LTIMindtree

Whitepaper

Spatial Computing

A window into the future of interactions

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01 Executive summary

The way we interact with the digital world is about to transform, thanks to the novel concept called 'Spatial Computing.' This whitepaper aims to provide a comprehensive overview of this emerging technology and its potential applications. Spatial computing is a rapidly expanding technological concept that utilizes digital technology to generate and collaborate with spatial data, enabling more efficient and effective ways of engaging with actual locations and producing more immersive and interactive digital experiences.

This whitepaper highlights the numerous and diverse uses of spatial computing, from immersive gaming experiences to virtual reality surgical simulators. However, before it can become a conventional technology, several critical issues must be resolved. There are concerns about privacy and security and the need for better user-friendly interfaces that interact with the digital world naturally and simply for end users.

In addition, the whitepaper provides business leaders, experts, and other stakeholders with a thorough understanding of spatial computing, including its advantages, complexities, and use cases. It explores different aspects, including its distinct characteristics, necessary technology stacks, strategies, and best practices for implementation across various business fields. It also includes insights and worldwide market data to provide a reference for enterprises looking to deploy spatial computing and get the most out of their investments. Overall this point of view will be an invaluable resource for anyone wishing to learn more about the potential applications of spatial computing and how businesses might benefit from them.

02 Introduction

Spatial computing describes the seamless integration of digital content and the physical world, creating an immersive and interactive environment. This technology uses a combination of Augmented Reality (AR), Virtual Reality (VR), Mixed Reality (MR), and other technologies to create a spatial computing platform. Spatial computing enables the users to interact with digital content more naturally and intuitively, using gestures, voice commands, and other input forms.

Simon Greenwold, an MIT researcher, coined the term "Spatial Computing" in 2003. Spatial computing uses a 3D environment as the primary computing platform rather than the traditional 2D Graphical User Interface (GUI). This environment can be a virtual or augmented reality, where the user can interact with digital objects and information in a 3D space. It allows for natural and intuitive interaction, such as gestures, body language, and spatial awareness. These interfaces are designed to be human-like and can naturally interact with the world around them instead of using a mouse and a keyboard.

Data gathering, pre-processing, data interrelation and normalization, data interpolation, data analysis, and visualization collectively comprise the complex workflow of spatial computing. A high-level spatial computing process workflow comprises six steps, as shown below:

