ANNEXES A-2

IMMERSIVE MEDIA

AND

ADVANCED INTERFACES

SG:D TECHNOLOGY ROADMAP
INFOCOMM MEDIA DEVELOPMENT AUTHORITY

CONTENTS

1 INTRODUCTION & OVERVIEW

The Immersive Media & Advanced Interfaces (IMAI) report explores how the advancement of digital technologies are impacting all aspects of our lives. With the digitisation of information and content, our means of interfacing with information is constantly changing. The report seeks to highlight the advancements and recent megatrends and to imagine how we will interact with these developing technologies.

Next, this report will elaborate further on what constitutes IMAI and assess the 2 key considerations for enterprises seeking to explore the possibilities in IMAI:

- **Market Study:** Understanding where the market opportunities lie
- **Technology Study:** The key technology components (near / mid / long-term) that make up IMAI

The report will then provide a SWOT analysis of the Singapore market with regards to IMAI technologies and provide recommendations to summarise on the proposed approach for enterprises to leverage on IMAI for their businesses.

1.1 Immersive Media & Advanced Interfaces (IMAI) – Interface of the Future

IMAI plays a critical role in providing a compelling avenue for users to interface with the latest technologies and fully leverage the potential that these technologies offer. It represents an evolution towards intuitive interactions. The user interface has shifted from punch cards and paper in mainframes, to point-click-type computers, to touchscreens on mobile phones. IMAI can take it one step further, by removing any tangible interface at all, allowing users to communicate through natural modes of interaction such as gaze, gesture, voice, and eventually context. By shortening the chain of commands, attention is shifted from the device or machine to more real-world interactions.

IMAI can be defined as the technologies that impact the 5 human senses of:

a) Vision (sight)

b) Tactile (touch)

c) Gustation (taste)

d) Auditory (hearing)

e) Olfaction (smell)

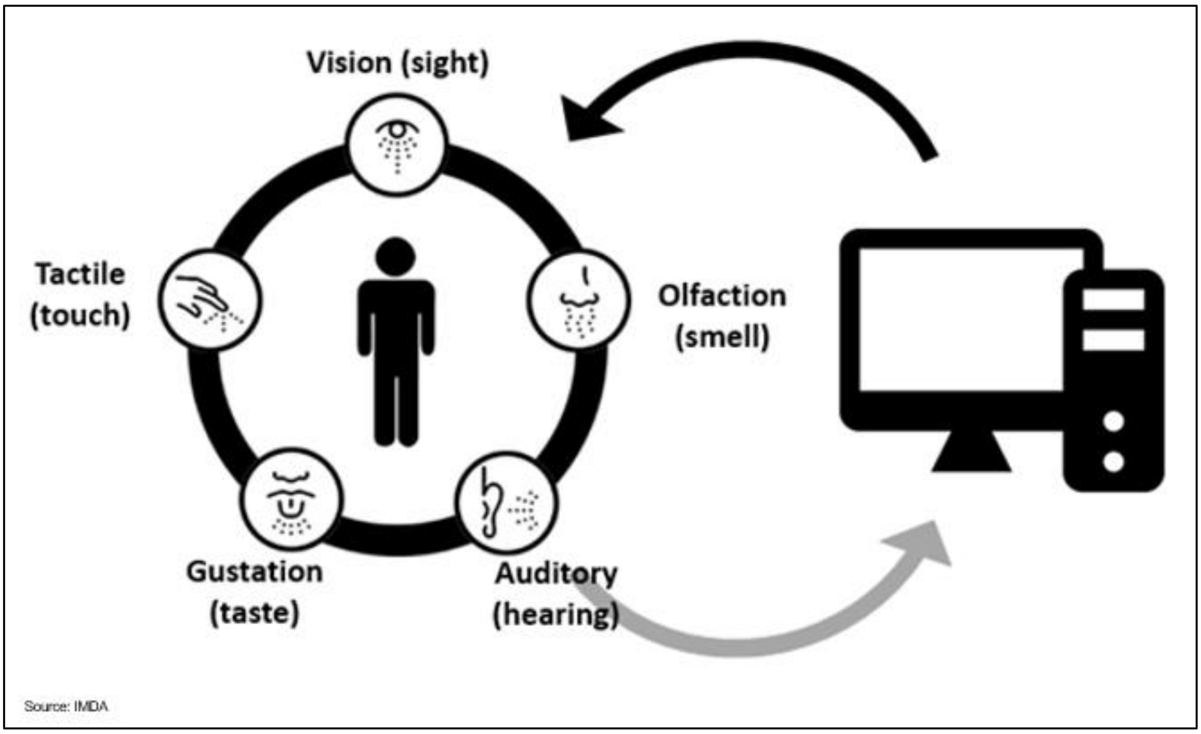


Exhibit 1: Immersive Media and Advanced Interfaces

In other words, IMAI can be seen as an enabler for the 4th wave of computing power, with the potential to become the "form factor" for next-gen computing as a universal, smart, and intuitive interface for users to interface with new, disruptive technologies. As a result, IMAI has the potential to ultimately impact every sector and company by transforming how they communicate, design, manufacture, and sell products. Here are some potential ways in which IMAI could further accelerate the pace of adoption for immersive experiences amongst consumers and businesses:

Vision (sight)

Vision technology has been constantly evolving. Display resolution technology for television screens, as an example, has been advancing and offer a higher screen quality to users. 8K resolution was recently launched in the market, which is considered currently the highest Ultra-High-Definition (UHD) television with 8K pixels width. 8K is an upgrade from a 4k television screen, which was first launched in 2012. The pace at which vision technology is advancing and improving underpins the following possibilities:

a) **Visually high quality media content**: Consumers have access to 'super' resolution (8K) media content. With 8K resolution display screens projected to go mainstream from 2019 onwards, there will be growing demand for 8K resolution content. For example, the first consumer TVs (employing 8K technology) were exhibited at the Consumer Electronics Show (CES) 2017. This was followed up by actual product launches at the *IFA Event Berlin 2018*. 8K TVs is expected to set the standards for the next generation of vision technologies.

b) **More affordable hardware**: With advancements in vision technologies, earlier generations of vision technologies and corresponding hardware will undergo a drop in production costs and pricing. For example, the price of a 4K television has been continuously decreasing from ~US$ 1,300 to ~US$700 in one year [1].This means more affordable hardware and devices which the masses can consume higher quality content. What was once out of reach of the wider consuming public is now more easily accessible, thus reinforcing the acceleration in adoption of Immersive Media and Advanced Interfaces.

c) **Impact on content creators**: Improved resolution and greater frame rates directly impact the quality and fidelity of visual content produced. With readily available 8K capture technology (such as 360-degree video cameras offered by *GoPro* and *Insta360*), this opens up new spaces for content creators to explore and monetise. The evolving technologies with growing availability of technology to consume the content and growing consumer base will improve the adoption of immersive media experiences. This growing demand is expected to be translated into hardware upgrades, optimisations and changes to existing media production pipelines (from a content creators' perspective), all of which will drive development of the Immersive Media industry.

d) **Innovation and Costs**: With emerging and improving resolution technologies, hardware and software companies are able to produce higher resolution display components at lower costs. These components are used in the production of VR headsets (Pimax), smartphones, smart watches etc. The lower production costs translate into more affordable consumer prices (for the end user), driving adoption of the technology. In addition, with lower production costs, it is more feasible and justifiable to innovate and create next generation devices and software to support 8K content.

Tactile (touch)

Haptic technology can provide more immersive learning experiences and augment existing teaching methods. For example, in industrial training, physical feedback such as recoil from heavy machinery and heat from furnaces could be integrated into the session to provide more realistic and safer experiences that closely mirrors the operational environment.

Gustation (taste)

Through the use of electrical currents delivered via electrodes, the taste buds on a person's tongue can be stimulated to create different taste sensations (e.g. salty, sour, etc.). These signals trick the brain into receiving a full and authentic taste sensation that may differ from the actual reality. For example, a person may be drinking tap water, while his/her brain is sensing gin or wine.

The benefit of this technology is that it allows for the creation of custom flavours, making it possible for people to enjoy the flavour that they love without needing to worry about the adverse reactions (e.g. allergic reactions, high calorie count, lack of nutritional value, etc.) to actual ingredients.

Auditory (hearing)

Advancement of spatial audio can provide users with experiences that both place sounds in a 3D context as well as detect the positional source of a sound. The Google VR audio system creates multiple virtual loudspeakers to reproduce sound waves coming from any direction in the listeners' environment, while dearVR's Spatial Connect simplifies the integration between audio production environments and 3D-world rendering.

Another field that is closely linked to the Auditory (hearing) domain is Speech Recognition, which has witnessed a number of significant advances in the past few years (spurred on by advances in signal processing, algorithms, computational architectures, and hardware). Major companies such as Google, Apple, and Microsoft are leveraging their huge customer base and using advanced methodologies such as statistical pattern recognition paradigm and neural networks to process, understand, and take decisive actions based on real-time voice inputs from the user. As a result, Speech Recognition is gaining high penetration in various industries such as:

a) **Automotive**: High end passenger car manufacturers are deploying Speech Recognition technology to offer intelligent personal assistance systems that allows the driver easy, hands-free access to content and services. This prevents the driver from being distracted from driving, thus enabling a safe driving experience.

b) Healthcare: Speech Recognition has two applications in the healthcare industry: first is front-end speech recognition which allows clinicians to self-edit, dictate, and sign transcription directly into electronic health record (EHR) and second is background speech recognition which turns dictation into speech-recognised drafts medical language specialists can edit.

c) **Consumer electronics:** When combined with Artificial Intelligence, Speech Recognition would allow for ubiquitous robots that are likely to be able to interact like humans and provide assistance in day-to-day work. There are already a few voice-assisted robots in the market, for example, Echo by Amazon and Alexa by Google, which are voice-activated, hands-free devices that answers questions, plays music, provides information, checks sports scores, reads the news, and so on.

Olfaction (smell)

Although less commonplace, immersive technologies related to smell are also available in the market place. Olorama Technology is an innovative start-up which created a technology that combines hardware, software and essential oils to provide a wide variety of safe, bespoke scents. This technology has been used by notable perfume manufacturer Lancome as a training tool for their staff on new products. Another start-up VAQSO (from Japan) is developing a device for context-sensitive scent diffusion in VR experiences, and is intended to be compatible with popular headsets (e.g. Oculus Rift, HTC Vive, PlayStation VR) and its associated contents.

2 MARKET STUDY

The purpose of this chapter is to give an understanding of the global, regional and Singapore market potential for IMAI technologies – Vision, Tactile, Auditory, Olfaction, and Gustation. We also share our view on key trends, enablers and key potential application sectors that have been and will be continuously driving the global market for IMAI technologies.

2.1 Global Trends

The pace of technological advancements is increasing rapidly, led by disruptive technologies which are accelerating innovation, improving efficiencies, transforming established sectors and creating new business opportunities. This in turn, is profoundly impacting both the way consumers live and how enterprises conduct their businesses. Technology can make consumer experience more interactive and memorable and also support consumers' decision-making processes. Technology has been improving work efficiency, effectiveness and safety, as well as enhancing worker's physical and perceptual abilities, increasing their value [2]. The impact can be significantly different between consumers and enterprises. For example, Virtual Reality (VR), Artificial Reality (AR) and Mixed Reality (MR) are one of the pervasive IMAI technologies and their adoption among consumers and enterprises is significantly different. For consumer market, VR is dominant due to high demand from gaming, experiential activities, and entertainment, while the proportion is inversed for the enterprise market and AR and MR are expected to show rapid adoption.

Here are some examples of such megatrends:

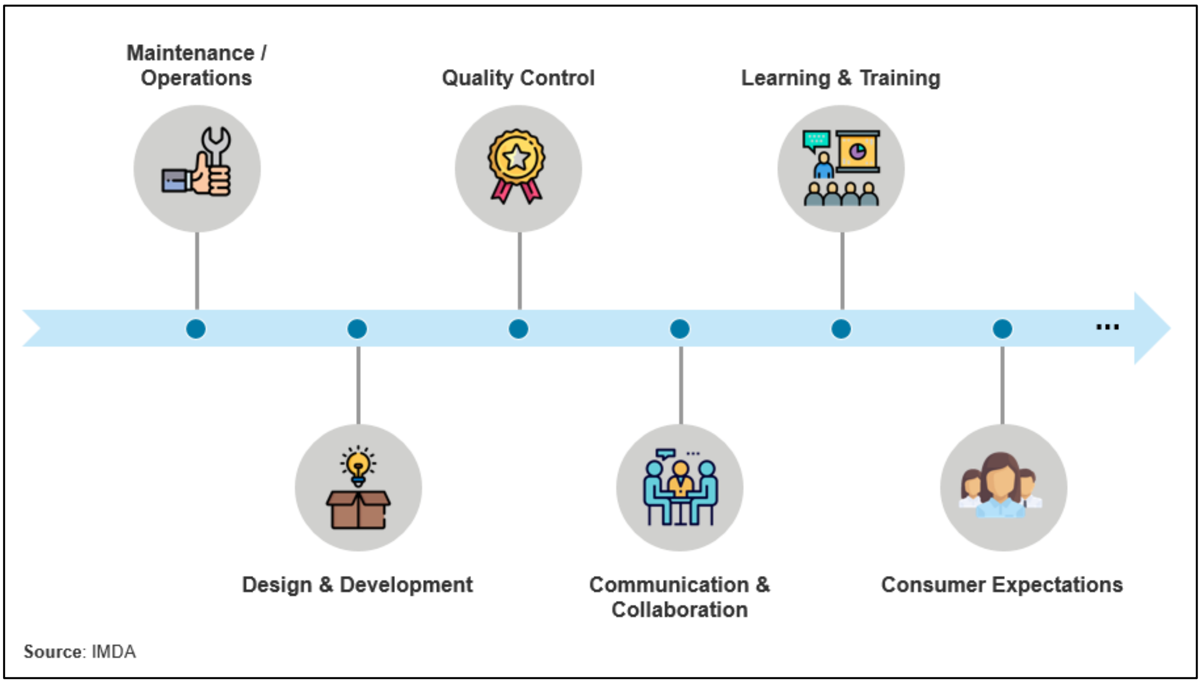


Exhibit 2: Examples of Megatrends

Consumer expectations

There is an increasing shift of users' expectations in terms of how they prefer to consume and interact with content and information. Highlighted as one of Gartner's Top 10 technology trends for 2018 and beyond (see "Top 10 Strategic Technology Trends for 2018"), Immersive Experiences offer the potential of moving from a static to richer, more immersive experiences. From advanced haptic sensors that capture richer friction-free input to using 3D to present new visual information, the boundaries between people's perception of physical and virtual reality is starting to blur, and could result in a drastic impact on lives and society. The way we live, work and consume information and media is fundamentally changing. This could be game-changing; users will no longer be detached consumers of content, but will be placed inside ever-expanding digital worlds and find themselves at the centre, hence the "immersive" nature of the technology e.g. physical spaces like offices and changing rooms in clothing stores may be replaced by digital spaces.

Communication and collaboration

Modern organisations are no longer tied down into a single location for work purposes; colleagues and consumers are often spread out across different geographic locations. In order to ensure that teams can still work together and interact with consumers seamlessly, various communication and collaboration tools have emerged to support this kind of next-generation interaction by replacing shared productivity tools and videoconferencing with immersion and a sense of presence. Technologies such as wearable and hearables enable more cost-effective collaboration, by enabling cooperation without collocation. Workers in disparate locations can interact with the same digital artefacts, just as if they were in one conference room manipulating the same physical objects. For example, automotive manufacturers are applying these methods to visualise design improvements of existing components—dramatically accelerating the concept-to-manufacturing process among globally distributed teams. Likewise, research and development functions, construction and engineering firms, and even some services organisations are exploring this new style of collaboration, removing geo-temporal constraints from both creative processes and more tangible operations.

Maintenance / operations

In modern manufacturing and production, advanced machinery and equipment can generate large amounts of diagnostic data which helps predict failures and improve productivity. However, it is a challenge for workers to process and correlate the information quickly enough; especially in environments where they require both hands for operations i.e. unable to hold onto monitoring screens or panels to check the information. As a result, smart goggles are increasingly being used in such situations; these devices can overlay digital images / data to provide metrics, instructions, remote support and training to these workers as they operate in the challenging / hazardous physical environment. Support from smart devices and workplace safety, especially in energy, utility and construction sectors, are becoming more important as increasing workforce participation from older workers due to aging population[a] [3]. Examples of such solutions include wearables and wireless gas detectors, which can detect and alert workers and companies for emergency cases.

Design and development

Markets are becoming increasingly competitive, and companies are constantly seeking to design and develop their products to launch to market as soon as possible. Where in the past prototypes may be created physically, technology has since evolved to allow for virtual prototypes. These digital 3D versions are as detailed as a physical version, and allow for rapid iteration, assembly simulation, advanced testing and remote collaboration between geographically separated teams. Full-body motion tracking / feedback can also be incorporated into the design / development process, to inform on the ergonomic design of products/ workspaces / assembly lines. For example, many architecture companies start to leverage on technologies to help their clients visualise and imagine the designs of interior spaces and external buildings.

Quality control

The increasing mechanical complexity of modern products is a challenge for the quality control process. It is no longer feasible for inspectors to perform checks manually in a timely and accurate manner. Hence advanced scanners and imaging devices have been developed, which can use sensors, computer vision, and photogrammetry to evaluate products accurately against pre-set standards. The

[a] By 2026, 37 percent of those aged 65 to 69 years will be actively employed, versus 22 percent in 1996

results can be presented in detailed 3D models that can be manipulated into different viewing angles/perspectives to highlight defects, hence allowing inspectors to quickly locate and remedy the issues.

Learning and training

Immersive learning is an alternative method of learning that provide effective training in a safe, cost-effective environment as training has always been in dilemma between easy but ineffective, or effective but expensive and risky in the real world [4]. For example, VR simulation can let trainees feel authentic experiences and learn how to respond to a crisis such as a fire break out. During medical trainings, extremely rare and dangerous experiments and treatment experiences can be done via immersive training, giving doctors better exposures and lower pressure in repeated simulations. For example, a cardiologist can use 3D model to see a heart defect, not just from symptoms or test results. It was found that Computer Based Trainings (CBT)'s attention rate is around 7 to 8%, significantly lower than immersive learning's attention rate of ~80%[b].

The next 2 sections will detail key considerations for enterprises seeking to explore opportunities in IMAI – the markets with the most business potential, and the near-to-long term technology components that will advance the capabilities of IMAI.

2.2 Global and Regional Market Potential

The five IMAI technologies are expected to experience continuous growth in the 2017 to 2022 forecasted period (*Exhibit 3*). The estimated market sizes of each technology are reflected by the market sizes of key sub-technology components:

a) **Vision**: Augmented Reality (AR) and Virtual Reality (VR) technology

b) **Tactile**: Haptic technology

c) **Auditory**: 3D Audio and Speech Recognition technology

d) **Olfaction**: Digital Scent technology

e) **Gustation**: (emerging technology)

Vision technology will have the greatest market potential and growth among the IMAI technologies, with forecasted global market spending of US$209.2 billion in 2022 (which accounts for over 85% of total identified IMAI market, ~US$237.8 billion) and a CAGR of 71.6% from 2017 – 2022. The technology development in IMAI is restricted to a few geographical locations globally. The U.S. will hold the leading position in AR/VR market, with the highest CAGR of 99.1% from 2017 – 2022 [5]. Many US-based technology leaders such as Facebook [c], Apple [d], and Google have been actively investing in the mobile AR market, which is expected to reach US$60 billion by 2021 [6]. In the APAC region, China is expected to hold over 90% share of the total APAC (excluding Japan) AR/VR market (~US$11 billion) [7] driven by strong investments by technology companies such as Alibaba and Tencent [e] [8] [9].

