industry in XR development. However, it's crucial to recognize that the use of game engines for XR is transitional, and dedicated XR engines will likely to emerge in the near future.

Indeed, it is crucial to address this misconception early on and consider it when formulating policies, as it could exacerbate future skill gaps. The integration of the XR sector with AGCV sectors may inadvertently limit policy considerations to entertainment industries alone, disregarding the far-reaching potential impact of XR across various sectors.

To mitigate this risk, it's imperative to acknowledge the distinct roles and potentials of both sectors and tailor academic programs and policies accordingly. This proactive approach will ensure that the educational landscape adequately prepares individuals for the diverse opportunities offered by XR technologies while also fostering innovation and growth in related industries beyond entertainment.

Chapter - 11

PRELUDE TO POLICY RECOMMENDATIONS

With global XT/ST projections set to grow significantly, there's an opportunity for India to establish itself as a leader in this field. The current whitepaper and the forthcoming policy report emphasizes the need for India to move beyond its traditional role in IT services and take ownership of technology and intellectual property to achieve greater economic gains.

Key recommendations include substantial investments in education, research, development, and innovation, along with favorable government policies to support XT. The establishment of an XR Corridor, comprising physical and virtual innovation centers across the country, is proposed to facilitate collaboration and knowledge exchange in the XT/ST domain.

The report underscores the importance of collaboration between industry, government, academia, and research organizations to develop the XT ecosystem. It suggests aligning XT/ST policies with existing IT and semiconductor policies while also addressing issues such as IP protection, data privacy, and security. Additionally, it advocates for a startup-friendly business climate and emphasizes the potential of XT/ST to revolutionize sectors like healthcare and public administration.

The report calls for comprehensive policy measures to create a conducive environment for XT/ST investments and development in India, positioning the country as a technology and economic su-perpower in the coming decades, although we are far behind many countries today.

REFERENCES

[1] "Immersive Technology Market - Global Industry Analysis, Size, Share, Growth, Trends, Regional Outlook, and Forecast 2023-2032", Report by Precedence Research, www.precendenceresearch.com

[2] Statista Market Insights. https://www.statista.com/outlook/amo/ar-vr/india

[3] Bhagwat et al. "VR/AR in the Energy Sector", VR/AR Association White Paper, April 2021

[4] Emil Torma. "Understanding the VR/AR Landscape & Its Major Players", Blog Post, https://www.sharethrough.com/blog/understanding-the-vr-ar-landscape-its-major-players

[5] "Giving computers a sense of smell: the quest to scientifically map odours", https://www.theguardian.com/science/2023/oct/28/giving-computers-a-sense-of-smell-the-quest-to-scientifically-map-odours

[6] Vipin Chandran, "AR and VR Applications Transforming User Experiences in Software Development",
Artificial Intelligence, 17 Jan 2024, https://cubettech.com/resources/blog/ar-and-vr-applications-transforming-user-experiences-in-software-development/

[7] "Immersive Technology and Infrastructure: Building America's Future", XR Association Report

[8] "Viroo Enables UTR to Create the Biggest Education VR Center in the World", https://www.virtualwareco.com/news/the-vr-center-university-retono-unveiled/

[9] "Virtualware | GE Hitachi Pioneering Virtual Reality Fuel Movement Simulator", https://www.youtube.com/watch?v=DAaL7hc-75w

[10] "GE Hitachi and Virtualware Revolutionize VR Workforce Training", https://www.youtube.com/watch?v=8xJ_qK0nbW0

[11] FVR Demo Video, https://www.youtube.com/watch?v=Qsq9lkck6c0

[12] "Virtual Reality for Exelon Case Study", Oberon Technologies, https://oberontech.com/wp-content/uploads/2020/07/Exelon_CaseStudy_OBERON.pdf

[13] https://www.oberontech.com/solutions/vr-training/

[14] Sol Rogers. "How Extended Reality Can Bring Climate Change Front Of Mind", Forbes Newsletter, https://www.forbes.com/sites/solrogers/2020/04/21/how-extended-reality-can-bring-climate-change-front-of-mind/?sh=3828f3114b18

[15] Juliano Calil. "Virtual Reality Enhances Sea Level Rise Planning and Community Engagement", Middlebury Institute of International Studies at Monterey, 5 May 2021, https://www.cityofsantacruz.com/Home/Components/News/News/9321/36

[16] ADB Report. "Digital Technologies for Climate Action, Disaster Resilience, and Environmental Sustainability", October 2021.
https://www.adb.org/sites/default/files/publication/700396/digital-technologies-climate-action.pdf

[17] Chiradeep BasuMallick, Spiceworks Article. "Upskilling Strategy 2020: Is Your Workforce Acquiring Extended Reality (XR) Skills?", October 2021. https://www.spiceworks.com/hr/learning-development/articles/upskilling-strategy-digital-skills-ar-vr-mr-xr-skills/