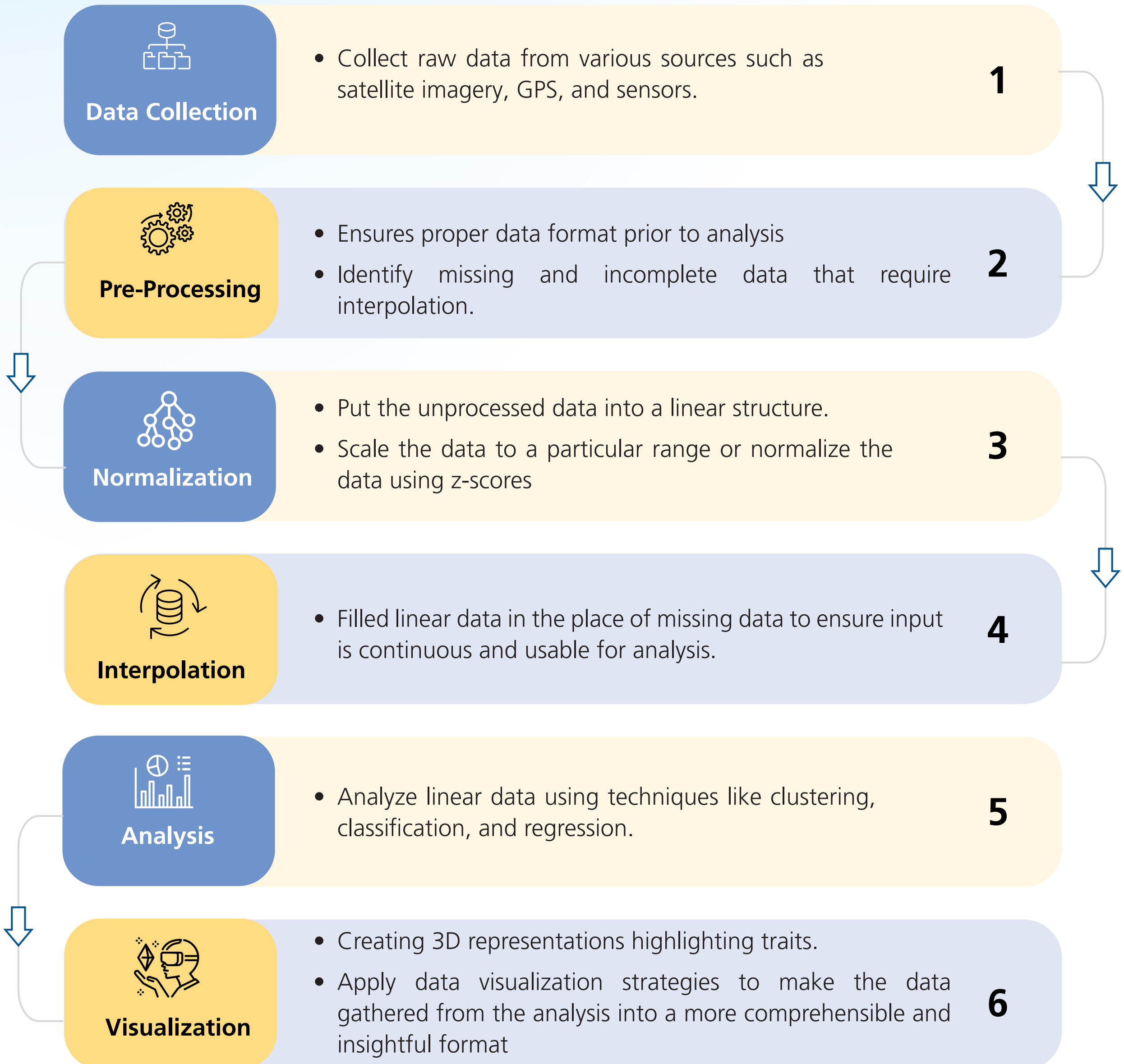

Figure.1: Spatial computing workflow diagram

03 Key challenges

Some of the factors affecting the adoption of Spatial Computing by IT executives are listed below:

1. **Cost of developing** robust and affordable computing hardware and more natural and intuitive human-computer interfaces.
2. **Lack of standardization** to create and deploy solutions compatible with different hardware and software platforms.
3. **Cybersecurity and data privacy concerns** due to the collection and storing of sensitive data.
4. **Intellectual Property management** to ensure protection and maximize the value of their technology.
5. A **high cost** is associated with building spatial experiences like high-quality 3D material. However, as AI and ML technologies develop, the price of creating 3D content will eventually decline.
6. **Limited standards** for accurate representation of data and lack of guidelines for algorithms

> "Technological advancements the devices would become much cheaper and easily accessible. With increased penetration of digital content and devices, there would be a greater need for spatial computing techniques and algorithms."

04 Technology insights

Technology Building Blocks

The building blocks of spatial computing organized into different layers work together to create intelligent systems that can interact with the physical world. These layers are:

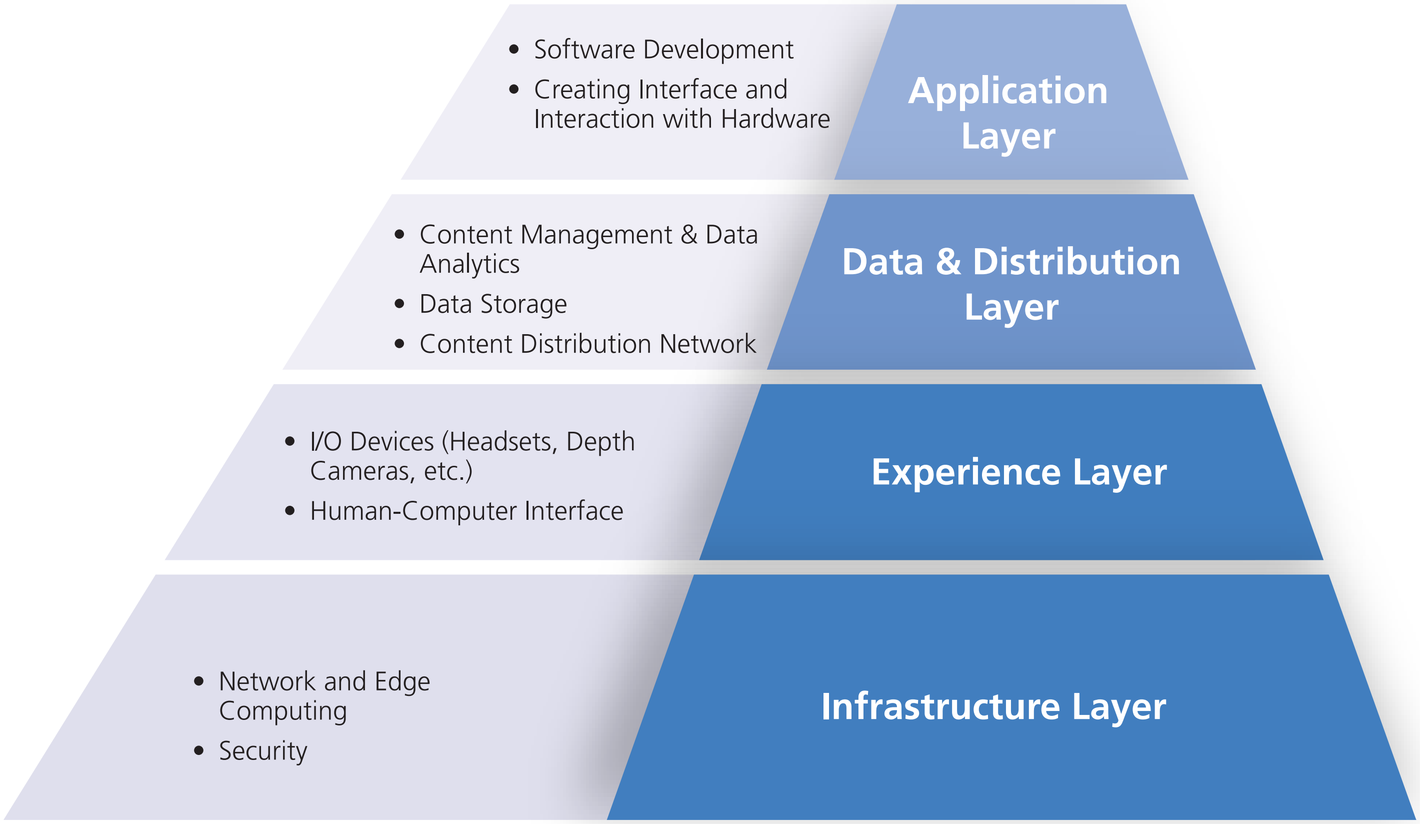

Figure 2: Building blocks of spatial computing

All these layers work together to create a complete spatial computing system that interacts with the physical world in intelligent and interactive ways. Each layer is crucial to the system's overall functionality, and they must work together seamlessly to provide a smooth and intuitive user experience.

The layering approach enables developers and engineers to focus on specific aspects of the system and to optimize each layer for its function. Spatial computing is a field that involves the integration of various technologies and concepts to enable the creation of intelligent and interactive systems that can interact with the physical world. The building blocks of spatial computing include -