[b] Deloitte expert interview
[c] Facebook indicated AR and VR technologies to be their top three tech priorities along with connectivity and artificial intelligence
[d] Apple announced its ARkit for iOS in 2017 as "the largest AR platform in the world"
[e] China-based investors participated in 36 deals totalling US$1.2 billion in disclosed funding in the AR/VR field, which includes (1) Alibaba's participation in Magic Leap's US$794 million series C round, (2) Tencent-backed Hollywood film studio STX Entertainment's acquisition of US-based VR content producer, Surreal.

	Vision	Tactile	Auditory	Olfaction	Gustation
Global Market Spending in 2022 (17-22 CAGR) *(USD Billion)*	209.2 (71.6%)	19.6 (16.2%)	17.8 (16.6%)	1.2 (30.4%)	*Emerging Technology*
APAC Market Spending in 2022 (17-22 CAGR) *(USD Billion)*	62.5[1] (68.5%)	8.4 (15.5%)	7.5 (18.0%)	0.3 (30.7%)	
APAC Market Share *(%)*	29.9%	42.9%	41.9%	22.9%	

Note: The estimated market sizes of each technology are reflected by the market sizes of key sub-technology components: Vision – AR/VR technology, Tactile – Haptic technology, Auditory – 3D Audio & Speech Recognition technology, Olfaction – Digital Scent technology; (1) APAC excluding Japan;
Source: International Data Corporation (IDC); Markets and Markets; InkWood Research; Global Market Insights; Transparency Market Research; Coherent Market Insights; Newzoo Market Research; Monitor Deloitte Analysis

Exhibit 3: Estimated Market Sizes for Five IMAI Technologies

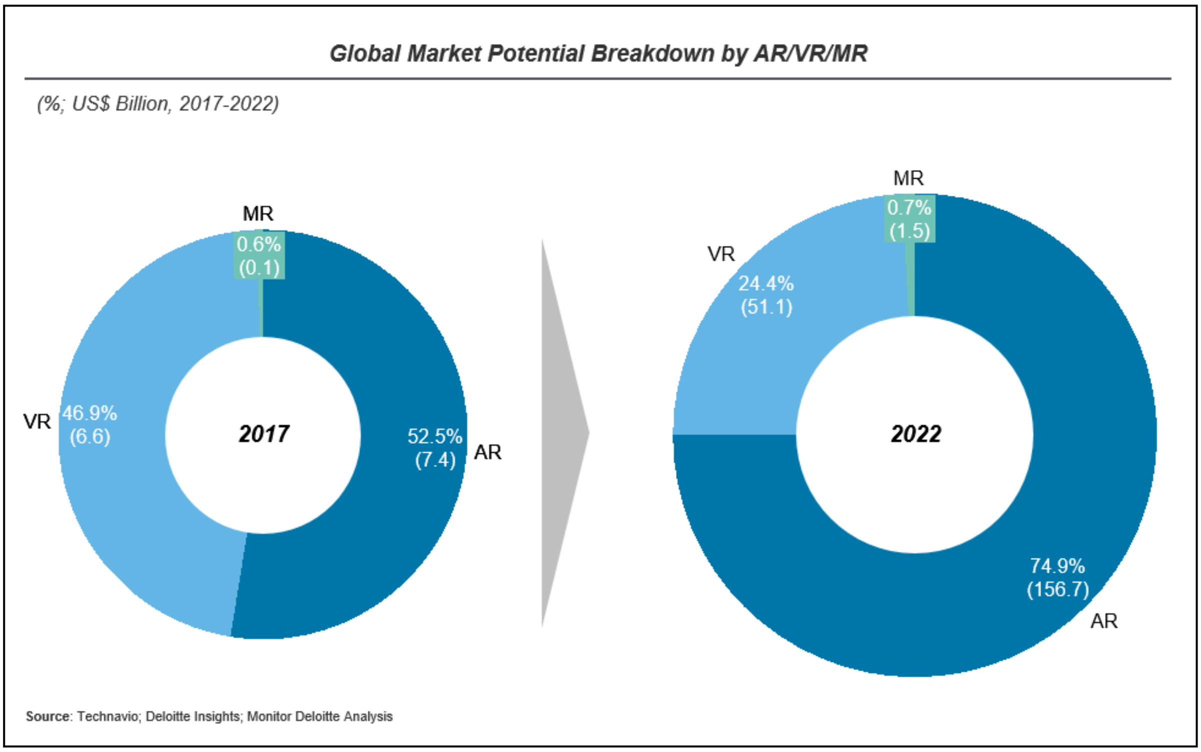


Exhibit 4: Breakdown of Largest IMAI Segment - Vision

2.2.1 Vision (Sight)

2.2.1.1 Market size

The global augmented reality and virtual reality (AR/VR) market is estimated to be US$209.2 billion in 2022, achieving a five-year growth rate (CAGR) of 71.6% over the 2017 to 2022 forecast period [5]. It is forecasted to reach US$27.0 billion in 2018, which is a significant increase in value from US$14.1 billion in 2017.

Asia Pacific (excluding Japan) is expected to experience the fastest growth of 68.5% from 2017 to 2022 [7]. This trend can be shown from more than 100% increase in total spending on AR/VR from US$4.6 billion in 2017 to US$11.1 billion in 2018. However, within APAC, China market size is estimated to be more than US$10 billion in 2018, with over 90% share in Asia Pacific (excluding Japan). (Exhibit 5)

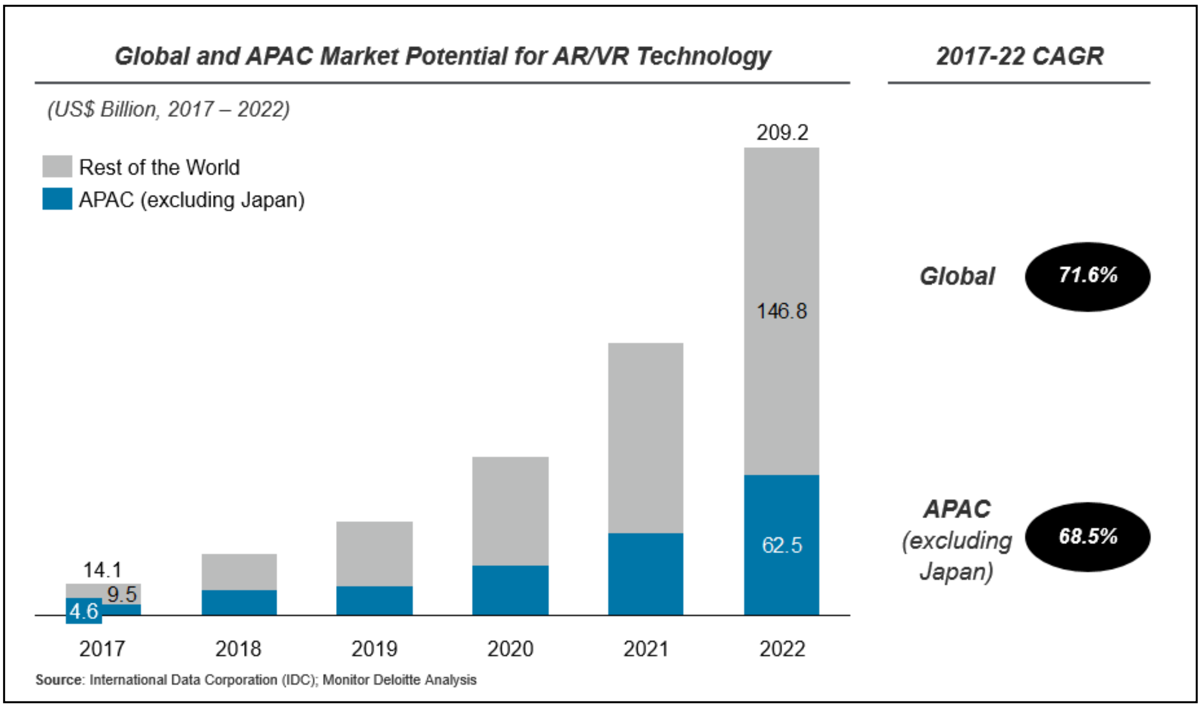


Exhibit 5: Global and APAC Market Potential for AR/VR Technology

2.2.1.2 Enablers

Six key enablers were identified for the growth of vision technologies [10]:

a) **Proliferation of mobile applications along with the increased use of smartphones**: The development of mobile application and content ecosystem has enabled AR/VR technologies to be easily adopted to mobile devices. Samsung Gear VR and HTC Vive are some of the examples of smartphone powered VR devices [11]. The overall mobile application market was estimated at US$61 billion in 2016, and is forecasted to continue expanding at a CAGR of 23% to reach US$173 billion by 2021 [10].

b) **Increasing use of digital reality in advertising**: Digital reality is increasingly used in highly immersive advertising and marketing, especially for mobile advertising. The mobile AR advertising market was estimated at US$1.1 billion in 2016 and is expected to reach US$20 billion in 2021 [10].

c) **Improved network connectivity**: Advancement in internet connectivity enables AR/VR devices to bring seamless experience to users. As part of its Digital Strategy [f][12], the UK government recently launched six 5G testbed projects with a total grant size of US$35 million in 2018, in order to collaboratively build the future of wireless 5G infrastructure with private and public sector cooperation [11]. 5G Smart Tourism is one of the six projects, with its focus on delivering enhanced visual experiences for tourists using vision technologies including AR/VR enabled by enhanced 5G network, in major attractions in Bath and Bristol, including the Roman Baths and Millennium Square.

d) **Declining average selling price (ASP) of digital reality hardware**: With increasing number of enterprises commercialising their solutions [g], ASP is expected to decline.

e) **Tetherless access**: Improvements and innovation in device design empowers tetherless user experience without wires or unwieldy battery packs. For example, leading players like Apple and Samsung announced their plan to launch a wireless headset for AR/VR by 2020.

f) **Capital funding**: The global AR/VR market is attracting investments and there have been over 225 VC investment activities from 2014 to 2015, raising US$3.5 billion in capital. For example, Apple acquired Faceshift, a facial recognition capture and animation Company in November 2015 and Facebook acquired Oculus, a virtual reality start-up for US$2 billion in March 2014 [13].

2.2.1.3 Future projections

Prior to 2015, the AR/VR market was relatively new to both consumer and enterprise markets due to lack of a proper equipment which could provide users with the immersive experience promised by these technologies. Up until 2015 when the HTC Vive and Oculus VR was announced, the growth potential of these immersive technologies has not been fully explored. With the advent of the evolved VR head mounted displays, the hype for VR content began to garner market interest and both start-ups and enterprises began to make significant investments in the digital reality industry to develop the ecosystem and new technologies.

[f] Digital Strategy launched in March 2017 to continually drive the UK's connectivity, telecommunications and digital sectors, and invest in industries, infrastructure and skills.
[g] The Venture Reality Fund; the number of AR companies has increased by 50% to 290 in 6 months (from the end of 2017 to mid-2018)

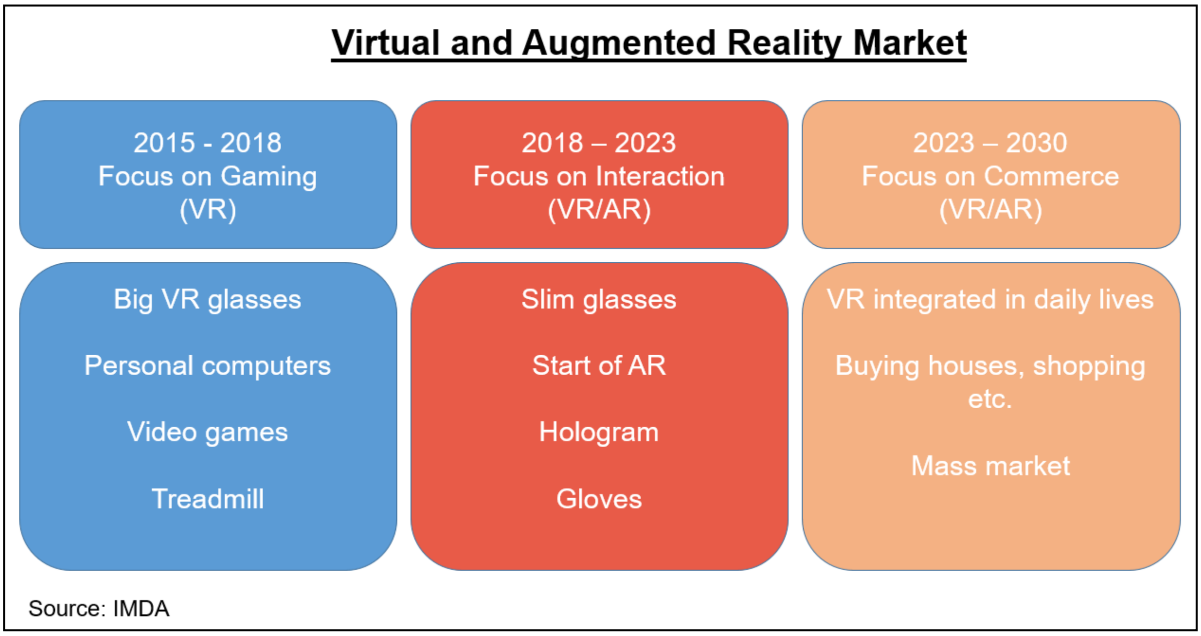


Exhibit 6: VR and AR Market Forecast

Based on the chart above (*Exhibit 6*) the focus on these immersive technologies shifts over the years with:

a) The development of virtual reality experiences in games from 2015 to 2018

b) Introducing interactive immersive technologies for both VR and AR in compact devices from 2018 to 2023

c) VR and AR being applied in commerce for various industries and mass market

With VR and AR (and potentially MR) having the potential to become the next computer platform, there will be expectations of the emergence of new markets and existing markets to be disrupted. There is no shortage of examples of how these new immersive technologies can reshape the way people live and do things – from purchasing a new home, reducing the complexity of learning through simulations, enhancing the experience of daily activities. As the technology advances, price points decline and the entire marketplace of applications (both enterprise and consumer) hit the market, the AR/VR industry has a potential to spawn a multibillion-dollar industry, and possibly become a game changer as the advent of the PC.

There is a huge potential for the AR/VR market to grow to the size of the current smartphone market [14]. There may also be a disruption in the smartphone market as the development of hardware reach a point where these immersive technologies no longer require touch devices and instead, will be done in mixed reality like the Microsoft Hololens. The Microsoft Hololens is a prime example of mixed reality whereby users will have a clear headset with perfect vision of their environment, with information being layered onto the screen to enable engagement with digital content and interaction with holograms in the physical world.

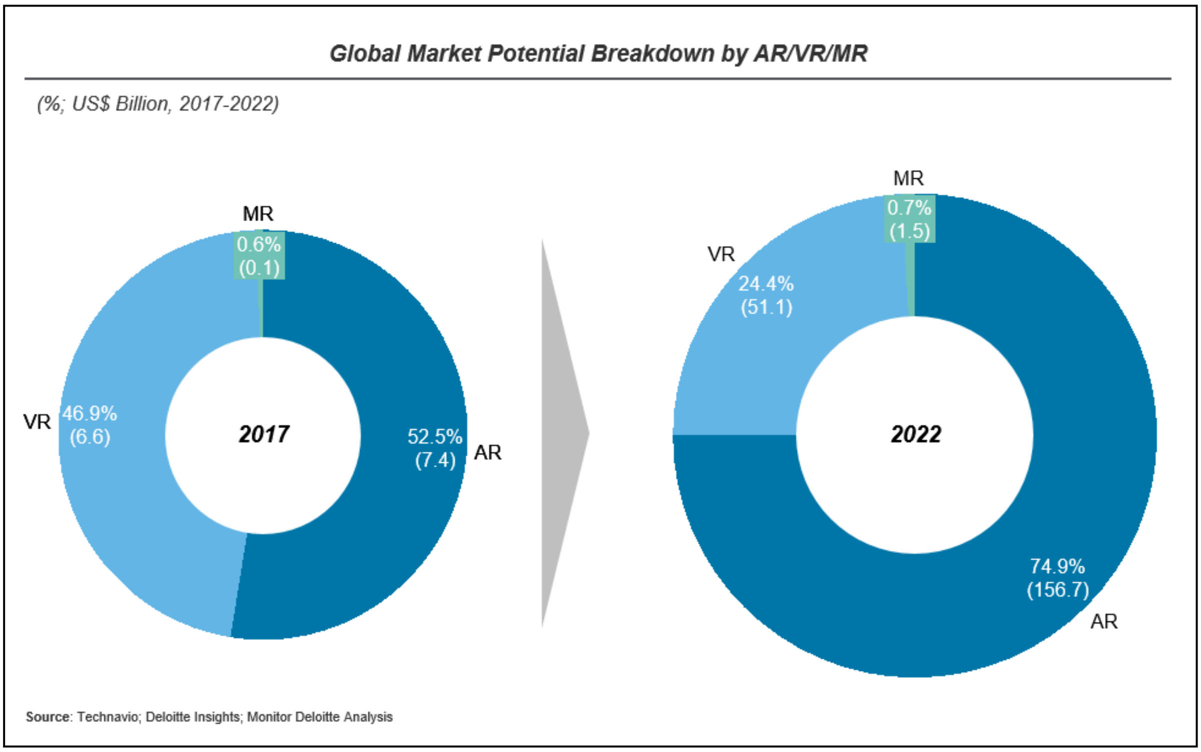


Exhibit 7: Market Segments of VR, AR and MR

a) **Augmented reality market:** The global AR market was estimated at US$7.4 billion in 2017, and is expected to reach US$156.7 billion by 2022. (*Exhibit 7*) The increasing penetration of 4G — and prospectively 5G, thanks to strong government as well as industry support in various countries — is a key factor in achieving this forecasted growth. Subsequently, with the global success witness in Pokémon Go, it has paved the way for the usage of AR in business applications such as commerce, media and education.

b) **Virtual reality market:** The global VR market was estimated at US$6.6 billion in 2017, and is forecast to reach US$51.1 billion by 2022. (*Exhibit 7*) Increasing compatibility of smartphones with VR technology, along with the growth in the mobile gaming market, is opening new opportunities for VR headset manufacturers. There have also been breakthroughs in lowering the retail cost of head-mounted displays (i.e. Oculus Go) to be available in the consumer market at a starting price of $199. With a lower price point which makes VR technology accessible to the masses, it would drive demand and growth up by 3.54 times the market size in 2016.

c) **Mixed reality market:** The global MR market was valued at US$87 million in 2017, and is forecast to exceed US$1.5 billion by 2022. (*Exhibit 7*) The advent of entry-level VR headsets in the market and a marketing push by smartphone manufacturers have boosted MR market growth. The market has yet to fully understand the capabilities of MR and how it bridges the gaps between AR and VR. MR is likely to be the technology which will bring us to the next level of digital reality where it will be difficult to distinguish the imaginary from the real. The new technology is meant not to disrupt the original work processes of enterprises, but to provide a solution to existing problems and boost efficiency in processes. The challenges for the market is likely to be the high initial costs of the hardware and the ecosystem for developers to create content.

2.2.1.4 Sector Application

AR/VR software market accounts for over 40% of the total market and is largely driven by the end-consumers (60%) while the remainder by enterprises and public sector [13]. Nine key driving sectors are videogames, live event, video entertainments, healthcare, real estate, retail, education, engineering, and military. (*Exhibit 8*) Among them, AR and VR videogames are one of the high potential sector with projected 2017 to 2022 CAGR of 90.9% and 54.7% respectively [7].