[18] "Metaverse and Web 3.0 opportunities in India", KPMG and CII Report, November 2022, https://assets.kpmg.com/content/dam/kpmg/in/pdf/2022/11/metaverse-and-web-3.0-opportunities-in-india-updated.pdf

[19] Dion Hinchcliffe, Zdnet, KPMG in India, June 2022

[20] Turolla et al. "Virtual reality for the rehabilitation of the upper limb motor function after stroke: a prospective controlled trial", J NeuroEngineering Rehabil 10, 85 (2013).

https://doi.org/10.1186/1743-0003-10-85
[21] Wong K. P., Tse M. M. Y., Qin J. “Effectiveness of Virtual Reality-Based Interventions for Managing Chronic Pain on Pain Reduction, Anxiety, Depression and Mood: A Systematic Review”, Healthcare (Basel). 2022 Oct 17;10(10):2047. doi: 10.3390/healthcare10102047
[22] Open-source smart glasses, https://github.com/TeamOpenSmartGlasses/OpenSourceSmartGlasses
[23] “Allied Market Research, Virtual Training and Simulation Market Size, Share, Competitive Landscape and Trend Analysis Report by Component (Hardware and Software) and End User (Defense & Security, Civil Aviation, Education, Entertainment, and Others): Global Opportunity Analysis and Industry Forecast”, 2020-2027
[24] Goldman Sachs Global Investment Research, virtual and augmented reality report, Equity Research Report, 2016
[25] Deloitte Research Report, Technology, Media, and Telecommunications Predictions 2021
[26] Queiroz, A., Fauville, G., Herrera, F., Leme, M., & Bailenson, J. (2022). “Do Students Learn Better with Immersive Virtual Reality Videos than Conventional Videos? A Comparison of Media Effects with Middle School Girls”. Technology, Mind and Behavior. https://doi.org/10.1037/tmb0000082
[27] WHO Global Report on health equity for persons with disabilities, December 2022
[28] Chen R. W., Chan K. K. (2019). “Using Augmented Reality Flashcards to Learn Vocabulary in Early Childhood Education”, Journal of Educational Computing Research, 57(7), 1812–1831
[29] Craig et al. “Developing and Evaluating Complex Interventions: The New Medical Research Council Guidance”, International Journal of Nursing Studies, 50(5), 587-592, 2008
[30] Seymour et al. “Virtual Reality Training Improves Operating Room Performance: Results of a Randomized, Double-Blinded Study”, Journal of Surgical Education, 59(6), 737-741
[31] “Telemedicine Market Size, Share & Trends Analysis Report By Type (Telehospital, Telehome), By Component (Services, Software), By Delivery Mode (On-premise, Cloud-based), By End-use, And Segment Forecasts”, Grand View Research, 2021 – 2028
[32] Malloy, K. M., Milling, L. S. “The Effectiveness of Virtual Reality Distraction for Pain Reduction: A Systematic Review”, Clinical Psychology Review, 30(8), 1011-1018, 2010
[33] Ferrer-García et al. “Virtual Reality Based Treatments in Eating Disorders and Obesity: A Review”, Journal of Contemporary Psychotherapy, 43(4), 207-221, 2013
[34] “Extended Reality (XR) Market by Component, Application, Device Type, Delivery Model, Industry Vertical And Region - Global Forecast to 2026”, MarketsandMarkets Report, 2021
[35] “Seeing is Believing: The Potential of VR and AR in Education”, PwC Report, 2019
[36] “XR: A new Reality for Industrial Enterprises”, Accenture Report, 2021
[37] Bailenson et al. “Virtual Reality Fosters Intergroup Contact through Embodied Experiences”, Computer Mediated Communications, 2018
[38] “Virtual Reality in the Fight for Human Rights”, Amnesty International Report, 2020

[17] Chiradeep BasuMallick, Spiceworks Article. “Upskilling Strategy 2020: Is Your Workforce Acquiring Extended Reality (XR) Skills?”, October 2021. https://www.spiceworks.com/hr/learning-development/articles/upskilling-strategy-digital-skills-ar-vr-mr-xr-skills/
[18] “Metaverse and Web 3.0 opportunities in India”, KPMG and CII Report, November 2022, https://assets.kpmg.com/content/dam/kpmg/in/pdf/2022/11/ metaverse-and-web-3.0-opportunities-in-india-updated.pdf
[19] Dion Hinchcliffe, Zdnet, KPMG in India, June 2022
[20] Turolla et al. “Virtual reality for the rehabilitation of the upper limb motor function after stroke: a prospective controlled trial”, J NeuroEngineering Rehabil 10, 85 (2013). https://doi.org/10.1186/1743-0003-10-85
[21] Wong K. P., Tse M. M. Y., Qin J. “Effectiveness of Virtual Reality-Based Interventions for Managing Chronic Pain on Pain Reduction, Anxiety, Depression and Mood: A Systematic