- **I/O Devices:** They are devices and equipment required for spatial computing, such as VR and AR headsets, depth cameras, motion sensors, and other specialized hardware.
- **Software:** These are software platforms and tools required for creating and running 3D environments, such as Geographic Information System (GIS), 3D modeling software, and physics simulation software.
- **Human-computer interfaces:** They are methods and technologies used for input and interaction, such as gestures, voice recognition, and brain-computer interfaces.
- **Network and edge computing:** These are network infrastructure and cloud-based resources required for handling the data and the processing power needed for spatial computing.
- **Data and analytics:** This includes data management and analytics platforms required for collecting, storing, and analyzing the data generated by spatial computing.
- **Security:** The measures required to secure data and devices and protect them against unauthorized access or tampering, which is essential to secure sensitive data.
- **Integration:** It is the capability to integrate spatial computing technology with existing systems and technologies, such as Enterprise Resource Planning (ERP) systems, Customer Relationship Management (CRM) systems, and other relevant data sources.

Some encouraging statistics:

- By 2030, spatial computing applications that can precisely locate and map 3D movements will become ubiquitous. These applications will improve operations and maximize interactions between humans, machines, objects, and working environments.
- By 2030, manufacturers can improve their IIoT capabilities owing to spatial computing, which adds motion awareness to the analytical mix. They will advance from occasionally optimizing specific operations to continuously optimizing the entire factory.
- As per sources, by 2026, the second and third iterations of spatial computing glasses will arrive, creating a more pervasive metaverse experience connected to the physical world.

05 Market insights

Market potential

Spatial computing technology is a rapidly growing market, driven by the increased demand for immersive experiences, data-driven decision-making, IoT, and 5G. Various gaming, healthcare, and manufacturing applications use these features. Here is a snippet showcasing the key highlights of the current spatial computing market:

Huge Presence In Gaming Industry
The most common industry for Spatial Computing is video gaming, they demand high quality graphic experiences. Relevant talent also exists in Gaming industry.

R&D Needed For Developing New Algorithms
R&D required for development of advanced algorithms for analyzing, interpreting and storing spatial data.

High Cost Of Devices
The current devices in the market are costly, and have large form factor, and have limited performance.

Rapid Advances In The Technology Catalysts
AR is now a mature technology as per Gartner, others are also rapidly advancing, like LiDAR, and 5G which is now available for consumer use.

Gesture -based Computing Aiding Growth
The increasing adoption of Gesture - based computing is aiding the market growth by opening several applications and opportunities.

2X — Increase in patents from 2018 to 2021 – McKinsey

~66% — Enterprise adoption in AR though 2026 – McKinsey

~$4 bn — Venture capital investments made in this space in 2021 – McKinsey

Figure 3: Technology insights-current state

Spatial computing is an amalgamation of technologies such as VR, AR, Metaverse, Digital Twins, and 3D mapping and modelling, among other types of digital representation of physical locations. The market potential for these related technologies is substantial and growing. Various factors contributing to the growth include:

1. Increased demand for immersive digital experiences
2. Advancements in hardware and software
3. A growing interest in the use of spatial computing for various applications across various industries

06 Use cases

1. Remote collaboration and accessibility

Spatial computing can transform various industries, including healthcare, manufacturing, and education. In healthcare, it could eliminate the need for physical visits, enabling virtual consultations and treatments and the virtual participation of international experts in appointments. It could also allow surgeons to virtually guide their colleagues in performing surgeries on patients thousands of miles away.

2. Surgical procedures

Surgeons may perform procedures combining haptic capabilities, bespoke 3D-printed surgical instruments, and hands-free digital models. The surgical team might virtually gather around a 3D digital twin of the patient's heart before starting the procedure.

3. Education

Remote accessibility in education can help with online learning, and spatial computing can provide students with immersive and engaging learning experiences. Through the remote accessibility feature, spatial computing can aid with remote monitoring and management of production lines in manufacturing. The retail industry leverages AR and VR technologies to provide virtual shopping experiences.

4. Digital twins

Spatial computing enables the creation of digital twins or digital replicas of large-scale assets such as construction projects. Digital twins help to simulate and test construction projects, which reduces costs and errors. The technology allows for optimization in 3D simulations, leading to faster project turnaround times.