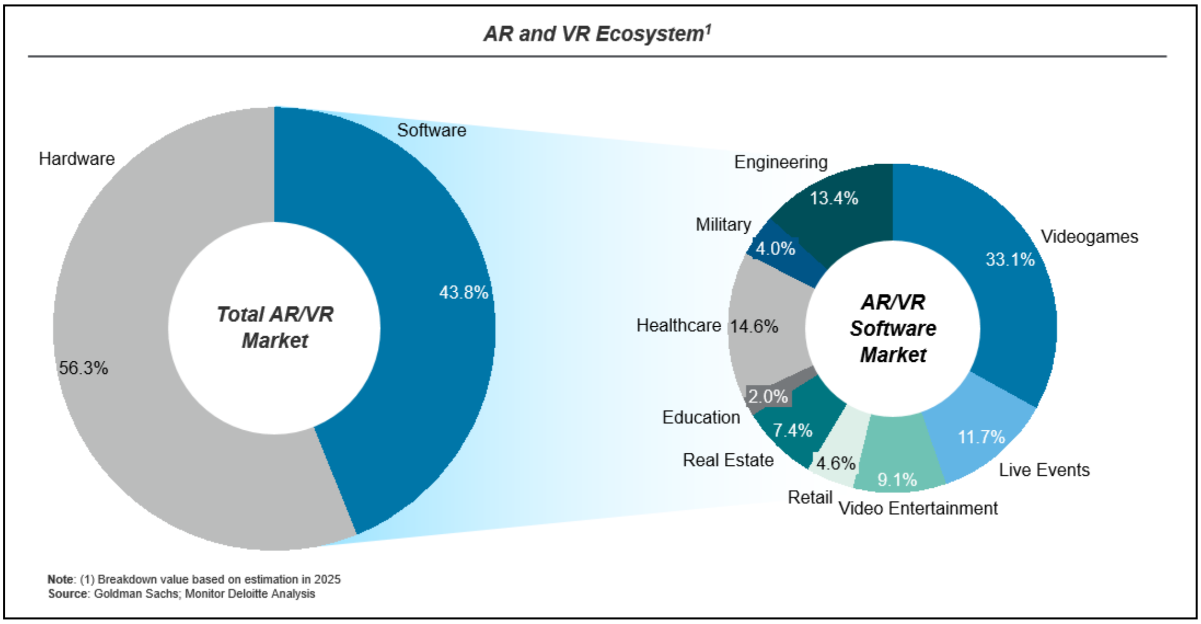


Exhibit 8: AR and VR Ecosystem

2.2.2 Tactile (Touch)

2.2.2.1 Market Size

The global haptic technology market is estimated to be US$19.6 billion by 2022, achieving a CAGR of 15.5 % over the 2017 to 2022 forecast period [15]. Asia Pacific haptic technology market was valued US$4.1 billion in 2017 and expected to grow faster than the global market at a CAGR of 16.2% from 2017 to 2022. APAC market accounts for nearly 45% of the global market, followed by North America and Europe [16]. The growth in APAC region is largely driven by countries such as China, Japan, South Korea, and Taiwan, where these countries have a number of major consumer electronics companies. As the main end-users of haptic technology, they would continue to play a leading role for the APAC market [15] (Exhibit 9).

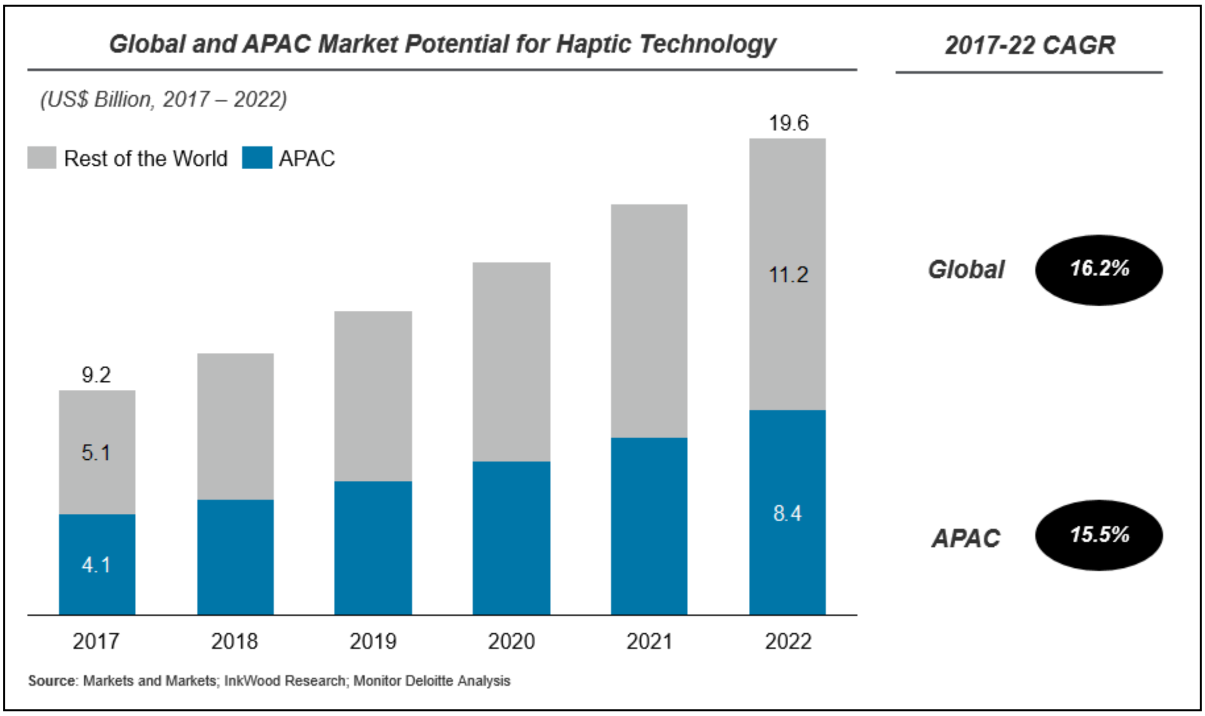


Exhibit 9: Global and APAC Market Potential for Haptic Technology

2.2.2.2 Enablers and Sector Application

Haptic technology market is largely application-driven market and the key enablers contributing to the growth of this market are increasing use of haptics in different sectors [15], which includes consumer electronics, videogame, industrial (engineering), automotive, healthcare, defence, gaming and POS [17].

a) Consumer electronics devices such as smartphones and tablets, and videogame consoles are the major end-user segments, increasingly adopting haptic technology. Consumer electronics sector accounts for over 30% of haptic technology market [16] and the global haptic touchscreen market was expected to achieve a strong growth with a CAGR of 41% from 2013 to 2018 [18].

b) Healthcare is one of key potential market with increasing application use cases. For example, Cambridge Research & Development is testing a haptic system for use with surgical robots [19].

c) Automobile sector leverages on haptic technology to increase the security and safety standards for their consumers [17].

2.2.3 Auditory (Hearing)

2.2.3.1 Market Size

Global Home Audio Equipment Market size is estimated to be US$24.0 billion by 2022, achieving CAGR of 4.0% over 2015 – 2022 [20]. Asia Pacific market is expected to witness faster growth with a CAGR of 5.0%. With continuous innovation, Home Audio Equipment market includes from traditional audio devices to more immersive auditory technologies such as 3D audio, surround sound speakers, stereo sound speakers, and multi-channel amplifiers.

The global 3D audio and Speech Recognition market is estimated to reach US$7.8 billion by 2022, with a CAGR of 16.6% over 2017 to 2022 [21] [22]. Similar to Tactile technology, with many major consumer electronics companies having their presence in the region, Asia Pacific will continue to lead the 3D audio and Speech Recognition market, growing faster at a CAGR of 18.0%. (*Exhibit 10*)

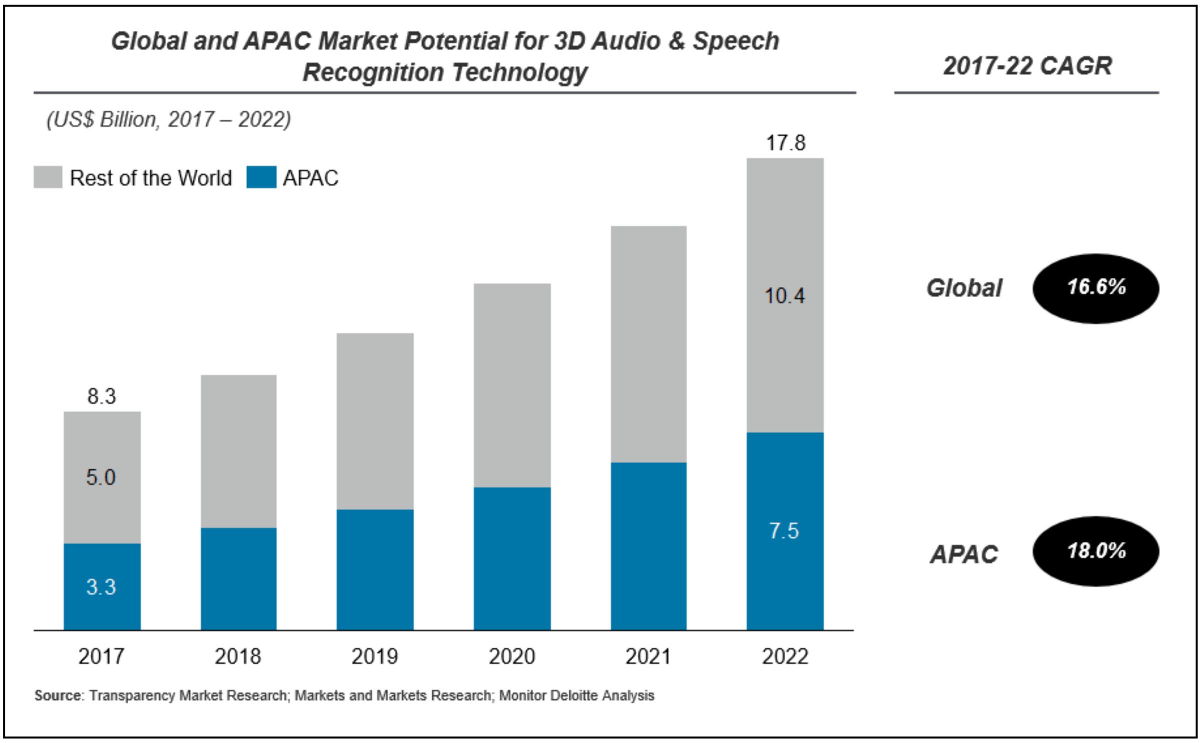


Exhibit 10: Global and APAC Market Potential for 3D Audio Technology

2.2.3.2 **Enablers and Application Sectors for 3D Audio Technology**

Technological innovation has been continuously transforming the Home Audio Equipment market, supported by increasing demand for high quality products and seamless consumer experience. Commonly used equipment includes video games, Blu-ray disks, MP3 players and computers, which are primarily used as personal/in-house applications [20]. Adoption of sophisticated technologies such as wireless and mobile technologies have empowered innovation and design development in order to make audio equipment more portable, affordable and simple.

The 3D audio market is largely driven by commercial end-user segments including the videogame and cinema sectors [21]:

a) Videogames are rapidly adopting advanced 3D audio sound engines from traditional 2D engines. Specialised neuro-auditory research and advanced digital sound processing (DSP) algorithms can be leveraged in order to integrate directly into a game's sound engine.

b) Cinemas have been also adopting 3D audio sound systems as well as digital screens. With the entertainment industry that is expected to continuously grow and reach a global market size of US$1.8 Trillion by 2017 [20], the use of 3D audio in Cinema will also follow its trend.

c) Other application areas include VR and automobile. With the rapid growth of VR, its penetration enhances the potential for 3D audio market, especially in museums and exhibits in order to complete the virtual experience.

Recent EU-funded project [h] called the BINCI Project (January 2017 – June 2018) aims to develop an integrated software and hardware solution [i] to ease the production, post-production and distribution of 3D audio content. This integrated software and hardware are to be designed for applications in the creative industries such as music, movies and cinematic VR. Its pilot program is planned in 2018 to offer the world's first 3D audio-guide productions and usher at several cultural and heritage sites such as Fondació Joan Miró (Barcelona, Spain), Opéra Garnier (Paris, France), and Alte Pinakothek BStGS (Munich, Germany) [23].

2.2.3.3 Enablers and Application Sectors for Speech Recognition Technology

The major driver for the growth of Speech Recognition market is the increased demand for speech-based biometric systems in verticals such as finance, military & defence, automotive, consumer, healthcare, retail, and enterprises. In particular, the consumer industry is expected to hold the largest market share in speech recognition technology market in 2016. High penetration of speech recognition technology in smartphones and personal computers is driving the speech recognition technology in consumer segment. The market for the retail industry is expected to grow at a CAGR of 24.2%, followed by the automotive industry at a CAGR of 21.4% between 2016 and 2022 [22].

In terms of the growth by region, the Americas is estimated to hold the largest market share, while the APAC market is expected to grow at the fastest rate during the forecast period.

a) **Americas:** The U.S. recently mandated the Visa Waiver Program (VWP), the border management control programs, e-passports, national ID programs, and physical and logical access control programs for buildings. These measures are to ensure the security and authentication in the data provided, and to protect any discrepancies in the correct identification of a person. The higher government funding for such advancements in security equipment offers tremendous growth opportunities for speech recognition in the Americas.

b) **Asia Pacific:** The speech recognition market in APAC is expected to witness tremendous growth, owing to technological advancements and awareness among the masses to accept the technology. China and India are the fastest-growing economies in the world. Their financial strength enables them to make significant investments in the speech recognition market. China, Japan, and South Korea are also the leading countries in the consumer electronics sector. The presence of major consumer electronics device manufacturers such as Huawei (China), Sony (Japan) and Samsung (South Korea) creates a lucrative market for speech recognition in this region.

c) **Europe:** European market for speech recognition is driven by automobile and enterprise industry. For the automotive industry, this is driven by luxury car makers such as BMW (Germany), Audi (Germany), and Jaguar (U.K.) who are using speech recognition technology in their next-generation cars to process human commands. On a related note, speech recognition companies such as Nuance (U.S.) have been investing in the next-generation software (such as Dragon Drive) to tap on this market for luxury car manufacturers.

d) **Rest of the world (RoW):** The increasing disposable income, decreasing prices of consumer electronics devices in price sensitive regions in Middle East & Africa region, and introduction of technologically advanced devices are the primary factors driving the growth of the speech recognition market for consumer devices in Rest of the World

Speech Recognition is used in several verticals and the below exhibit shows the breakdown of the projected market sizes by sector:

[h] Under the programme Horizon 2020

[i] Includes: (1) innovative binaural measurement system for professionals, (2) binaural production and post-production plugins, (3) binaural engine and player for interactive rendering, (4) head-tracking device for binaural rendering, a way of recording sound for 3D audio system

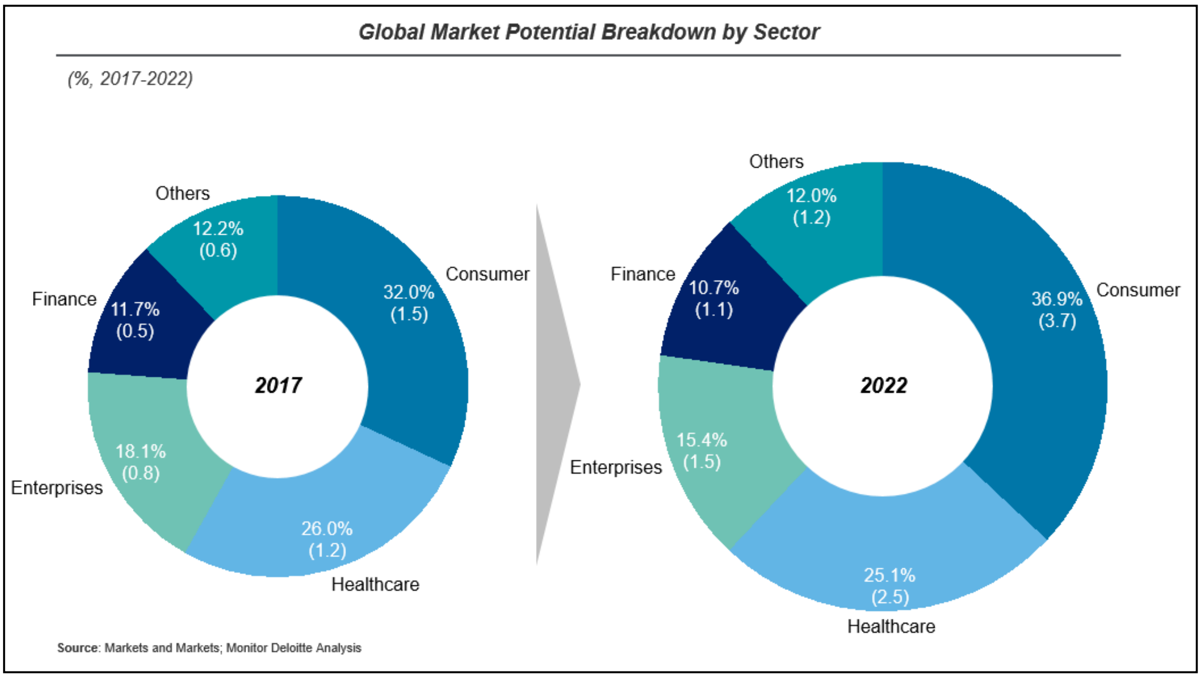


Exhibit 11: Market for Speech Recognition

The most significant sectors by size are the following:

a) **Consumer:** This holds the largest market size worth US$1.5 billion in 2017 and is expected to reach US$3.7 billion by 2022. This is attributed to the higher penetration rate of speech & voice recognition technologies in consumer products such as smartphones, laptops, and tablets. The factors such as growing demand for wearable devices and increasing security concerns of managing consumer devices are expected to fuel the growth of the speech recognition technology for the consumer vertical. The increasing demand of consumer electronic products in technologically advanced countries such as China, India, and Brazil is expected to drive the growth of this market.

b) **Healthcare:** The healthcare vertical holds the second largest market size worth US$1.2 billion in 2017 and is expected to reach US$2.5 billion by 2022. The use of speech recognition software for the healthcare vertical has grown rapidly because it streamlines the clinical workflow and efficiently completes the patient chart. It also provides better accuracy for billing and compliance documentation, which are crucial since several organisations are facing pressures due to the shift from Fee-for-Service to value-based reimbursements. Finally, it frees clinicians from manual data entry as the data can be entered verbally using a microphone. The information can be quickly captured real-time and eliminates the need for the clinician to search again throughout the document which is highly time consuming.

c) **Enterprises:** The global speech recognition market for the enterprises vertical, by application was valued at US$0.8 billion in 2017 and is expected to reach US$1.5 billion by 2022. Enterprises can benefit from speech recognition technology by improving the business performance and effectiveness of the agents. For example, the technology can be implemented in applications such as call centres to identify demographic details such as age, gender, dialect/accent as well for topic and sentiments. The identified information presents interesting findings about the consumer perception regarding the product or service.

d) **Finance:** The global speech recognition market for finance vertical was valued at US$0.5 billion in 2017 and is expected to reach US$1.1 billion by 2022. As a subset, the market for mobile banking is expected to reach US$0.7 billion by 2022. The increase in the adoption of speech recognition in finance vertical is mainly driven by the high adoption amongst banking service providers in contact centres. Banks are increasingly offering mobile and digital services to target tech-savvy customers and enhance customer service.

2.2.4 Olfaction (Smell)

2.2.4.1 Market Size

The global Digital Scent technology market is estimated to be US$1.2 billion by 2022, achieving a CAGR of 30.4% over 2017 – 2022 [24]. While the North American region is continuously holding the leading position for Digital Scent technology as it is still at an emerging stage with strong R&D requirements, the Asia Pacific region is expected to witness the fastest CAGR over the forecast period (~30.7%). (Exhibit 12)

Digital Scent technology leverages on hardware devices such as Electronic Nose and scent synthesiser to sense, receive and digitally transmit different types of smells. The global E-Nose market is expected to reach US$42.7 million by 2025, with a CAGR of 11.7% over 2017 – 2025 [25]. Asia Pacific region accounted for the market share of 22.6% in 2016, and is expected to increase to 23.1% in 2025.