Review", Healthcare (Basel). 2022 Oct 17;10(10):2047. doi: 10.3390/healthcare10102047
[22] Open-source smart glasses, https://github.com/TeamOpenSmartGlasses/OpenSourceSmartGlasses
[23] "Allied Market Research, Virtual Training and Simulation Market Size, Share, Competitive Landscape and Trend Analysis Report by Component (Hardware and Software) and End User (Defense & Security, Civil Aviation, Education, Entertainment, and Others): Global Opportunity Analysis and Industry Forecast", 2020-2027
[24] Goldman Sachs Global Investment Research, virtual and augmented reality report, Equity Research Report, 2016
[25] Deloitte Research Report, Technology, Media, and Telecommunications Predictions 2021
[26] Queiroz, A., Fauville, G., Herrera, F., Leme, M., & Bailenson, J. (2022). "Do Students Learn Better with Immersive Virtual Reality Videos than Conventional Videos? A Comparison of Media Effects with Middle School Girls". Technology, Mind and Behavior. https://doi.org/10.1037/tmb0000082
[27] WHO Global Report on health equity for persons with disabilities, December 2022
[28] Chen R. W., Chan K. K. (2019). "Using Augmented Reality Flashcards to Learn Vocabulary in Early Childhood Education", Journal of Educational Computing Research, 57(7), 1812–1831
[29] Craig et al. "Developing and Evaluating Complex Interventions: The New Medical Research Council Guidance", International Journal of Nursing Studies, 50(5), 587-592, 2008
[30] Seymour et al. "Virtual Reality Training Improves Operating Room Performance: Results of a Randomized, Double-Blinded Study", Journal of Surgical Education, 59(6), 737-741
[31] "Telemedicine Market Size, Share & Trends Analysis Report By Type (Telehospital, Telehome), By Component (Services, Software), By Delivery Mode (On-premise, Cloud-based), By End-use, And Segment Forecasts", Grand View Research, 2021 – 2028
[32] Malloy, K. M., Milling, L. S. "The Effectiveness of Virtual Reality Distraction for Pain Reduction: A Systematic Review", Clinical Psychology Review, 30(8), 1011-1018, 2010
[33] Ferrer-García et al. "Virtual Reality Based Treatments in Eating Disorders and Obesity: A Review", Journal of Contemporary Psychotherapy, 43(4), 207-221, 2013
[34] "Extended Reality (XR) Market by Component, Application, Device Type, Delivery Model, Industry Vertical And Region - Global Forecast to 2026", MarketsandMarkets Report, 2021
[35] "Seeing is Believing: The Potential of VR and AR in Education", PwC Report, 2019
[36] "XR: A new Reality for Industrial Enterprises", Accenture Report, 2021
[37] Bailenson et al. "Virtual Reality Fosters Intergroup Contact through Embodied Experiences", Computer Mediated Communications, 2018
[38] "Virtual Reality in the Fight for Human Rights", Amnesty International Report, 2020

BIBLIOGRAPHY

Michael S.W. Lee, Damien Chaney. "The Psychological and Functional Factors Driving Metaverse Resistance", Internet Research, 2023

Kay M Stanney, JoAnn Archer, Anna Skinner, Charis Horner et al. "Performance Gains from Adaptive Extended Reality Training Fueled by Artificial Intelligence", The Journal of Defense Modeling and Simulation: Applications, Methodology, Technology, 2021

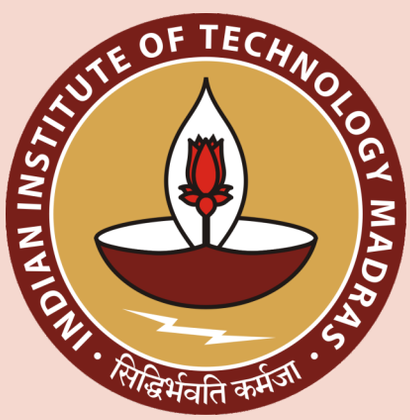
Arvind Kumar, Anand Rajendran, Mohd Usman, Jatin Ahuja et al. "Development and Validation of a Questionnaire to Evaluate the Knowledge, Attitude and Practices Regarding Travel Medicine Amongst Physicians in an Apex Tertiary Hospital in Northern India", Tropical Diseases, Travel Medicine and Vaccines, 2022

"Advances in Risk-Informed Technologies", Springer Science and Business Media LLC, 2024

Chandan Kumar Behera, D. Lakshmi, Isha Kondurkar. "Enhancing User Privacy in Natural Language Processing (NLP) Systems", IGI Global, 2023

Kuldeep Singh Kaswan, Jagjit Singh Dhatterwal, Vivek Jaglan, Balamurugan Balusamy, Kiran Sood. "Fog Computing in the IoT Environment", Institution of Engineering and Technology (IET), 2023

THIS PAGE
INTENTIONALLY
LEFT BLANK



Contact:

Dr. M. Manivannan, Professor
IoE Research Center for VR and Haptics
MSB-223, Department of Applied Mechanics and Biomedical Engineering
IIT Madras, Chennai-36, 600036
mani@iitm.ac.in, 044-22574064