A good example is Saudi Arabia, where, for their proposed futuristic city, NEOM, they are creating a 3D digital twin metaverse platform. Avatars that enable simultaneous presence in the physical and digital worlds, matching user profiles to foster interaction, gamified experiences, instant language translation, and integrated cryptocurrency and NFT digital asset platforms are some of the platform's key features.

5. Generative AI

Generative AI is a powerful tool used in spatial computing to create realistic 3D models, textures, and environments and generate the assets used in 3D virtual spaces. For example, training Generative Adversarial Networks and Variational Auto Encoders on large datasets of real-world 3D models, textures, and environments helps generate new, realistic assets.

Various applications can use these generated assets, like virtual and augmented reality, video games, and architecture visualization. Spatial computing is crucial in Generative AI because it enables the development of AI systems that can interact with the physical world in real time and generate spatially relevant outputs. Following are some important aspects of spatial computing used in generative AI.

Content generation: Spatial Computing, in conjunction with Generative AI, can generate 3D material for AR and VR applications, resulting in immersive and interactive digital experiences.

Real-time simulation: Generative AI models can produce real-time simulations using spatial computing to represent the system's behavior dynamically for decision-making and analysis.

Interactive design: Interactive design tools, developed using spatial computing, use Generative AI to build designs depending on the user's preferences and limitations.

Personalized user experience: Creating unique and engaging digital experiences tailored per user preferences and habits is possible using generative AI and Spatial Computing.

6. Smart spaces

Smart Spaces, a spatial computing application, leverages this technology to create an interactive and responsive physical environment. In a smart space, for instance, sensors and AI might collect environmental data, such as lighting levels, temperature, and occupancy, and then utilize this data to make real-time environmental adjustments. A smart space, for example, may automatically adapt the lighting and temperature per the user's preferences.

Spatial computing lays the groundwork for smart spaces by enabling the production of digital twins and other interactive technologies. These technologies facilitate a smart space to create a responsive and data-driven environment. The following are some essential decisive factors for the implementation of spatial computing within smart spaces:

Interaction of related technologies: Smart environments can integrate AR, VR, and MR technologies to improve the user experience. Smart environments allow users to engage with digital information in new and fascinating ways in the actual world.

Sensor networks: The data from the smart spaces collected using sensor networks support decision-making. It can boost energy efficiency, track occupancy, and enhance safety.

Context-aware applications: Contextual information such as location, time, and user behavior helps construct context-aware applications that adapt to the environment and user demands in smart environments.