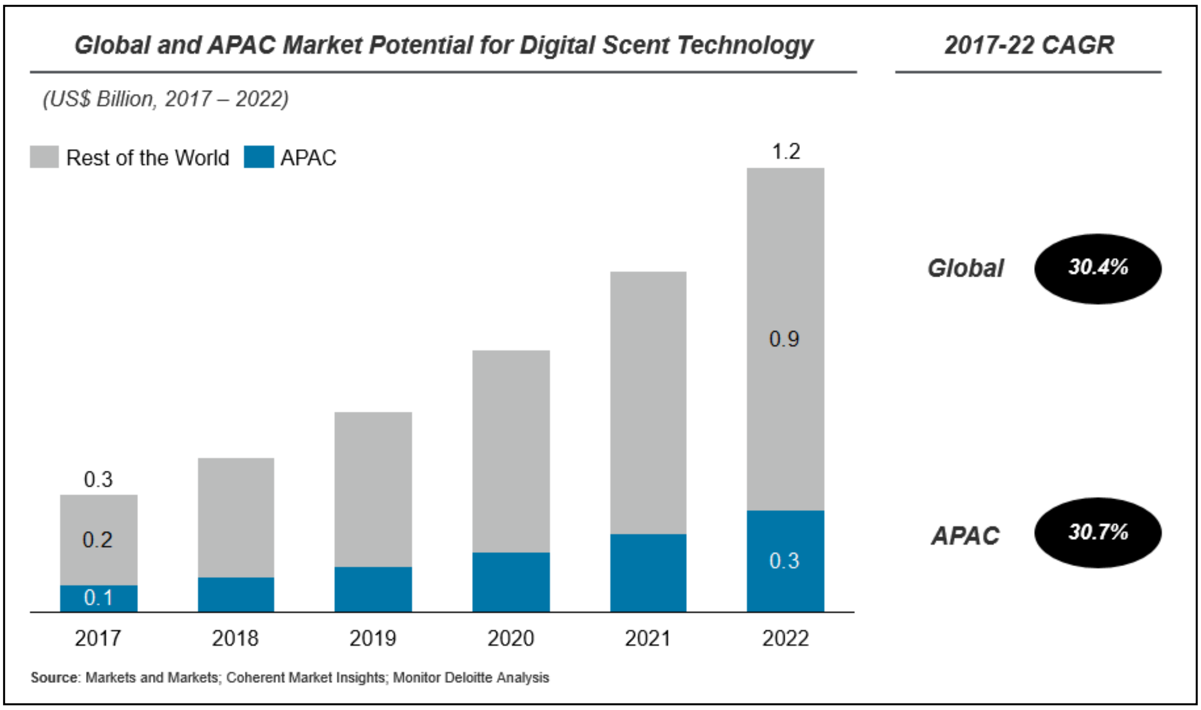


Exhibit 12: Global and APAC Market Potential for Digital Scent Technology

2.2.4.2 Enabler and Application Sectors

With technological advancement and rising adoption of smart devices, there has been continuous efforts around developing Digital Scent technology. Diverse applications of E-Nose in the military & defence sectors, such as explosive detector and quality control product, is another key driver for the growth of Digital Scent market. The quality control product sub-segment is expected to grow significantly [26].

Other end-user sectors for E-Nose include healthcare, food & beverage and environment monitoring [25]. Environmental monitoring accounted for the largest market share of 34.6% in 2016. With increasing concern about air pollution and related health issues (7 Million people died due to air pollution in 2016 [27]), E-Nose has significant opportunity in environment monitoring sector. There is also an increasing demand for E-Nose based quality assessment for raw material and food safety test which can reduce wastage of food and risk of diseases caused by food contamination.

2.2.5 Gustation (Taste)

Gustation technology is one of the most emerging IMAI technologies with significant potential. This technology can be categorised into electronic tongue (E-tongue) and food-texture device.

E-tongue systems can sense and transmit virtual taste information and simulate taste via using varying composition of electrical responses. Initially, E-tongue was designed to recognise five basic tastes, which are Salty, Sour, Sweet, Bitter and Umami [28]. Continuous development has enabled the sensors to analyse and classify combinations of tastes. Two exciting technologies that are most promising within E-tongue technology are digital lollipop, and thermoelectric device. Singapore has been pioneering these technologies, where a group of researchers from the National University of Singapore developed digital lollipop in 2012 and thermoelectric device in 2016. Digital lollipop is an electronic device that can simulate virtual tastes (four of basic taste, Salty, Sour, Sweet and Bitter) with electric currents [29]. Thermoelectric elements can simulate the sweet taste through changes in temperature.

Japan has been actively participating in the initial development of food-texture device. Electrical Muscle Simulation (EMS) device has been experimented at the University of Tokyo in 2016 [30]. By changing electricity frequencies on the masseter muscle [j], EMS device can simulate virtual food textures such as hardness and bring chewing experience. EMS device can be continuously explored and enhanced with more complex textures and combination with other sensory technologies such as auditory [31].

There are potential applications that have been continuously investigated in the pharmaceutical industry, food and beverage, and hospitality industry, and environment monitoring such as water quality [32].

a) **Pharmaceutical**: Taste assessment of drugs to evaluate the bitterness of drugs to determine taste-masking effectiveness of formulations compared to placebos [k].

b) **Food & beverage and Hospitality**: E-tongue and EMS device can potentially help people with special dietary needs and reduce sugar intake. For example, thermoelectric elements can be implemented to mug and glasses, enabling no-sugar drinks [31]. Other application areas include food quality sensor used in the quality control of winery industry to classify grate varieties, adulteration, or the time of aging of the wine sample [l].

c) **Environment monitoring**: Assessment and monitoring of water quality in real water samples, through simultaneous monitoring of elements such as sodium, chloride, and nitrate ions [33].

Some innovative companies such as US-based Project Nourished [m] have been looking into the prospects of combining various IMAI technologies (vision, tactile, auditory, olfaction, and gustation) to get an enhanced gastronomic virtual experience [34]. Leveraging on devices such as VR headsets, bone conduction transducer [n], virtual cocktail glass [o], aromatic diffuser, and a 3D-printed food, they aim to evolve people's dining experience by merging the taste, feel and smell of food [35].

---

[j] Jaw muscle used for chewing
[k] Evaluation of a taste sensor instrument (electronic tongue) for use in formulation development
[l] A voltammetric electronic tongue made of modified epoxy-graphite electrodes for the qualitative analysis of wine
[m] Kokiri Lab Inc., a think tank that builds disruptive products and services with an emphasis on the well-being of people and society.
[n] A device that mimics the chewing sounds that are transmitted from the diner's mouth to ear drums via soft tissues and bones
[o] A glass with built-in sensors for beverage and creating simulated intoxication

2.3 Singapore Market Potential

2.3.1 Supply-side View on Market Potential

In Singapore, IMAI technologies are estimated to be valued at US$685 million by 2022. (*Exhibit 13*) Likewise, vision technology (AR/VR technology) will account for the majority of the IMAI market. As a small city-state, Singapore's domestic demand will be a small portion of the global market. However, Singapore can develop itself as a hub for IMAI technologies by developing strong capabilities and ability to market products globally.

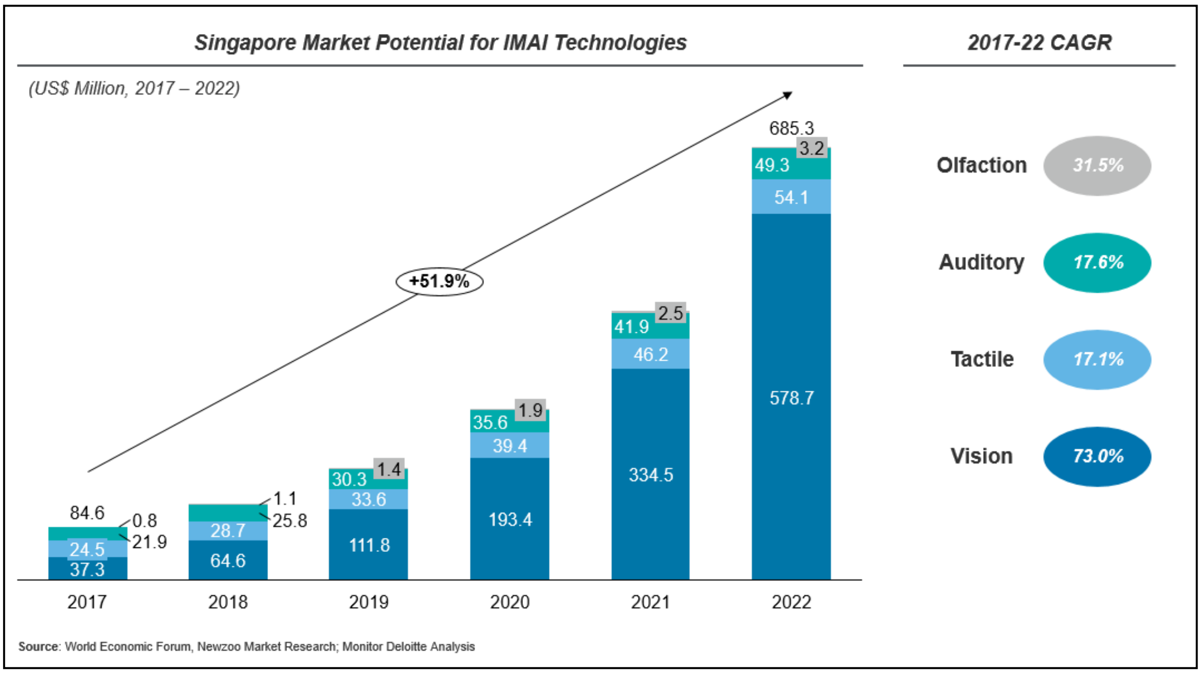


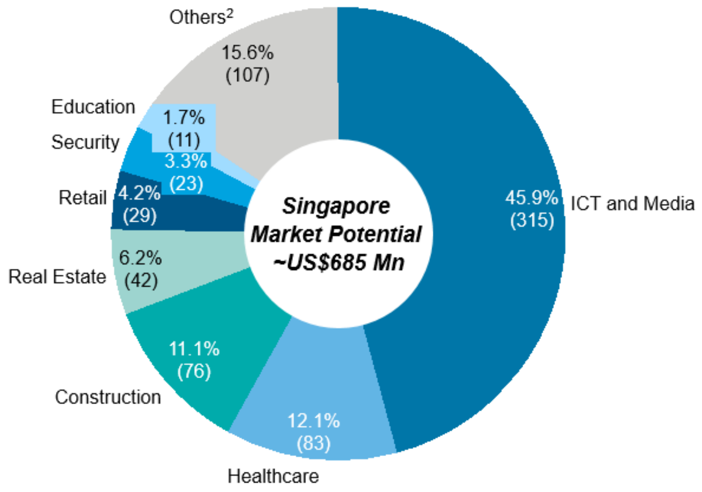
Exhibit 13: Singapore Market Potential for IMAI Technologies

2.3.2 Demand-side View on Market Potential

As vision technology accounts for the majority of the IMAI market, ICM and Media sector (including videogames) is expected to have the largest potential with the market share of 45.9%. Healthcare and construction sectors show the second and third largest demand, followed by real estate, retail and other sectors such as security, education, food & beverage, and automotive. (*Exhibit 14*)

Singapore Market Potential Breakdown in 2022[1]

(%; US$ Million, 2022)



Note: (1) Estimation based on the Global market values for the Visual (AR/VR) technology; (2) Sectors for Tactile, Auditory and Olfaction technologies – Tactile technology accounts for ~8% of the total IMAI market, of which Electronics sector accounts for 30% of the market and other sectors includes ICT and Media (video games), Automotive, Healthcare, and Security; Auditory technology accounts for ~7% of the total IMAI market, of which Electronics sector accounts for 37%, Healthcare accounts for 25%, Finance accounts for 11% of the market (based on Speech Recognition technology market - ~75% of Auditory technology market); Olfaction technology accounts for ~0.5% of the total IMAI market and sectors include Healthcare, Food & Beverage and Environment monitoring
Source: World Economic Forum; Goldman Sachs; Monitor Deloitte Analysis

Exhibit 14: Singapore Market Potential Breakdown in 2022

3 TECHNOLOGY STUDY

The purpose of this section is to enable the reader to relate the technologies to the use cases. Firstly, with a framework highlighting the relationship amongst IMAI technologies, industry sectors and areas of experience enablers, the capabilities of these technologies are showcased. Next, a Technology Adoption Readiness Map is developed to outline the maturity of various IMAI technologies. Finally, the use cases are illustrated by a detailed convergence of technologies that highlights how experience enablers can be enhanced by IMAI technologies.

The Immersive Media and Advanced Interfaces (IMAI) technologies are grouped into the following categories: **Human-Machine Interaction (HMI)**, **Media Creation/Display**, **Media Capture**, **Virtual Reality (VR)**, and **Augmented/Mixed Reality (AR)** (*Exhibit 15*). These categorical headings are chosen because they succinctly encapsulate the nature and purpose of these technologies. This categorisation allows greater clarity in determining the technologies' effectiveness.

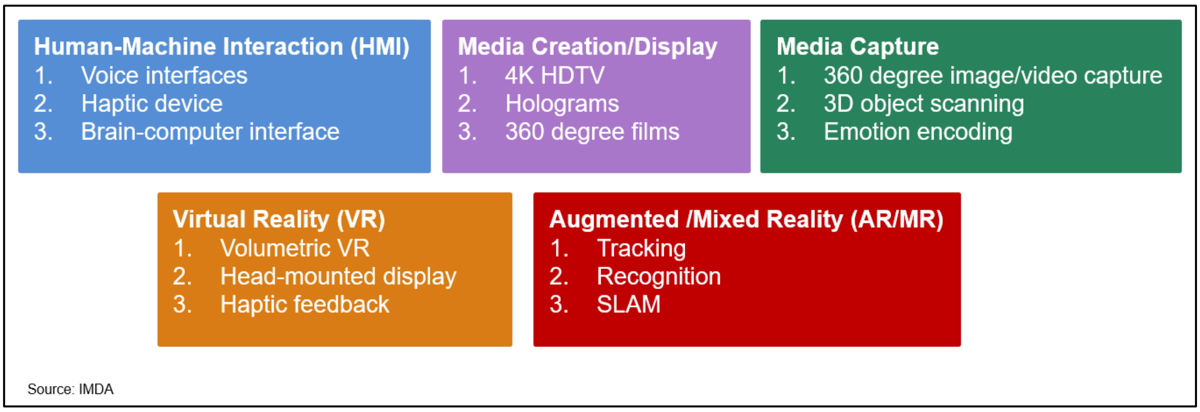


Exhibit 15: IMAI Technology Categories

IMAI technologies are the front-end of both software and hardware. They enable and define the interaction between humans and machines. Referring to *Exhibit* 16, we can see how IMAI technologies rely on other technologies to process its input and output. With a capable backend infrastructure, large input data is transferred quickly between technology components by communications technology such as 5G and processed within intelligent components (AI). This results in quick and meaningful feedback data to the user.

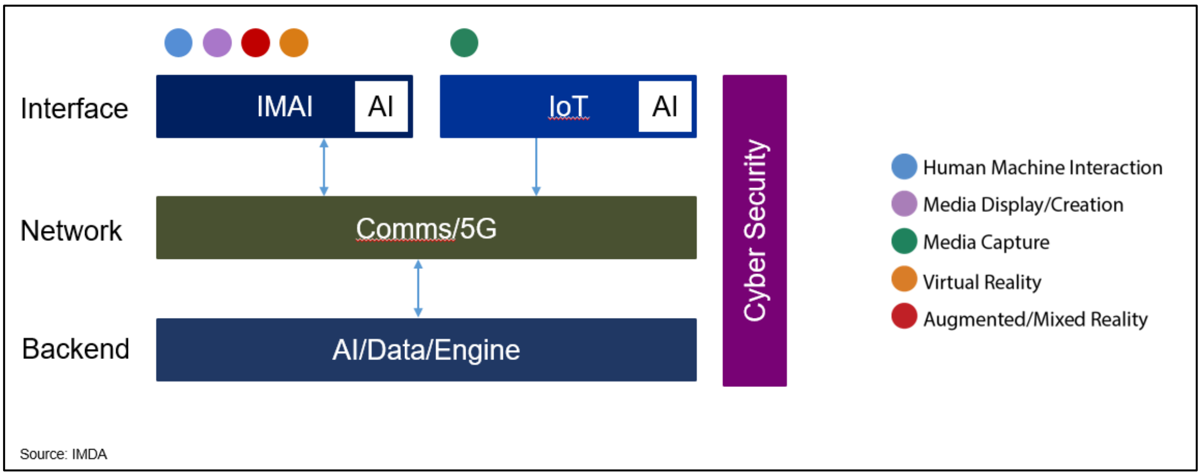


Exhibit 16: IMAI and Other Technologies

Human-Machine Interaction

Human-Machine Interaction is defined as the cycle of: 1) human input to a machine and 2) the machine's corresponding output. Technology components in this category consist of: 1) sensors capable of recognising and encoding human input, and 2) devices dependent on such human input to provide quick feedback.

Human-Machine Interaction (HMI) has been and will be relevant for decades as it defines mankind's ability to communicate with machines. Over the years, HMI has evolved to incorporate more channels of human input and produce new and enhanced sensory responses. This results in expanded possibilities for the proliferation of new interfaces and experiential media.

Referring to Gartner's Hype Cycle for Emerging Technologies (*Exhibit 17*), emerging technologies in HMI such as Brain-Computer Interface and Conversational User Interface are still in the research phase. However, with recent demonstrations of AI conversations from Google (Google Duplex), conversational AI might be available for mainstream adoption sooner. Other types of mainstream human-computer interaction technologies can be seen from *Exhibit 17*.

Media Creation/Display

Media Creation or Display is defined as technologies that produce output that can be understood and processed by human senses. By default, these technologies do not require human inputs to function but they can be designed to incorporate them.

Improved hardware, internet connectivity and technological integration paved the way for new media trends and creation platforms. The average consumer can now easily create and consume a plethora of new media content via highly accessible software and hardware. Electronics are now multi-purpose, capable of communicating with each other and use cross-platform applications.

With reference from *Exhibit 17*, volumetric displays are still early in terms of adoption. Currently, new forms of media creation and displays rely heavily on integration of multiple technologies and hardware improvements.

Media Capture

Media Capture is defined as technologies capable of digitally encoding non-digital information. This does not include the encoding of human input. Media capture technologies define media content. Greater capacities of digital content encoding allow for greater forms of media expressions, creating new consumer demand. These technologies usually take a longer time to materialise as they involve the discovery and application of research theories.

In terms of mainstream adoption, new forms of media capture technologies are used mainly by content creators. When these new forms of media are appreciated, people will then demand for access to these technologies.

Virtual Reality

Virtual Reality (VR) allows a user to interact in a generated digital environment in a seemingly real manner. VR technology components consist of several technologies working together to simultaneously process the user's input and generate realistic behavioural output in the digital environment.

Virtual Reality (VR) is greatly hyped as the entertainment medium of the future. By integrating multiple technologies, VR is able to create deeper immersion compared to existing media forms. The VR industry has attracted substantial investment towards both its software and hardware development. As a result, VR is becoming more accessible with mobile devices (e.g. smartphones), more enjoyable with greater content and more affordable with cheaper hardware.

As illustrated in *Exhibit 17*, VR is currently approaching mainstream adoption. Big technology providers in the market are racing to create the best VR platform, and companies are also looking for VR solutions/experiences to gain a foothold in a new market.

Augmented or Mixed Reality

Augmented Reality (AR) refers to the capability of processing image information and overlaying digital content on top of it through a device. There is minimal interaction between real world and digital objects. Mixed Reality refers to a hybrid of VR and AR, where digital content is able to interact with real physical objects and utilise knowledge from the physical world.

Augmented Reality (AR) rose in popularity alongside VR. In VR, the user is brought into the digital realm, while in AR, the digital realm is brought out into reality. AR is more readily available with smartphones compared to VR as they do not require expensive hardware. Currently, tech giants such as Facebook, Apple, and Google are currently racing to create the social AR applications.

Similar to VR, AR is approaching mass adoption (*Exhibit 17*). Technology companies are creating hardware and software that support AR. Companies are looking into AR solutions and developing new AR applications for a variety of purposes.