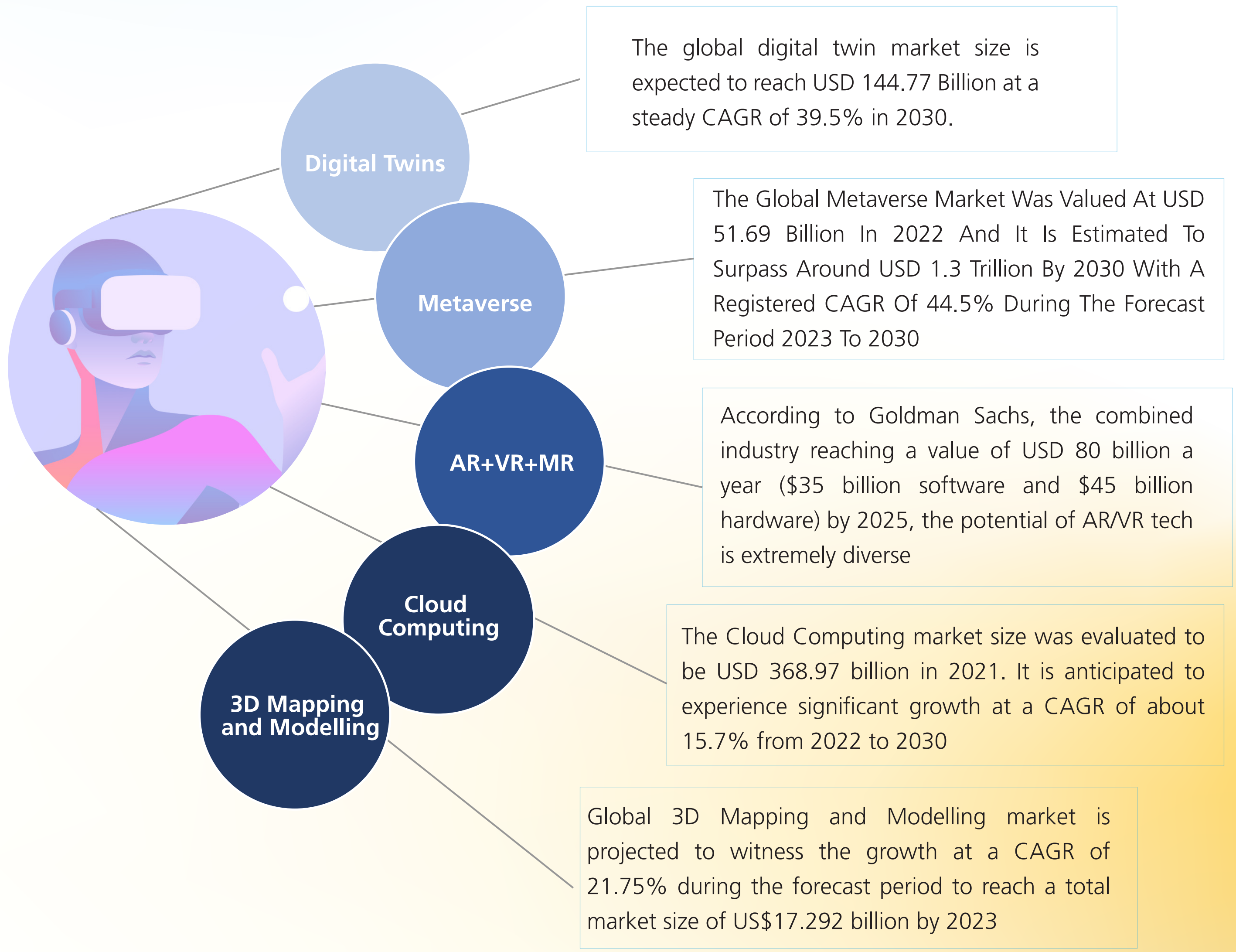

Figure 4: Market potential of related technologies

> “The market potential of spatial computing is expected to rise positively owing to the growing demand for its associated technologies. Spatial computing has the ability to change the way people interact with technology and their surroundings. It can improve consumer experiences, increase efficiency, and present new opportunities for firms in a variety of industries. The market for spatial computing is expected to expand rapidly in the coming years, owing to the usage of Augmented Reality (AR) and Virtual Reality (VR) technologies, the proliferation of IoT devices, and the development of 5G networks. As a result, businesses that invest in spatial computing are more likely to profit from the rising market demand and acquire a competitive advantage.”

Geographical Analysis

North America

- The HoloLens project by Microsoft, a mixed reality headset
- The Meta 2 project by Meta, a holographic computer
- The Project Tango by Google, uses computer vision & sensor tech to facilitate mobile devices understand and navigate the physical world.
- The Oculus Quest project by Oculus, a standalone VR headset for fully immersive digital content interaction.
- The Magic Leap project by Magic Leap, a mixed reality
- The Metaverse project by Unity Technologies, a virtual world platform that allows users to create and interact with digital content in a shared environment.
- The Realsense project by Intel
- The ARKit project by Apple, a set of tools for developers to create augmented reality apps for iOS devices.
- The Hololens 2 project by Microsoft

Europe

- The VR in Construction project by the Universidad de Chile
- The VR in Health Care project by the Fundación Cardioinfantil in Colombia
- The VR in Tourism project by the Brazilian Tourism Board
- The VR for Education project by the Universidad de la República in Uruguay
- The VR in Agriculture project by the Universidad de la Frontera in Chile, which aims to use VR technology to improve agricultural productivity and sustainability