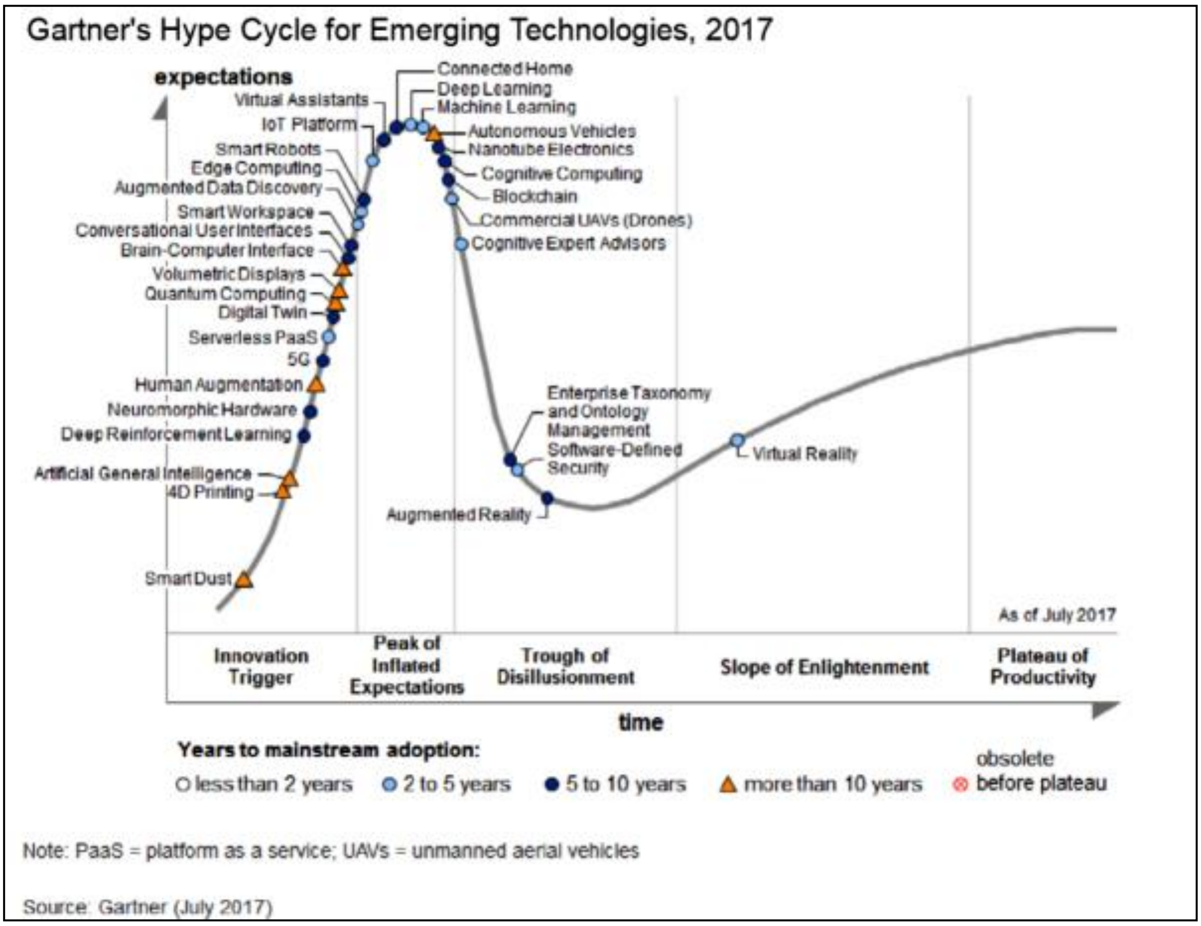


Exhibit 17: Gartner Hype Cycle for Emerging Technologies 2017

3.1 IMAI Technology Application Framework

To illustrate the capabilities of IMAI technologies and how they enhance our economy, IMAI Technology Application Framework was leveraged. (*Exhibit* 18) The framework is for readers to understand the relationship between Experience Enablers and IMAI Technology components and how they are applied to our industries. The clusters and industry verticals follow those identified in the

Industry Transformation Map (ITM). Amongst the thirty-six clusters, we focus on four of them – built environment, trade and connectivity, modern services and lifestyle.

With these industries in mind, we proceed to discover and subsequently validate company processes which benefit from better experiences. We define these processes as experience enablers. These experience enablers are categorised in a manner that minimises the overlaps amongst their overall purposes. These processes hold relevance across many industry clusters (e.g. marketing is crucial for most companies' reach). From a company's perspective, these experience enablers consequently translate to either increased profits and/or cost savings.

Before covering the tangible IMAI technology components and maturity projections, to measure the importance and effectiveness of these technologies we now project their capabilities to enhance experience enablers. For any experience enabler, one or many technologies – not just from IMAI – can be applied and maturity level of each technology varies as well.

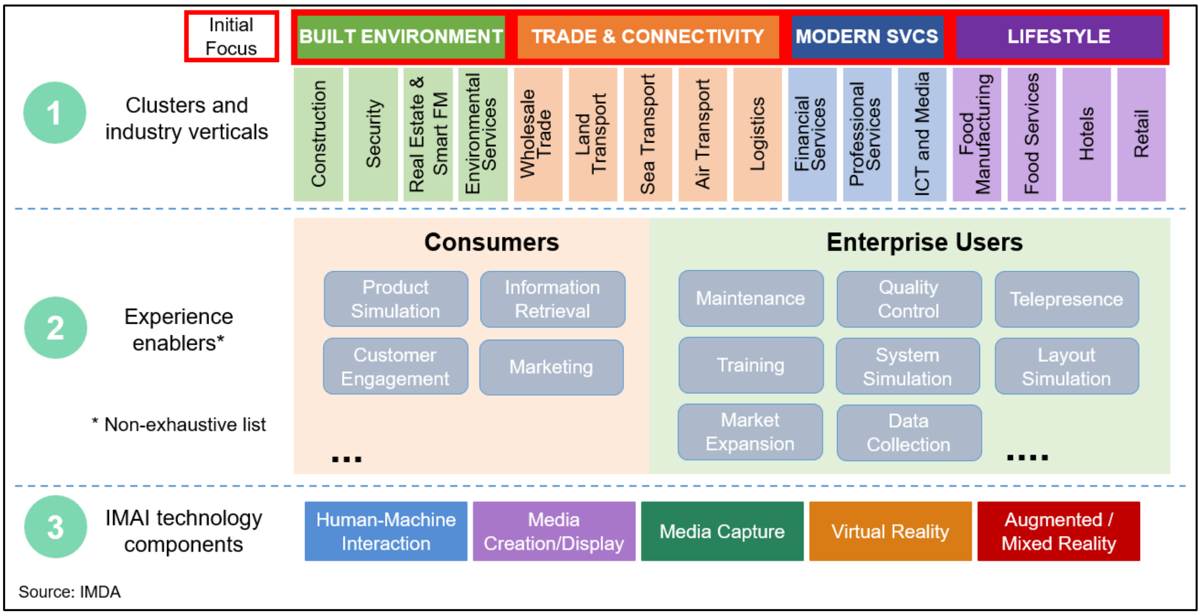


Exhibit 18: IMAI Technology Application Framework

Here, some examples of experience enablers identified include:

a) **Marketing**: Marketing refers to activities related to the selling of goods to a buyer, including advertising, shipping, storage and selling. Having a better purchasing experience generally leads to greater customer retention and better branding impression. (e.g. Advertisement displays)

b) **Market expansion**: When a business is spreading to other areas or new territories, immersive media allows decision makers to showcase their products in new markets. Consequently, new consumers understand the context and usage of new products via immersive experiences, helping enterprises enter new markets. (e.g. Cross cultural wedding concepts)

c) **Training**: A better training experience transfers knowledge and skills more effectively, thus being more cost-effective. With better visualisation through immersive media, new employees can learn faster. (e.g. AR enhanced components assembly)

d) **System simulation**: System simulation allows the digital replication of tangible job processes. This results in clearer visualisations and an environment for safe experimentation or validation. (e.g. Virtual disaster simulation)

e) **Product simulation**: Product simulation allows the digital replication of tangible objects or experiences. Users can learn about and visualise an object by interacting with its digital replica.

As a result, users have more confidence in their product expectations. (e.g. AR furniture simulation)

f) **Layout simulation**: Layout simulation allows the visualisation of spatial arrangements and object placement. This enhances the creation and validation process of space design, reducing the chances of a need for physical reconstruction later on. (e.g. Microsoft Layout)

g) **Customer engagement**: By attracting and maintaining a customer's attention in a positive way, good customer engagement can lead to customer retention and branding. (e.g. Pokémon Go)

h) **Telepresence**: Telepresence uses technology to perform remote control or be digitally present at a different physical location. Better telepresence results in greater transfer of information and higher degree of control. (e.g. Video conferencing)

i) **Quality control**: Immersive media allows instructors to observe and ensure consistency in training scenarios. Furthermore, it can be more convenient and cost effective. (e.g. Nurse training, machinery training)

j) **Maintenance**: During the process of preserving the condition of a system or product, better interfaces and visualisations can highlight problems with greater clarity. Remedies can thus be deployed in a timelier manner. (e.g. AR aircraft maintenance)

k) **Information retrieval**: Information retrieval is the process of obtaining data or descriptions with regards to an object or system. Visualisations enrich the information received by the user, utilising digital graphics and physical space. (e.g. Localised data visualisation)

l) **Data collection**: Data collection is the process of encoding and storing data. Immersive media offers a new way of data collection and visualisation. This provides a more experiential way of understanding data. (e.g. Collection of behavioural data in VR)

In the following section, we examine in greater detail how IMAI technology components relate to the experience enablers.

3.2 Technology Components Research Coverage

A study on the technologies that local research institutes, universities, polytechnics and institute of technical education are working on reveals the current coverage of IMAI technologies. This can be seen in the *Exhibit 19* below.

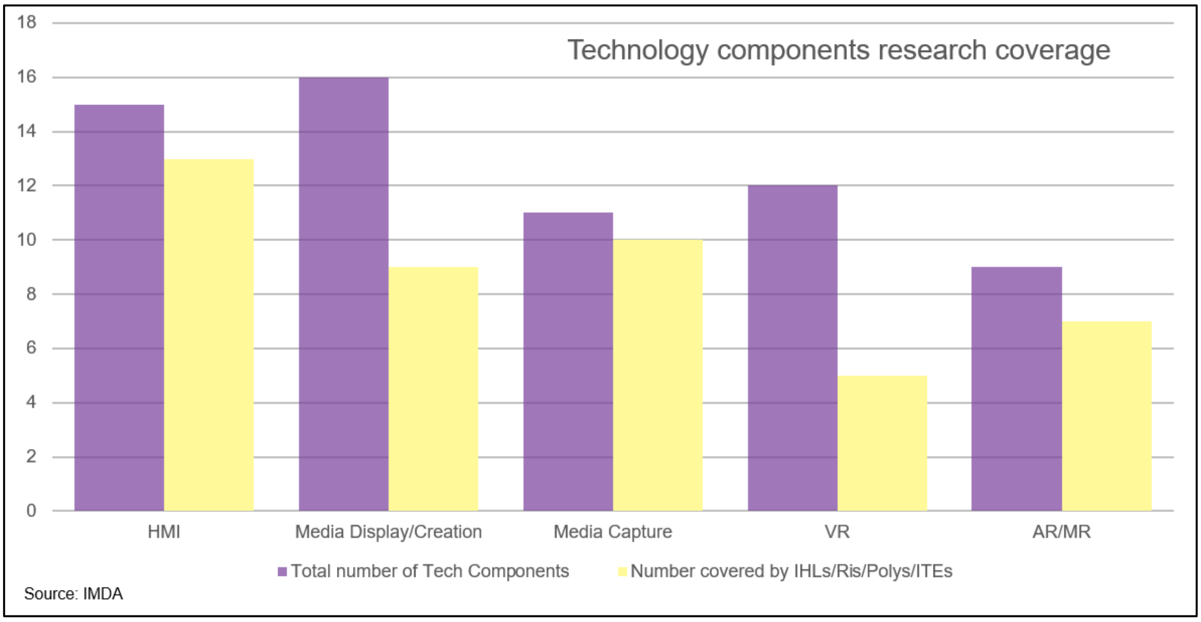


Exhibit 19: Technology Components Coverage

3.3 Technology Adoption Readiness Map

The technology adoption readiness map intends to inform the stakeholders on which technologies are expected to become mainstream in the coming years globally. A consistent time frame has been used in the narrative – now to 2 years (short-term), 3 to 5 years (mid-term) and beyond 5 years (long-term). Broadly,

- Technologies included in the now to 2 years timeframe are already or expected to be viable for adoption by the majority of industry players in now to 2 years (short-term);
- Technologies included in the 3 to 5 years timeframe have shown evidence of promising use cases, are being provided and afforded by a handful of companies but still not viable for mass adoption. These are expected to be viable in the next 3 to 5 years (mid-term);
- Technologies included in the beyond 5 years timeframe are mostly in the R&D stage and remain inaccessible to industry players. These are expected to become viable beyond 5 years (long-term).

3.3.1 Technology Adoption Readiness Map for Human-Machine Interaction (HMI)

NOW - 2 YEARS	3 - 5 YEARS	> 5 YEARS
Body pose recognition/tracking	Tangible haptic devices	Advanced haptic devices
Hand gesture recognition/tracking		Brain-computer interface
Voice enabled interface • Speech recognition/synthesis • Voice profile recognition • Voice profile generation	Voice-enabled interface • Conversable AI • Task/chat oriented spoken dialogue	Haptic feedback recognition
Eye tracking	Iris recognition Gaze control	Learning from observation
Haptics rendering	• Face gesture recognition • Emotion recognition	
Multi-user touch interfaces		

Table 1 HMI Technology Roadmap

The below section details the various stages of technologies development and adoption by users over time.

3.3.1.1 Now to 2 Years

a) **Body pose recognition/tracking:** Depth, RGB, infrared sensors can be used to collect 3D environment information. They are then parsed to identify and track body movements. Libraries to detect poses from images are also available. (e.g. Kinect, OpenPose)

b) **Hand gesture recognition/tracking:** Infrared sensors and cameras senses hand movements and extrapolates data to hand skeleton. 2D image information can be used to estimate hand poses as well. (e.g. Leap Motion, ManoMotion)

c) **Speech recognition:** Audio data is parsed to extract sentences and determine its purpose and context via Natural Language Processing (NLP). (e.g. Amazon Alexa, Google Home)

d) **Voice profile recognition:** The characteristics of voice data are recognised to perform user identification. (e.g. Amazon Alexa)

e) **Eye tracking:** Near-infrared light is directed towards the pupil and its reflection is tracked by an infrared camera. (e.g. iMotions)

f) **Multi-user touch interfaces** [36]**:** Multiple inputs are recognised and separated in an interactive display, allowing for multiple users to interact with a single interface. (e.g. Touchwall)

g) **Tangible devices:** Devices that have sensors for additional human input.

3.3.1.2 3 to 5 Years

a) **Emotion recognition:** The emotional state of faces is detected via 2D images with varying levels of confidence. (e.g. Emotion API)

b) **Conversable AI:** Human-like conversations can be performed based on a very specific context. (e.g. Google Duplex AI)

c) **Object identification:** Object identification determines the type of object detected from a 2D image. (e.g. Google Vision API)

d) **Iris recognition** [37]: Iris recognition uses unique patterns in the coloured eye section to identify the user.

e) **Gaze control:** User's eye movement is tracked (see Eye Tracking above) and used as an input for applications. (e.g. Windows 10)

3.3.1.3 More than 5 Years

a) **Advanced haptic interface** [38] [39] [40] [41]: Force and texture sensations are used as input and possibly replicated across a digital medium.

b) **Brain-computer interface**: Electroencephalography (EEG) records electrical activity in the brain and encodes it as an input for a digital interface.

3.3.2 Technology Adoption Readiness Map for Media Creation/Display

NOW - 2 YEARS	3 - 5 YEARS	> 5 YEARS
Holograms (waveguide displays)		3D volumetric image creation
4K UHD TV (3840 x 2160 pixels) Micro LED displays	8K UHD TV (7680 x 4320 pixels) Glasses-free 3D HD TV	16K UHD TV (15360 x 8640 pixels)
Smart mirrors	Natural focus adjustable displays	Electronics lenses
360 degree films	360 degree video streams	360 degree film theatres
HD video steaming	Taste creation	
AR enhanced displays		

Table 2: Media Creation/Display Technology Roadmap

The below section details the various stages of technologies development and adoption by users over time.

3.3.2.1 Now to 2 Years

a) **Holograms** [42] **(waveguide displays)**: A 3D image of an object can be displayed to be seen without the aid of any medium. Viewing angle is limited to avoid visual distortion. (e.g. Hololens)

b) **4K Ultra-high-definition television**: A television capable of streaming images with a resolution of 3840x2160 pixels.

c) **Smart mirrors**: Interactive mirrors that can display digital screens with the integration of hardware such as Raspberri Pi. (e.g. Two Way Mirrors)

d) **360 degree films**: A video stream of 360 degree images, with the intent of allowing the viewer to choose his/her viewing angle. (e.g. YouTube 360 videos)

e) **Cloud gaming**: The ability to leverage cloud hardware to play games. Takes input from the player and streams the resulting game video feed to the user. (e.g. PlayStation Now)

f) **Interactive video/game streaming**: With interactive video/game streaming, a user is allowed to record a video stream (of various media types) and simultaneously broadcast it to an audience. (e.g. Twitch, Youtube Live)

g) **AR enhanced displays**: Using AR capable devices, users can view superimposed digital graphics on certain AR-enabled displays (e.g. Layar).

3.3.2.2 3 to 5 Years

a) **8K Ultra-high-definition television**: A television capable of streaming images with a resolution of 7680x4320 pixels.

b) **Glasses-free HD television**: A television capable of streaming 3D images without the need for 3D glasses. (e.g. Ultra-D)

c) **Natural focus adjustable displays**: Displays/wearables capable of adjusting to the user's vision. (e.g. Deep Optics)

d) **360-degree video stream**: Streaming of live 360 degree videos over the internet. (e.g. Wowza)

3.3.2.3 More than 5 Years

a) **3D volumetric image creation** [43]: 3D image creation using lasers and light to move and illuminate particles respectively. Does not have a limited viewing angle.

b) **16K Ultra-high-definition television**: A television capable of streaming images with a resolution of 15360x8640 pixels.

c) **Electronic lenses** [44]: Contact lenses integrated with transparent nanomaterials capable of digital communication.

d) **360-degree film theatres**: Designated facility to show 360 degree films to large audiences. (e.g. Plymouth Europe)

3.3.3 Technology Adoption Readiness Map for Media Capture

NOW - 2 YEARS	3 - 5 YEARS	> 5 YEARS
Stereoscopic image/video capture Multi lens cameras 360-degree image/video capture Volumetric image/video capture		Light field image/video capture
3D audio capture	Taste encoding	
3D object reconstruction from image		
3D object scanning • Portable scanners • Stationary scanners	3D object scanning • Automated 3D model cleaning	
Drone assisted image/video capture		

Table 3: Media Capture Technology Roadmap

The below section details the various stages of technologies development and adoption by users over time.

3.3.3.1 Now to 2 Years

a) **3D image/video capture**: The ability to record and digitally encode 3D images and videos. (e.g. Sony Xperia XZ1) (Refer to *Chapter 3.3.3.4* for details)

b) **Multi lens camera**: Cameras with lenses of different focal lengths captures a single image with greater depth effects. Capable of performing better than normal cameras in low-light conditions. (e.g. Light L16 camera)

c) **360-degree image/video capture**: The ability to record and digitally encode 360 degree images and videos. (e.g. Ricoh Theta S)

d) **3D audio capture**: The ability to record 3D audio with a 4-channel output recording. (e.g. Sennheiser Ambeo VR Mic)

e) **3D object scanning**: Hardware capable of scanning and digitally encoding real objects to create a 3D digital model. (e.g. Artec)

f) **Taste Recognition** [45]**:** Encodes taste and smell information. Simulate taste via electrical and thermal stimulation.

3.3.3.2 3 to 5 Years

a) **3D object reconstruction from image** [46]: Libraries able to predict and create digital 3D models from 2D image(s). Uses the concept of photogrammetry.

3.3.3.3 More than 5 Years

a) **Light field image/video capture** [47]: Devices capable of capturing different light reflections bouncing in a scene, stitching them together to create scenes that show more accurate light reflections depending on viewer's angle and position.

3.3.3.4 3D image/video capture

Since videos are simply image streams, we focus on discussing 3D image capture technology in this section.

What is 3D image capture and how does it work?

3D image capture is the ability to digitally encode 3D images. 3D cameras perform this functionality. 3D image capture technology is based on stereoscopic imaging – a concept mimicking the functionality of human eyes. Two lenses capture two different images, one slightly displaced from the other. Each of these two images is shown to each human eye and the brain superimposes them together automatically like any real visual scene. The result is an image with parallax effect containing depth cues [48] that to a human, is more real. Continuous research and application of stereoscopic imaging technology has existed for decades [49].

To gain an understanding on how the latest 3D cameras work today, the Fujifilm FinePix Real 3D W3 Camera was examined [50] [51]. Two 10-megapixel Charge-coupled device sensors with dual Fujinon 3x f3.7-4.2 35-105mm lenses spaced about 3 inches apart approximates human-eye spacing for natural 3D effect in captured images. An additional manual Parallax Control allows for fine-tuning of 3D effect and it eliminates image ghosting. It also has an autostereoscopic LCD screen using rows of convex lenses, allowing users to see 3D images without the need for 3D glasses. The camera is also highly portable, supports instant playback when connected to televisions and supports 720p resolution for 3D video capture. Its price point is lower than its predecessor as well.

In its current technological state, 3D cameras are increasingly ready for widespread usage.

Why is 3D image capture technology important?

The success of media relies heavily on media recording technology. Without high resolution image recordings, there is little use for high definition television. 3D image capture technology plays an important role in the enablement and evolution of 3D media.

Consumers always demand for better media content. In terms of visual content, the easiest improvement comes in the form of enabling higher resolution media. 3D media complements VR content extremely well both utilises stereoscopic imaging technology. These content may be the next media types that see widespread consumption.

3.3.4 Technology Adoption Readiness Map for Virtual Reality (VR)

NOW - 2 YEARS	3 - 5 YEARS	> 5 YEARS
Untethered head-mounted display (HMD) • WiGig connectivity Standalone HMDs	3D Camera on HMD Volumetric VR Smell modules	Improved and integrated haptic feedback
Eye Tracking		
Multi-user VR	VR content sharing	
3D audio • Spatial audio	3D audio • Individualised binaural rendering • Dynamic binaural synthesis	
WebXR, OpenXR, OSVR, OpenVR	IEEE P2048 standards (VR/AR)	
		Improved hardware performance

Table 4: Virtual Reality Technology Roadmap

The below section details the various stages of technologies development and adoption by users over time.

3.3.4.1 Now to 2 Years

a) **Wigig connectivity**: Improved connectivity that allows low-latency wireless communication between head mounted displays (HMD) and the computer, removing the need for cable attachments. (e.g. Vive Pro) (Refer to *Chapter 3.3.4.4* for details)

b) **Standalone HMDs**: VR Devices capable of functioning on its own without the need for additional hardware (computer). (e.g. Oculus Go, Vive Focus) (Refer to *Chapter 3.3.4.4* for details)

c) **Eye tracking**: The ability to integrate eye tracking technology as a form of input in VR devices. (e.g. FOVE)

d) **WebXR**: An open specification to standardise web VR applications.

e) **OpenXR**: Cross-platform VR/AR standard which allows VR/AR applications to run on any VR/AR system respectively.

f) **OSVR**: Software that allows all VR headsets and controllers to be used with any game.

g) **OpenVR**: API that allows access to VR hardware from multiple vendors without any knowledge requirement on the application.

h) **Improved performance**: With advancements in each VR hardware component, the performance of VR devices increases as well.

3.3.4.2 3 to 5 Years

a) **3D camera on HMD**: 3D camera that allows replication of the environment via captured 3D image feed to the user. (e.g. Lenovo Mirage Solo)

b) **Smell modules**: HMDs that are capable of emitting smells to the users. (e.g. Vaqso VR)

c) **IEEE P2048 Standards**: Standards that ensure quality assurance and product testing for VR/AR products.

3.3.4.3 More than 5 Years

a) **Improved haptic feedback** [52]: Wearables that provide haptic feedback, including force and texture sensations based on VR experience.

3.3.4.4 Untethered head mounted display (HMD)

What is WiGig?

WiGig [53] refers to an extremely high speed, short range wireless technology. It uses a 60 GHz band to transfer data up to 7Gbps between devices. As such, it is useful for close proximity devices that require constant, heavy, real time data transfers without the use of communication cables.

Why WiGig in VR?

High-end VR HMDs currently require a cable attachment of some sort to a CPU. These cables hinder the most important quality of VR experiences – immersiveness. Next-generation high-end VR HMDs will do away with cables and transition towards wireless communication. Being able to replace them with a less restraining alternative such as WiGig wireless adapters is a huge step forward for high-end VR hardware. Examples of WiGig in VR include HTC's Vive Pro [54], leveraging a wireless adapter with Intel® Wireless Gigabit (WiGig) technology for high bandwidth data transfer.

What is a standalone HMD?

A standalone head mounted display (HMD) is a device capable of producing VR experiences without needing additional hardware. All necessary components including batteries, a processor, RAM, storage, display, lenses, batteries, etc. are stored inside the HMD [55]. Controllers are available for certain headset models.

Why standalone HMDs? [56]

A standalone HMD is designed to be an affordable and accessible option to a VR experience. It is also cableless with no reliance on external tracking, both of which are affordances for freer movement. However, it is less powerful compared to current high-end VR hardware because it can only rely on internally stored components to work.

Existing and future of standalone VR HMDs [56] [57]

There exist many different standalone HMDs. That said, the more mainstream models are:

a) HTC Vive Focus

b) Lenovo Mirage Solo

c) Google Daydream

d) Oculus Go

e) Oculus Santa Cruz

As hardware components become more compact and affordable, standalone HMDs will be the first and most attractive option for VR media consumption.

3.3.5 Technology Adoption Readiness Map for Augmented/Mixed Reality (AR)

NOW - 2 YEARS	3 - 5 YEARS	> 5 YEARS
Simultaneous Mapping and Localisation (SLAM)	Persistent AR content	AR Content Lenses
Computer Vision • Object recognition/tracking • Orientation/World tracking • Plane detection • Motion tracking	Computer Vision • Occlusion	Computer Vision • High precision measurement • High precision object tracking
Multi-user AR	AR content sharing	
3D audio • Spatial audio	3D audio • Individualised binaural rendering • Dynamic binaural synthesis	
OpenXR, AR Kit, AR Core, Vuforia	IEEE P2028 standards (VR/AR) Unity AR Foundation	

Table 5: Augmented/Mixed Reality Technology Roadmap

The below section details the various stages of technologies development and adoption by users over time.

3.3.5.1 Now to 2 Years

a) **Comprehensive SLAM databases** [58]: A massive collection of learned environments which allows applications to recognise and interact with mapped physical environments. (Refer to *Chapter 3.3.5.4* for details)

b) **Tracking**: Computer vision algorithms are able to detect image features and track them over successive frames. With a library of learned images, the algorithm can also recognise and identify objects.

c) **Multi-user AR** [59]: AR experiences that can be shared with simultaneous users.

d) **OpenXR**: Cross-platform VR standard which allows VR applications to run on any VR system.

e) **ARKit**: Apple's AR development platform for iOS devices.

f) **ARCore**: Google's AR development kit for Android devices.

g) **Vuforia**: An AR development kit for Android and iOS devices.

3.3.5.2 3 to 5 Years

a) **IEEE P2028 Standards**: Standards that ensure quality assurance and product testing for VR/AR products.

3.3.5.3 More than 5 Years

a) **AR Contact Lenses** [60]: Wearables that provide haptic feedback, including force and texture sensations based on VR experience.

3.3.5.4 Simultaneous Mapping and Localisation (SLAM) [61]

What is SLAM?

With no prior knowledge of its location or the environment, how can a machine understand where it is and how the environment is physically structured? We can use SLAM algorithms to find out. Based on a set of sensor inputs, SLAM algorithms construct the map of an unknown environment while simultaneously tracking the device's location. There are multiple SLAM algorithms available (e.g. EKF SLAM, FastSLAM, Graph-based SLAM, and Topological SLAM) and their effectiveness varies depending on the environment and the device employing them. Visual SLAM algorithms use Visual Odometry (VO) and loop closure to estimate the device's local position based on an image stream and known feature sets [62].

For AR, VR, and MR, we focus on Visual SLAM and Sensor Fusion algorithms. Within capable devices, we usually have cameras, a gyroscope, and accelerometers providing images, angular velocity and acceleration (in three axes) data respectively.

How does Visual SLAM work?

a) **Propagation**: Device's Inertial Measurement Unit (IMU) consisting of a gyroscope and an accelerometer provide data relating to user movement – angular velocity and acceleration in three axes. Using this data, the Propagation Unit attempts to calculate its pose and relative position. There is a degree of inaccuracy here due to hardware limitations and noisy data.

b) **Feature Extraction**: Cameras capture image frames at a fixed rate over time. Image features are extracted, tagged, identified and fed to the Mapping Unit to build the feature map.

c) **Update**: Extracted features are also compared to the existing feature map. If the features exist, the Update unit can then derive the device's current position and pose from the known feature points.

d) **Combining**: Working together, the position and pose information from feature tracking (Update) supplement the position and pose information from sensors (Propagation). This results in greater accuracy in position and pose estimation. Simultaneously, continuous image capture builds the environment's feature map and knowledge.

SLAM algorithm implementations

a) Facebook camera [63]:

- 3D AR art showcases

- WorldTracker API, an umbrella interface that combines SLAM with other tracking algorithms to “place things in the world”
- Persistent AR experiences integrated with Facebook’s ecosystem
- Create comprehensive SLAM maps using deep neural networks and Caffe2

b) Google ARCore [64]:

- Native AR SDK for Android devices
- Cross-platform AR SDK

c) SLAMcore [65]:

- Visual SLAM solutions in robotics

d) NavVis [66]:

- Indoor digital mapping solutions

What’s next for SLAM?

According to Professor Andrew Davison [67], there are three cumulative levels of SLAM competence. Currently, most SLAM solutions belong to level 1, which is robust localisation based on a map of sparse feature points. Currently, ongoing research is carried out to improve SLAM to the next levels.

At Level 2, a denser feature map can enhance or replace the existing sparse feature map. Here, the map can be represented by meshes or functions as there would be enough points to estimate the shape of objects in the scene.

Finally, at level 3, the device is able to semantically understand the scene by separating known objects from each other. Therefore, instead of mapping to feature points, the device is able to semantically map to objects based on its shape and form.

3.4 Use Cases Illustrated by Technology Convergence Map

In this section, we will show use cases of possible solutions that comprises of different IMAI technologies. Technology Convergence Maps will be developed based on the Technology Application Framework and its three key components (i.e. Clusters and Industry Verticals, Experience Enablers, and IMAI Technology Components). (Refer to *Chapter 3.1*) It will clearly show how each experience enablers are empowered by various solutions which are supported by IMAI technologies, and ultimately bring impact to different industry verticals.

Next section will focus on use cases in the following industries:

a) Lifestyle: Retail

b) Built & Environment: Real Estate & Smart FM

c) Trade & Connectivity: Logistic

3.4.1 Lifestyle: Retail

Retail industry is one of the industry where IMAI technologies can be applied pervasively to bring enhanced experiences to customers. Some examples of the concepts that retail industry can explore include AR Retail Experience, and Unmanned Store. Of which, the concept of Unmanned Store is *illustrated in the Exhibit 20.*

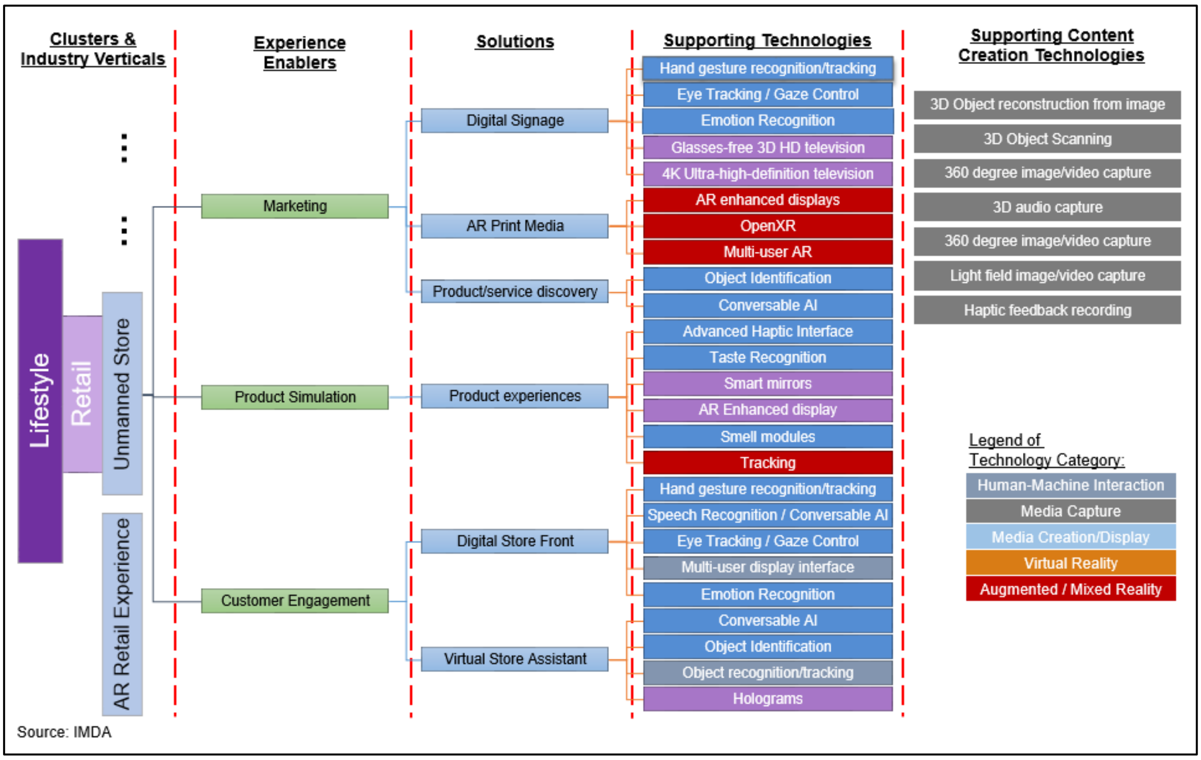


Exhibit 20: Technology Convergence Map for Unmanned Store in Retail Industry

Three key experience enablers are identified under the concept of Unmanned Store; Marketing, Product Simulation, and Customer Engagement. Each have related solutions and supporting technologies. The below section details each experience enablers by solutions:

Experience Enabler: Marketing

a) **Digital signage**: Digital signage can help retailers to showcase their product to the right audience and capture user's attention via highly interactive user experience. It needs to gather as much user information as possible to develop the necessary user insights. Information can come from various sources such as hand gestures, eyes movement and even emotions. Digital signage also needs to display their contents in a high resolution, especially for larger display screens, in order to draw user's attention. For example, the contents displayed using glasses-free 3D display can bring additional dimension to express details interactivity.

b) **AR print media:** Advertisements in the print media such as magazine, brochure, poster and newspaper need additional interactivity and dimension to portray their products and services to gain customer attention. Advertisement embedded with a QR code can direct users to the company website where their AR can be delivered through web using Web AR technology. This can reduce the resistance for users to download individual apps on their mobile and users will be able to receive more information on top of the print media.

c) **Product/service discovery**: Advancement in the virtual assistance allows users to easily make a query for product information. Virtual assistance is able to recommend products according to the user's requirements. Users can also search via image query to identify products offered by the retailer. The use of AR enables customers to view in-store offers and promotions. Retailer can also leverage the usage of AR to provide personalised pricing to individual customer based on their purchasing habits. Mall operators can also use AR to overlay advertisement on the retailer's storefront as additional form of revenue and retailer can benefit better footfall.

Experience Enablers: Product Simulation

a) **Product experiences**: Customers can use AR technologies to improve their product experience via digital means. Smart mirrors allow customer to experience virtual try-on. This enhances the user experience by allowing customers to try different apparels in a shorter amount of time. Furniture companies also make use of AR to overlay furniture in the user's home to provide additional experience.

Experience Enablers: Customer Engagement

a) **Digital store front**: Physical retail shops can install interactive digital storefront to allow customers to make a query for product information or display targeted advertisement to attract attention of the customers. Digital store front can be equipped with speech recognition technology or conversable artificial intelligence to achieve higher interactivity with the customers and to serve different customer enquiries.

b) **Virtual store assistant**: Virtual store assistant can help to alleviate manpower shortages in retail stores by providing support in attending the customer enquiries and also allowing better customer engagements. Virtual store assistant can also have facial recognition technology to identify customers and provide personalise experience to each individual.

3.4.2 Build & Environment: Real Estate & Smart EM

Real Estate & Smart FM industry in the Built & Environment sector can also adopt IMAI solutions in their daily operations. Solutions such as AR print media in the retail industry discussed in the previous section can also be applied into this industry. An example is to display layout and the interior of properties for sales on the print media as advertisement. This section will elaborate use cases that can help to improve the worker productivity, empowering them as Smart Operators. (*Exhibit 21*)

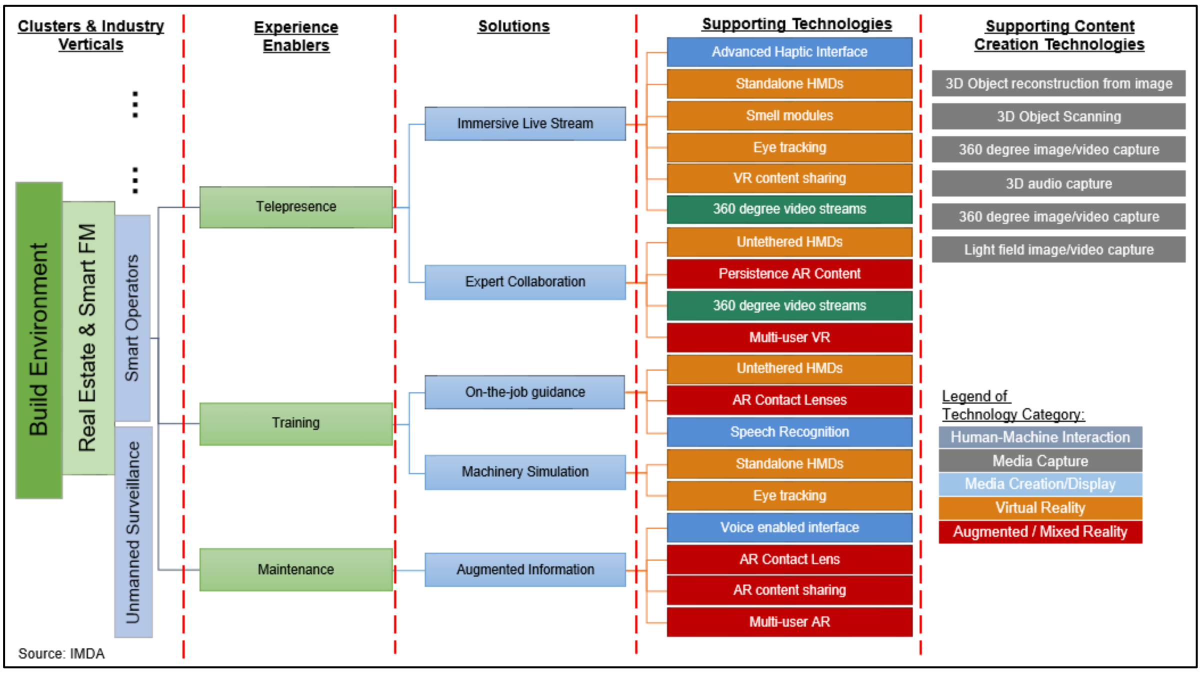


Exhibit 21: Technology Convergence Map for Real Estate & Smart FM industry

Three key experience enablers are identified under the concept of Smart Operators; Telepresence, Training, and Maintenance. Each have related solutions and supporting technologies. The below section details each experience enablers by solutions:

Experience Enablers: Telepresence

a) **Immersive live streaming**: With the advancement in communications technologies such as 5G technology, high-definition 360-degree video streaming can be made possible and allow security operators to monitor remotely from operation centre. Multiple drones can be deployed for security surveillance to assist the operators for better situation awareness from remote locations.

b) **Expert collaboration**: Technician on site can leverage on high bandwidth 5G capability to transmit high-definition videos from their AR/MR headset back to their company for greater support. Experts can remotely guide technician on site. Experts can highlight key points and the technician on site can see annotations via the AR/MR headset for better collaboration.