Asia-Pacific

- The VR for Education project by the University of Cape Town
- The VR in Agriculture project by the International Institute of Tropical Agriculture, which aims to use VR technology to improve agricultural productivity and sustainability.
- The VR in Health Care project by the Ghana Health Service,
- The VR in Construction project by the National Building Research Organization of South Africa, which aims to use VR technology to improve the planning, design, and construction of buildings and infrastructure

South America	Middle East & Africa	Africa
• The ViARproject by Fraunhofer, which is focused on developing a VR platform for use in the industrial and manufacturing sectors • The VRTogether project by EU, which is focused on using VR to enhance social interactions and communication. • The VR2Market project by EU, which is aimed at supporting the development and commercialization of VR applications and technologies.	• The Metaverse project by Tencent, which is a virtual world platform that allows users to create and interact with digital content in a shared environment. • The V-Sido project by Softbank Robotics, which is a robot control system that uses virtual reality technology to allow users to control robots remotely. • The XRSpatial project by Alibaba, which is focused on developing spatial computing technology for use in retail, entertainment, and other industries.	• The Virtual Interactive Museum project by Abu Dhabi's Tourism Development & Investment Company • The Virtual Heritage project by Qatar Museums • The VR & AR in Health Care project by Dubai Health Authority • The VR Lab by University of Bahrain, which focuses on researching and developing virtual reality technology for various applications. • The VR in Construction project by the Ministry of Municipality and Environment of Qatar, which aims to use VR technology to improve the planning, design, and construction of buildings and infrastructure.

Table 1: Geographical developlement of spatial computing

The spatial computing market is expected to witness significant growth in the upcoming years owing to the widespread deployment of enabling technologies, including AR & VR. North America, Europe, and Asia-Pacific are three regions where the industry is anticipated to expand, each having its potential and challenges.

> "Spatial computing is gaining a lot of traction in North America, especially in the US. However, Asia's market, including China and Japan, is also aiming for more indigenous and innovative solutions like AR and VR, of which spatial computing is an extension. More pilot runs and experiments are being conducted in the US. However, China is also finding its way into various sectors where spatial computing and other related technologies can be deployed."

07 Key technology drivers

Some specific drivers accelerate the growth and innovation of spatial computing. They expand the horizon of possibilities and opportunities for organizations and individuals and drive the adoption and advancement of this technology.

Advancements in AR, VR, and MR Hardware

Spatial Computing enhances AR, VR, and MR hardware through factors like:

Interactivity: The need for new forms of interaction, like voice commands and hand gestures, has propelled the demand for new hardware devices. Spatial computing supports these devices and offers a foundation for immersive experiences. Head-mounted displays, hand-held controllers, sensors, and peripherals are some devices that allow users to interact with virtual objects and settings in several ways. By enabling people to interact with virtual content more intuitively and engagingly, spatial computing can allow new forms of communication.

Need for high processing power: The more powerful the hardware, the more immersive and responsive the virtual experience. It lets users interact with virtual objects and environments more naturally and intuitively. VR and MR devices often require high-end Graphics Processing Units (GPUs) and fast processors to offer real-time, smooth, realistic graphics. High computing power enables these devices to handle complicated algorithms, such as hand tracking and body tracking, essential for a natural and seamless experience. In this regard, the ability to analyze and render massive volumes of data in real time is a critical component in spatial computing when integrated with AR, VR, and MR devices.

Broad adoption of 5G network: Spatial Computing is inextricably associated with developing 5G networks since 5G provides the infrastructure required to deliver high-bandwidth, low-latency spatial computing experiences. 5G networks have quicker data transfer speeds and lower latency than the earlier cellular networks. It allows smoother and more responsive AR, VR, and MR experiences, thereby boosting spatial computing, which requires 5G to support high bandwidth and low latency.

Booming industries of gaming and healthcare

Spatial Computing, including VR and AR, is being used in the gaming industry to offer more immersive and engaging gaming experiences. These virtual representations generate digital twins of real-world surroundings via spatial computing technologies such as AR, VR, and MR. VR and AR can transport gamers into virtual worlds, giving them a sense of presence and involvement, that traditional gaming cannot.