Experience Enablers: System Simulation

a) **Planning**: Civil engineers can create 3D building models and perform various scenarios to validate their design and requirements. Multiple engineers can collaborate together to run various scenarios such as HVAC failures, power failures and fire evacuations. VR or MR can allow better collaboration within engineers to identify problems and make decisions.

Experience Enablers: Training

a) **On-the-job guidance**: Technicians equipped with AR headsets can have better guidance when they are on-site performing maintenance duties. Instructions can overlay on machinery and step-by-step details can be shown on the screen. This allows new technicians to able to pick up skills at a faster rate.

b) **Machinery simulation**: To service and maintain complex machineries such as HVAC systems, water pumps and electrical power systems, more in-depth trainings are required for the engineers and technicians. Trainees can make use of AR/MR headset to provide higher details of information such as the breakdown of the machinery components to better understand on the maintenance procedures.

Experience Enablers: Maintenance

a) **Augmented information**: On-site technicians can put on AR headsets to receive and view all the necessary inspection tasks at different locations indicated by the facility manager. Additional information can overlay on the AR headsets such as electrical cabling pathway above the false ceiling so that the technicians can identify the exact location to rectify instead of randomly searching for the correct location.

3.4.3 Trade & Connectivity: Logistic

IMAI technologies can also bring innovative solutions to the logistic industry, allowing higher productivity for logistic operators in their daily operations and reducing errors and time required to deliver to the customers. *Exhibit 22* illustrates how optimised picking can be enabled by IMAI technologies.

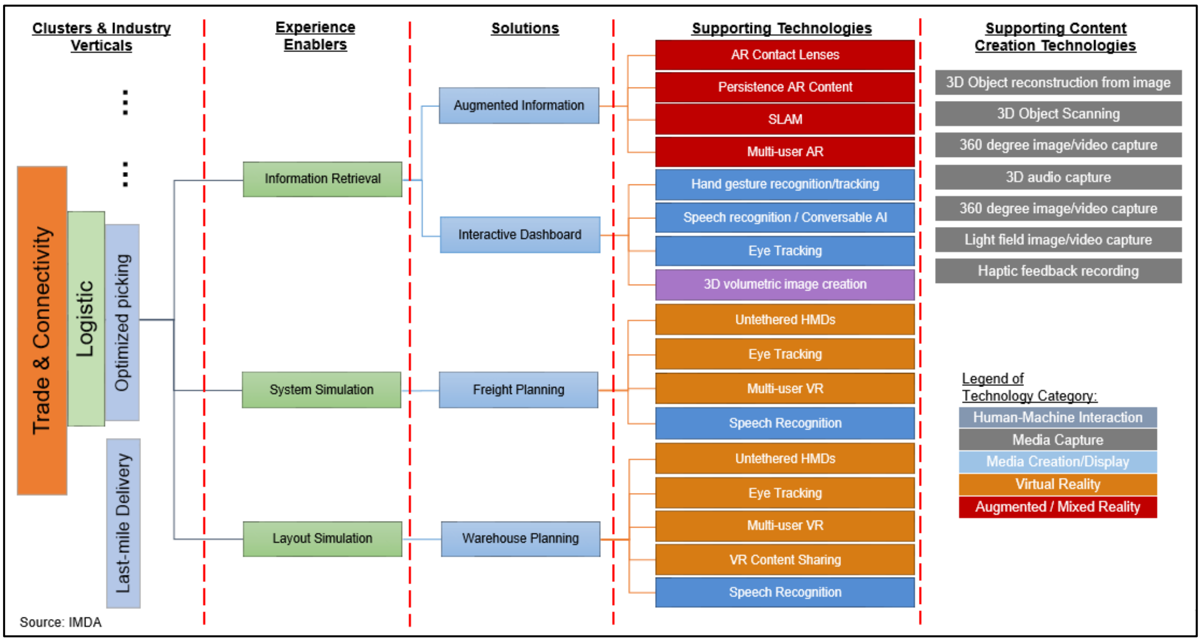


Exhibit 22: Technology Convergence Map for Logistic Industry

Three key experience enablers are identified under the concept of Information Retrieval, System Simulation and Layout Simulation. Each have related solutions and supporting technologies. The below section details each experience enablers by solutions:

Experience Enablers: Information Retrieval

a) **Augmented information**: Information such as tasks or goods locations can be displayed on their AR devices such as smart glasses. The “hands-free” experience allows operators to be more productive. The AR devices can also guide them to a location via the best route, to reduce the travelling time. This will also reduce the errors made by operators.

b) **Interactive dashboard**: Interactive dashboard can provide warehouse operations a consolidated view on various tasks and information at a glance. Information such as estimated time arrival of delivery truck, stock level of goods and critical information allows the operation manager to re-deploy their resources to better manage situations.

Experience Enablers: System Simulation

a) **Freight planning**: As cargos come in different sizes and weight, logistic operator can use VR for planning to make an arrangement to maximise available spaces in the vehicle. This information can also be shared to the warehouse operators via AR devices in order to provide instructions to those on the ground.

Experience Enablers: Layout Simulation

a) **Warehouse planning**: VR systems allow logistic operators to plan the layout of the warehouse more efficiently. Planners can test their design before actual implementation, allowing the optimisation of new workflows management. Multi-user VR system allows different operators and planners to collaborate by real-time information sharing.

3.4.4 Illustration on Developing an Enterprise Technology Roadmap

For individual organisation to build an enterprise road map, the organisation can refer to Technology Convergence Maps with Technology Adoption Readiness Maps (Please refer to *Chapter 3.3*).

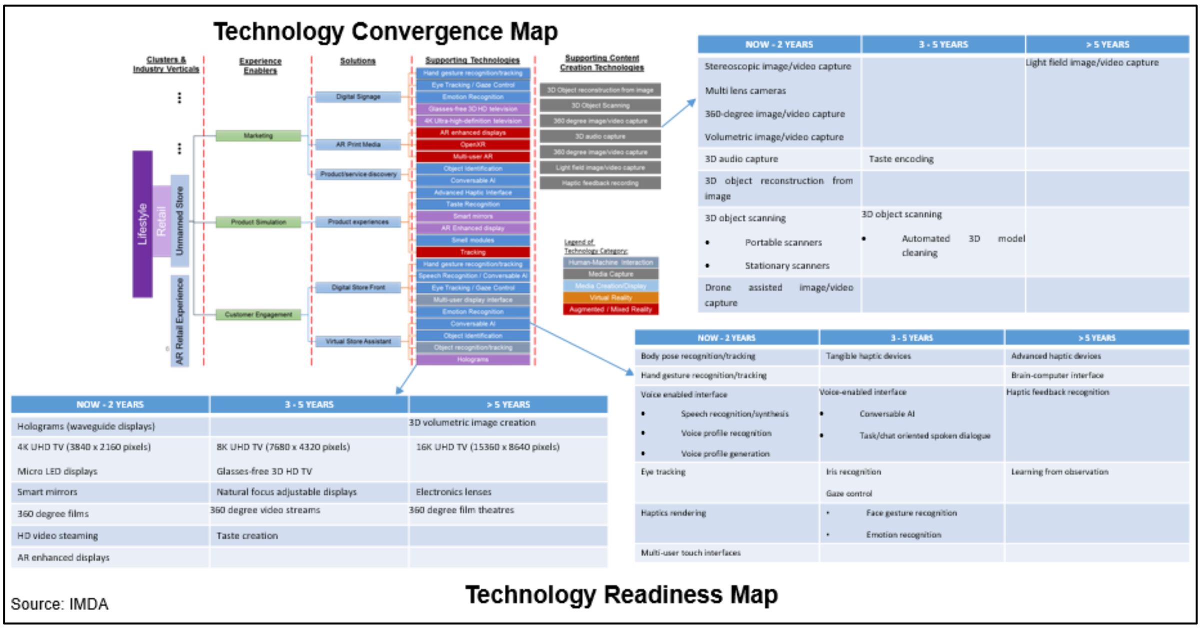


Exhibit 23: Developing an Enterprise Roadmap

From the Technology Convergence Map, there are specific use cases for different industry verticals that individual organisation can refer to. *Exhibit 23* illustrates the use cases related to creating an Unmanned Store in the retail industry. The unmanned store may require several experience enablers that encompasses different solutions to provide enhance customer experiences. Each solution is supported by various IMAI technologies that are listed in different categories of Technology Adoption Readiness Map.

In the Technology Adoption Readiness Map, different IMAI technologies have different technology maturity timelines. These timelines of underlying supporting technologies will determine the availability of the related solutions, hence allowing organisation to plan and construct their enterprise road map.

3.4.5 Supporting Technologies for IMAI

Communications technologies play an important role in supporting the IMAI technologies and this section elaborates how the advanced 5G network technologies can impact the adoption.

With network providers testing 5G networks around the world, it is only a matter of time before 5G replaces 4G. Running at speeds around 100 times faster than its predecessor, 5G networks are more capable of supporting emerging technological trends:

a) **Everyday digital media activities**: Many applications rely on (real time) download and upload speeds. With 5G, everything can become much faster. HD movies can be downloaded instantaneously, video calls are smoother with higher bit rates, and GPS location tracking is more responsive. Common daily activities involving the consumption of media content is becoming faster, improving our lives in the process.

b) **New media content**: Future media content demands greater storage space. High-definition 360 degree videos, for example, require more pixels to encode. In order to stream such videos, a much higher bit rate is necessary. 5G network enables real time consumption of such forms of new media. This consequently increases accessibility and hence, demand for new forms of media content produced by emerging technologies such as VR.

c) **Innovation**: Faster transfer speeds provide a room for new technologies and interfaces to surface. For example, Head Mounted Displays (HMD) are now able to communicate wirelessly, removing the need for cumbersome cables (e.g. Vive Pro). Car-to-car communication which is crucial in many self-driving vehicle implementations becomes more responsive and reliable.

d) **Internet-of-Things**: More devices and home appliances are connected to the internet. 5G networks can cater to all data requirements of these devices simultaneously. Multiple interfaces can communicate more seamlessly with each other.

3.5 IMAI Contribution to Cloud Native Architecture

As a part of the overall technology roadmap recommendation, Singapore needs to establish a Cloud Native Architecture to improve access to emerging technologies amongst the stakeholders and assure Services 4.0. We believe that Immersive Media & Advanced Interfaces (IMAI) Technologies will play an important part in ensuring the success of the Cloud Native Architecture as highlighted by the exhibit below. *Exhibit 24* below shows how IMAI technologies will contribute to various aspects of Cloud Native Architecture.

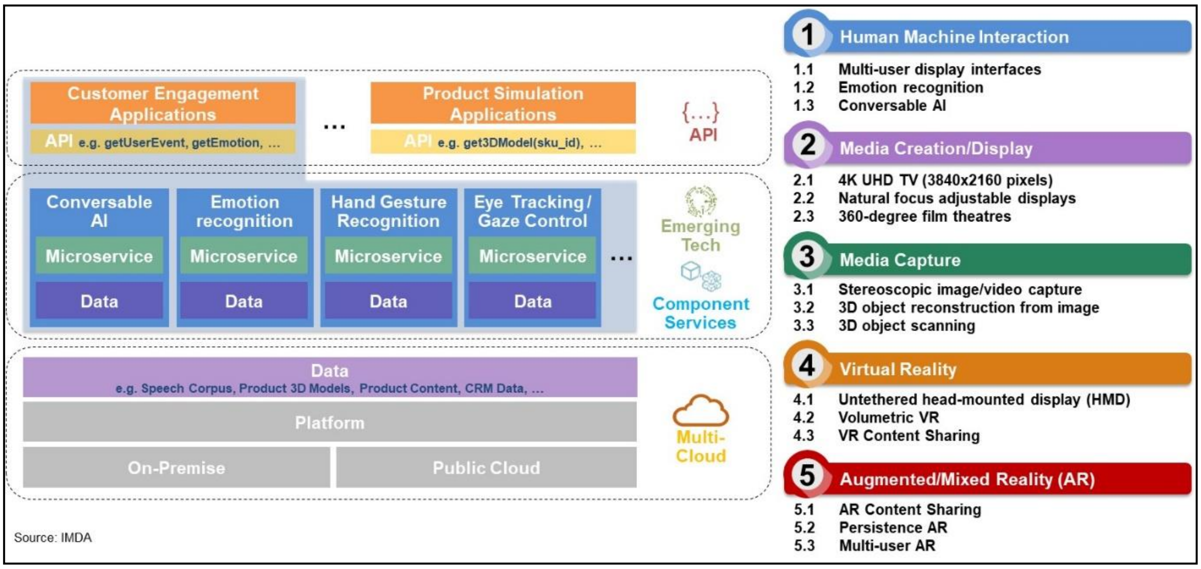


Exhibit 24: IMAI Contribution to Cloud Native Architecture

4 SWOT ANALYSIS

For Singapore to experience the benefits of IMAI technologies, it is crucial to understand the strengths, weaknesses, opportunities and threats (SWOT) of enterprises and businesses. With this understanding, we can ensure that the findings are relevant to their needs and concerns. The framework shown in *Exhibit 25* allows for a well-rounded analysis of this matter, with the following key criteria; Market, IP & Talent, Capital, Infrastructure & Ecosystem, Policy & Regulations.

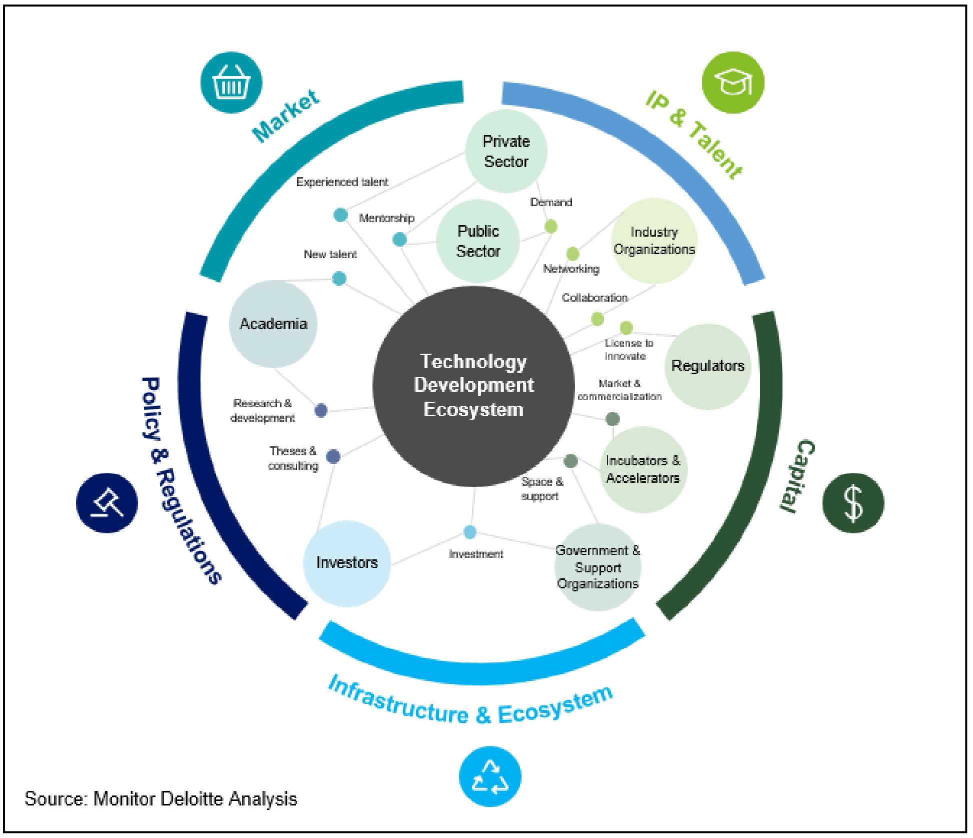


Exhibit 25: Framework for SWOT Analysis

A SWOT analysis of the Singaporean Landscape for Immersive Media and Advanced Interface (IMAI) revealed the following strengths, weaknesses, opportunities and threats clearly indicating the areas in which Singapore should expend resources in order to become a global player in the area of IMAI technology. (*Exhibit 26*)

STRENGTHS

1. Presence of international IMAI players (tech & media giants) in Singapore
2. Strong innovation hubs (e.g. IMDA's PIXEL) and global reputation of local research institutes & universities
3. Active R&D efforts by research institutes & universities, IHLs and local corporate labs in the IMAI space (e.g. Fraunhofer, CUTE, LiveLabs, ARTC, etc.)
4. Strong communication infrastructure such as mobile and network connectivity (e.g. piloting of 5G)
5. Government willingness to support promising local companies
6. Strong regulatory & legal framework (e.g. IP protection laws)

WEAKNESSES

1. Small domestic market and lack of scale
2. Low risk-appetite amongst enterprises to invest in new technologies like IMAI
3. Lack of talents for R&D and tech development
4. Core IMAI technologies dominated by international players – lack of local tech developers
5. Inconsistent level of IMAI adoption and digital capabilities amongst local enterprises (e.g. local tech providers need to upskill; local solution providers lack expertise / knowledge to quickly adopt IMAI tech)

OPPORTUNITIES

1. Existing Smart Nation initiative to be leveraged – make Singapore as a hub for experimental & innovative use of technology
2. Strong export market opportunities leveraging high growth potential in APAC
3. Strongly service-oriented country – sectors with high potential to adopt IMAI tech such as retail, healthcare

THREATS

1. Need for Singapore to constantly keep abreast with fast moving tech advancement, in order to fully realise market opportunities from IMAI R&D projects
2. Increasing competition in the region due to their lower cost (e.g. Thailand, Philippines), increasing competitiveness (e.g. Malaysia's EFTZ) and large investments and capital (e.g. China, Korea)

Exhibit 26: Summary of SWOT Analysis

In the following section, the below segments of the local ecosystem are considered for further assessment:

a) Research Institutes

b) Start-ups

c) Large Local Enterprises

d) Multinational Companies

4.1 SWOT: Research Institutes

SWOT ANALYSIS	
STRENGTHS	**WEAKNESSES**
• Competent and credible researchers • Robust frameworks / methodologies available for research and validation of research findings • Open mind set to explore new research areas, instead of following the convention (i.e. technologies with higher Technology Adoption Readiness Level) • Strong international networks and connections with other researchers / Research Institutes • Strong global reputation	• Insufficient research staffs to cope with demands • Disconnect between research areas and areas with actual tangible value for enterprises / industries • Low risk appetite for new unexplored research areas, which may have lower possibilities of immediate returns but larger potential upside in the future (i.e. technologies with lower Technology Adoption Readiness Level) • Challenges in hiring foreign workforce (i.e. more justifications required from employers)
OPPORTUNITIES	**THREATS**
• Leverage on Smart Nation initiative, and differentiate ourselves as a hub that is receptive to research of new, cutting-edge technologies • Leverage on improved rankings of our local universities, as well as Singapore's reputation for quality education and high standard of living, to attract top students and researchers • Closer opportunities for working with industry (proof of concept)	• Brain drain i.e. preference of top research talents to work in more lucrative sectors such as finance, and major IT firms • Industry needs moving faster than research outcomes