In healthcare, spatial computing technologies such as VR and AR improve patient care and medical education. VR can be used to deliver therapy to patients and to imitate surgical procedures, allowing doctors to practice and enhance their skills. AR can superimpose digital information in the real world, allow doctors and nurses to access patient information and medical imaging in real time, and provide virtual assistance and instructions to patients.

> "The increasing demand for an enhanced experience in human-machine interaction will boost the demand for spatial computing. Spatial computing can unlock significant productivity by streamlining workflows and interactions between people, objects, and machines. For instance, logistics and supply chain settings stand to gain substantially from this technology."

08 Key technology adoption opportunities

The topic of spatial computing has numerous prospects for technological and market expansion. Among the significant opportunities are:

Sensor technology advancements

The development of more modern sensors, such as Lidar and RGB-D cameras, can capture more precise and detailed spatial data to increase the performance of spatial computing applications.

Increased usage of cloud and edge computing

This allows processing massive volumes of spatial data, improving the performance of spatial computing applications. These applications can readily interface with other digital technologies, such as AI and IoT, leveraging cloud and edge computing, resulting in smoother and integrated experiences.

Growing need for smart cities and smart buildings

Developing smart buildings, smart transportation, and smart energy systems involves integrating multiple technologies such as IoT, big data, and cloud computing. There is potential for growth in the spatial computing market. Moreover, spatial computing technologies enable real-time data collection and analysis in smart cities and smart buildings, giving vital insights for decision-making and continuous improvement.

Autonomous Vehicles

Spatial Computing is a critical technology for developing autonomous cars since it allows the vehicle to recognize and interact with its surroundings. Advanced navigation systems are required for AVs to map their environment and make judgments in real-time accurately. Lidar and 3D mapping are two spatial computing technologies that can help develop these navigation systems.

09 Conclusion

Spatial computing has the potential to transform how organizations interact with customers, employees, and surroundings. However, it presents challenges such as adoption, standardization, and data privacy and security. When deploying spatial computing, organizations can face poor integration, lack of software optimization, inadequate hardware, insufficient network infrastructure, and ignoring compatibility issues. Hence, the successful deployment of spatial computing requires a comprehensive approach.

It means investing in appropriate hardware, optimizing software, integrating with existing systems, ensuring sufficient network infrastructure, and addressing compatibility issues. Organizations that overcome all the associated challenges and follow the right strategy can benefit from improved customer engagement, enhanced productivity, new revenue streams, and

10 Authors

Bharat Trivedi
Principal Architect, GTO

With 20+ years of experience, Bharat is a product developer by heart, he has been instrumental in introducing high tech in areas like Retail Banking, Capital Markets, Online Trading and the Regulatory Space. His unique way of looking at technology makes him an able mentor the to the aspiring.

Namrata Sharma
Senior Consultant, GTO

Collaborative and vigorous with a propensity to solve problems, Namrata brings a noteworthy amount of experience in the management consulting and research sector. Namrata's areas of expertise include strategic planning, creating market intelligence studies, data modeling, and domain critical evaluation.

Hakimuddin Bawangaonwala
Senior Consultant, GTO

Hakimuddin looks into beyond the horizon technologies and performs deep research to identify their need, opportunities, and implementation areas. He is also skilled at strategizing and creating use cases for the quick incubation and industrialization of these technologies.

Abhijeet Gundewar
Specialist, GTO

Abhijeet is a Techno Management professional with 9+ years of experience spanning multiple roles and domains in managing consulting, business development, and lifecycle management for Fortune 500 Companies. In LTIMindtree, he works as a Technology Evangelist hunting for new-age technologies, creating PoVs around them, chalking out strategies to convert the concepts into service offerings, and supporting in incubating and industrializing the offerings to a larger scale.

Chitrang Negi
Specialist, GTO

Chitrang is currently supporting the Quantum Technology incubation initiative. He is engaged in creating business cases, identifying, and defining service offerings, creating the go-to-market strategy, and contributing to marketing and promotional activities.

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