Table 6: SWOT Analysis for Research Institutes

4.2 SWOT: Start-Ups (Technology Provider)

SWOT ANALYSIS	
STRENGTHS	**WEAKNESSES**
• Willingness to experiment with new / ground-breaking ideas and business models • More agile and nimble in execution (i.e. able to pivot quickly) • Able to operate with lean resources • Attractive working environment to top talent who are looking for equity and autonomy	• Lack of established processes, funds and business models, leading to a fragile and unstable working environment • Greater physical / emotional / finance hardship involved in working at a start-up, possibly leading to a high turnover rate • Difficulty in penetrating overseas markets, due to entrenched local start-ups who have a stronger / more loyal community
OPPORTUNITIES	**THREATS**
• Potential for unlimited upside, if a new market is created (e.g. sharing economy (AirBnB, Uber), social networks (Facebook)) • Accelerated learning opportunities, as founders will fail, learn and iterate in multiple roles at a rapid pace • Partnering with larger international companies in Singapore, for localised content (require proactive approach to engaging with the larger international companies)	• Patent trolls, who issue frivolous lawsuits to take advantage the new products / services • Competition from entrenched incumbents who have more resources to develop similar products / services and overtake the market share

Table 7: SWOT Analysis for Start-ups (Technology Provider)

4.4 SWOT: Large Local Enterprises (End User)

SWOT ANALYSIS	
STRENGTHS	**WEAKNESSES**
• Strong global / regional reputation for being trustworthy and capable to do business with • Workforce in company has strong command of English (international language for businesses) • Strong database of customers' information (e.g. shopping history, spending habits etc.) for marketing and outreach purposes	• Rising labour costs, due to higher standard of living in Singapore and restrictions on hiring foreign workers • Over-emphasis on legacy / bread and butter issues, leading to inadequate focus on developing new products / solutions that could grow the business • Lack of talents who can create innovative / transformative business models and products • Reliance on global MNCs for core technologies
OPPORTUNITIES	**THREATS**
• Leverage on Singapore's global / regional reputation and brand name, and expand into other markets • Leverage on Singapore government's extensive range of grants / schemes to further expand the business, try out emerging technologies and train workforce • Leverage on R&D activities by research institutes (e.g. A*Star) instead of building in-house R&D capabilities	• Competition from overseas companies who may have greater resources, better products or more brand power to attract work force talents / customers • Small domestic market, which does not offer scale • Aging workforce • Lack of collaborative efforts within the industry (e.g. to expand to other markets)

Table 8: SWOT Analysis for Large Local Enterprises (End User)

4.6 SWOT: Large Local Enterprises (Technology Provider)

SWOT ANALYSIS	
STRENGTHS	**WEAKNESSES**
• Strong local reputation / brand recognition • Strong organisational / management structure • Diverse line of products / services	• Lack of reputation / brand recognition beyond Singapore • Over-reliance on a small number of major local clients (e.g. public sector agencies)
OPPORTUNITIES	**THREATS**
• Create “add-ons” to existing products / services, to further broaden the scope of company’s offerings and tap on existing customer base • Displace higher-priced competition with new technologies • OEM opportunities (e.g. white label solutions)	• May not be able to adopt latest technologies quickly enough, to continue providing value to customers and maintain competitiveness

Table 9: SWOT Analysis for Large Local Enterprises (Technology Provider)

4.8 SWOT: Multinational Companies (Technology Provider)

SWOT ANALYSIS	
STRENGTHS	**WEAKNESSES**
• Strong, well established brand name that brings credibility and is attractive for business connections • Loyal customer base that is familiar with and reliant on the company's products / services • Sufficient financial / workforce resources to invest in new ventures	• Greater administrative and financial overheads, due to larger workforce and scope of operations • Less agile and nimble in reacting to new market trends and experimenting on new ideas • May not be as knowledgeable as the smaller local / regional competitors, on the preferences & requirements of local / regional market • May be perceived as a less attractive place to work (due to bureaucracy, lack of autonomy, slow pace of progress, etc.)
OPPORTUNITIES	**THREATS**
• Leverage on the established business processes and brand name, to expand overseas and capture new markets • Potential to expand existing IP into other complementary product lines • Acquire other companies / patents, to accelerate acquisition of new customer bases or products	• Intense competition from other MNCs and start-ups who are targeting the same market • Slowing rate of growth, as the company's pace of innovation and expansion plateaus

Table 10: SWOT Analysis for Multinational Companies (Technology Provider)

4.9 Conclusion

In conclusion, IMAI technologies require a focussed set of strategies, with Singapore's unique strengths and weaknesses in mind. These recommendations need to enable development of local technology capabilities and drive adoption of IMAI technologies amongst industries, in order to tap onto the strong regional growth potential. As a highly service-oriented country, Singapore already has active R&D efforts demonstrated by innovation hubs and local research institutes, aiming to meet increasing demands from global and local IMAI players. Furthermore, existing initiatives such as Smart Nation initiative could be leveraged to make Singapore as a hub for emerging technologies, encouraging collaborative efforts across the region. Singapore also need to continue providing a favourable environment with government support, necessary regulatory and legal framework, which ultimately can help Singapore to lead the fast-moving tech advancement.

5 RECOMMENDATIONS

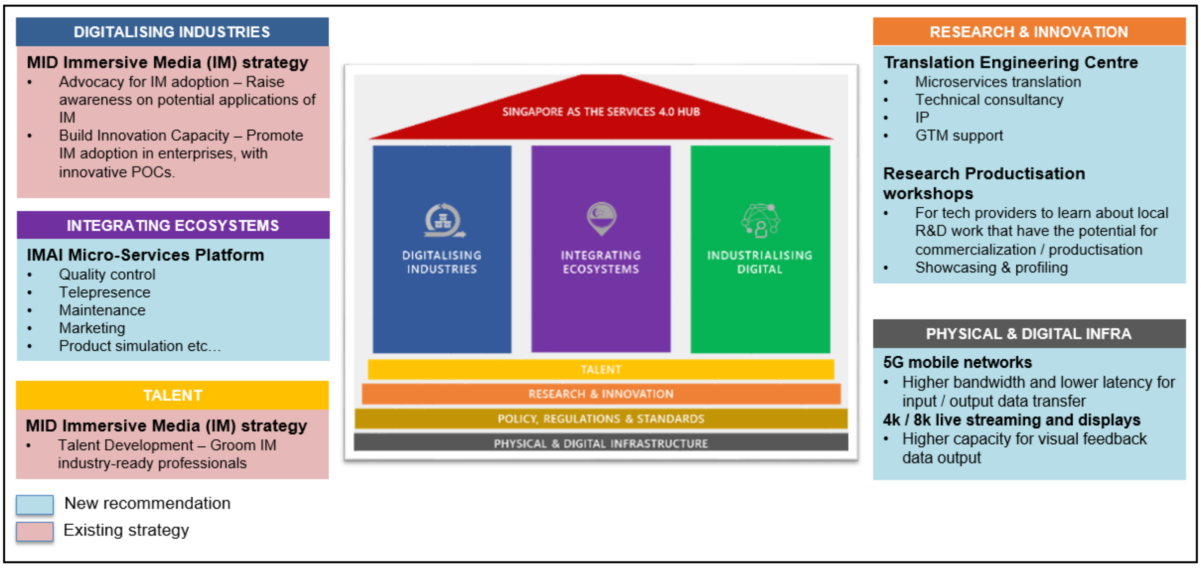


Exhibit 27: Alignment of Recommendations in IMAI Technologies to DE Framework

Based on the findings established from the SWOT analysis, five main recommendations have been identified, and will be further elaborated in this section:

a) IMAI Micro-Services Platform

b) IMAI Translation Engineering Centre

c) Research Productisation Workshops

d) IMAI Technologies to invest in

e) Supporting Technologies to invest in

5.1 IMAI Micro-Services Platform

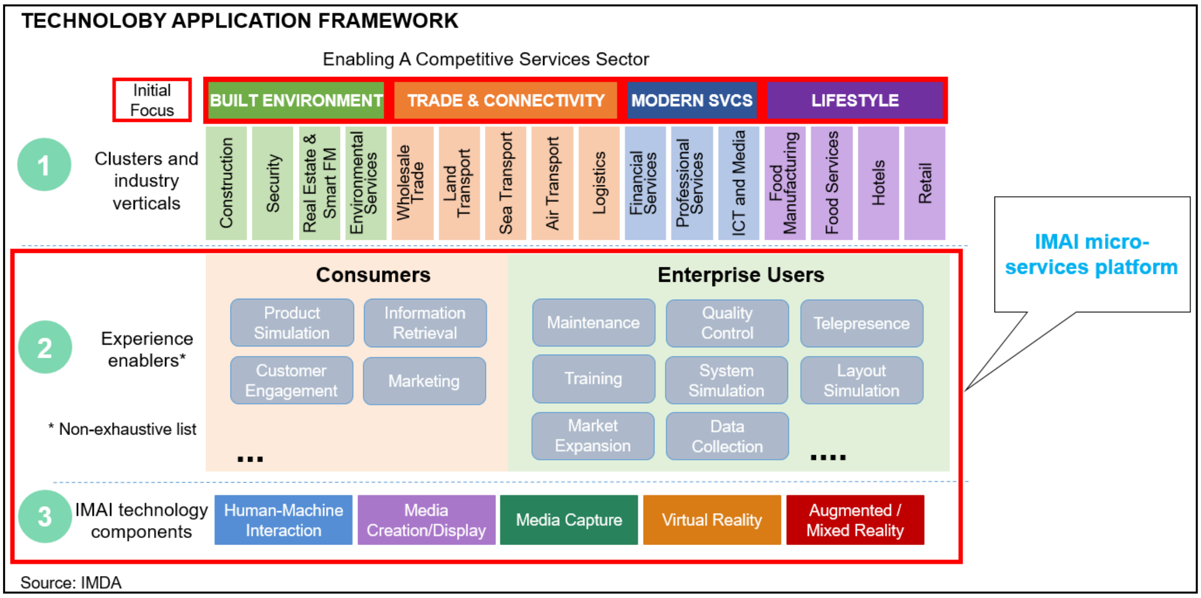
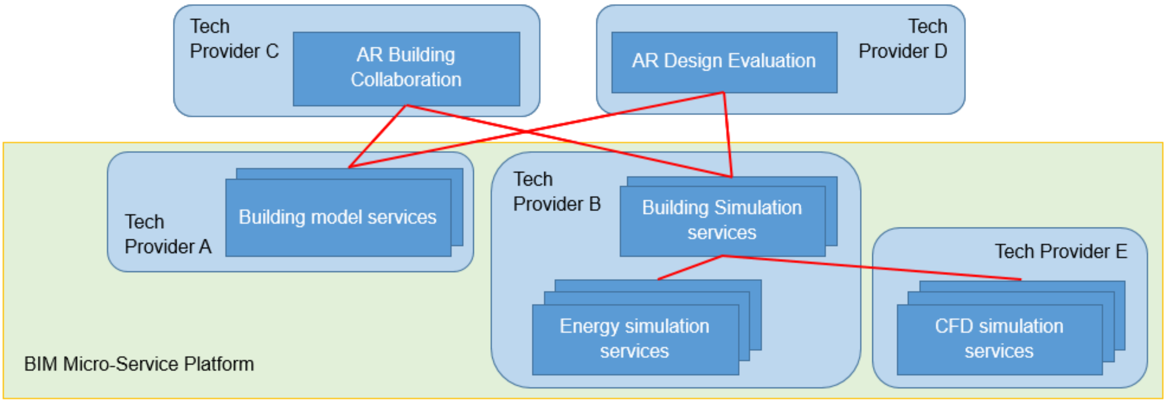


Exhibit 28: IMAI Micro-Services Platform

To catalyse the growth of the local IMAI ecosystem, it is crucial to democratise access to IMAI technologies. This can be achieved by adopting a Cloud Native Architecture approach, which offers the potential to improve ease of use, provide more flexibility, ensure scalability and reduce cost. In turn this will reduce friction in adoption of IMAI amongst users, and empower them to create more innovative IMAI products and solutions. To accomplish these objectives a micro-services platform could be developed, which can integrate and harmonise the disparate experience enablers offered by the various local enterprises.

This platform should have differentiating factor(s) from the current platforms in the market to have a unique selling point i.e. it should not be a rehash/amalgamation of other existing platforms/interfaces. It will also be based on industry standards that are widely accepted, to avoid re-inventing the wheel and ensure interoperability. There should also be close consultations with industry stakeholders/partners to gather buy-in (e.g. exposure of their APIs to integrate with the platform, agreed upon pricing structure, etc.). Through such a platform, the local enterprises can benefit from better economies of scale and can tap onto the other micro-services available on the platform (e.g. data analytics, Cyber Security, etc.) to augment and complement their own offerings. This platform will also be periodically reviewed to ensure that it continues to push the boundaries in terms of providing value to enterprises and users, and not remain stagnant.



Source: IMDA

Exhibit 29: Building Information Modelling (BIM) Micro-Service platform

An example of a Building Information Modelling (BIM) Micro-Service platform is illustrated in the above *Exhibit 29*. Each individual technology providers can focus on their core product by providing APIs to other technology providers. This also allows better integration of services and information such as 3D building models can be easily shared among different technology providers. This allows collaboration, evaluation and simulation and thus, enabling a shorter time to market and integration cost compared to silo approach for individual technology providers.

In addition, a secondary version of this platform could be developed in tandem. This platform is intended to provide a sandbox environment for testing of emerging, new technologies from RIs and IHLs (i.e. Alpha or Beta versions) before they are launched onto the main IMAI Micro-Services platform.

5.2 IMAI Translation Engineering Centre

The intent for the proposed IMAI Translation Engineering Centre is to assist local SME technology providers who may not have the dedicated product engineering resources to develop R&D concepts and ideas from RIs and IHLs into market ready, commercial productions and solutions.

An option for such a centre could be public-private partnership (PPP) model, which is a collective approach where public sector organisations (e.g. research institutes, institutes of higher learning, etc.)

and private sector organisations (e.g. corporate research labs, commercial innovation hubs, etc.) combine resources and know-how to identify and develop solutions and products on the most critical areas of IMAI technologies. Such a lab has the potential for:

a) Micro-Services translation for Alpha/Beta trials

b) Venue for ideation/innovation

c) Provider of consultancy/experimentation services

d) Commercialisation opportunities for R&D projects

e) Networking/business match-making

The use cases for this centre will be curated to ensure that they have a nation / industry-wide impact as opposed to specific user or company use cases that benefit only a narrow segment. Efforts will also be conducted in crafting an effective IP framework, to facilitate ease of co-sharing IP between the collaborators. To ensure that the local ecosystem is plugged into and keeping pace with global developments, this centre could also explore collaborations / partnerships with other similar centres / hubs around the world.

5.3 Research Productisation Workshops

To augment the efforts by the IMAI Translation Engineering Centre, roadshows and engagement sessions could be organised to put local technology providers in touch with RIs and IHLs to understand more on the R&D works. From such engagements, the technology providers can have a better understanding on the potential R&D work that they can leverage on to develop into commercial products and solutions. This also allows the RIs and IHLs to be updated and in sync with the needs of the industry, so they can better direct their R&D efforts in areas with greater commercial and practical potential as opposed to working in silo or purely for academic purposes.

5.4 IMAI technologies to invest in

After conducting market studies, technology studies, and industry engagements (e.g. workgroup meetings and focus group discussions), the findings reveal that Singapore should prioritise investments in technologies which drive Augmented Reality (AR), Virtual Reality (VR) and Mixed Reality (MR) applications. This refers mainly to research topics such as computer vision and HCI, as well as related technologies and others listed in Tables 4-5 and Tables 1-3 respectively. To summarise, here are the reasons for our prioritisation:

a) **Market potential and readiness:** Referencing to Exhibit 3, the market spending on vision technologies is the highest among IMAI technologies (including Tactile, Auditory, Olfaction, Gustation technologies), underscoring the level of interest the technology is drawing. In Chapter 2, the discoveries highlight the potential and growth opportunities in the AR/MR/VR local and global markets and reinforce the notion that the market is ready for a new ecosystem incorporating these technologies.

b) **Patents and inventions.** Based on a research with Intellectual Property Office of Singapore (IPOS) [68], many players (e.g. Epson, Microsoft and Osterhout) have innovation portfolios of up to 522 related inventions each. Inventions relating to AR/MR headsets is still on the increase, yielding 2,805 inventions over the past decade and is estimated to grow at 36.2% CAGR over the 5-year period preceding 2018. Interest in deploying AR/MR headsets to various industries has been demonstrated by the related inventions growing at a significant CAGR of 35.7% across the six studied industries, namely information & communication media, logistics, retail, finance, medical and education. Despite the high growth rate, industrial applications of these headsets are relatively unsaturated with only 769 inventions generated in the past decade and majority of the top players holds an individual patent portfolio with fewer than 10 inventions. Thus, our inventions research highlights the potential for AR related technologies to manifest in different types of players in the market.

c) **Accessibility of AR/MR/VR content:** Based on the feedback from local technology providers, it is believed that AR/MR will reach mainstream adoption much sooner than VR, because the former is more accessible. Smartphones are already capable of accessing AR content. With the approach of web-based AR/MR content sharing platforms (WebAR), AR/MR content can be easily shared and streamed from the web. Such platforms for VR content accessibility and sharing are also in the works with WebVR.

d) **Immersive content creation:** Content creators are already creating new types of contents such as 360 degree videos to cater to AR/MR/VR technologies. In addition, newer forms of immersive contents such as volumetric image and scene capture are surfacing as well. The creation of such contents will further fuel the growing demand for AR/MR/VR devices.

e) **Need for hands-free interaction**: To augment physical work processes, display devices are required to offer hands-free interaction. AR/MR technologies can be heavily utilised in this regard. For example, AR headsets such as the HoloLens or Lightwear can be used to guide component assembly.

f) **Research in IMAI technologies:** Based on the surveys and findings about the IMAI technology research scene, local researchers are actively working on AR/MR based technologies. The areas of research include vision based high precision measurement and tracking technologies. A concurrent study conducted by IPOS, highlights the field of occlusion as another technology example critical to the further development of AR/MR based technologies. As VR, AR and MR hardware converge together, this will greatly benefit the immersive technology ecosystem.

In conclusion, innovation in AR/MR/VR applications should be considered for investment in the coming years as they will play an important role in defining the way we live, work and play in the future. Singapore should proactively look at studying the evolving market demands in key sectors (e.g. Retail, Logistics, Build Environment, and Media Entertainment) and assess available resources to re-evaluate optimal technologies to invest in.

5.5 Supporting technologies to invest in

Apart from the core IMAI technologies, it is also crucial to invest in and develop a strong layer of supporting technologies and infrastructures to ensure the growth and proliferation of IMAI technologies. In particular, communications technologies such as 4k/8k displays and 5G mobile networks have been identified as potentially critical elements for the future success of IMAI technologies:

a) **4k/8k displays**: This refers to the underlying infrastructure (e.g. 4k/8k ready TV's, set top units, broadcast / transmission spectrum, etc.) to support delivery of 4k/8k content. High display resolution allows for higher graphical fidelity, thus facilitating enhancements in the creation and visualisation of IMAI contents. This could potentially further drive the adoption of IMAI technologies amongst mass consumers.

b) **5G mobile networks**: This refers to the communications infrastructure to support delivery of higher quality IMAI content which typically have larger file sizes. While this is not a concern for contents that are installed on the devices, it may create performance issues when real-time streaming. Advanced 5G mobile networks can improve connectivity and latency, becoming increasingly important for the lag-free streaming of the high quality IMAI contents.

There are other supporting technologies which have been identified as key to the growth and development of IMAI (e.g. optimised data storage/access to cope with increasing sizes of IMAI content, GPU accelerated computing to improve rendering of complex graphics/visuals). Similar to IMAI technologies, these will be re-evaluated in due course to assess its potential for investment.

In summary, the 5 recommendations above can be illustrated as follows:

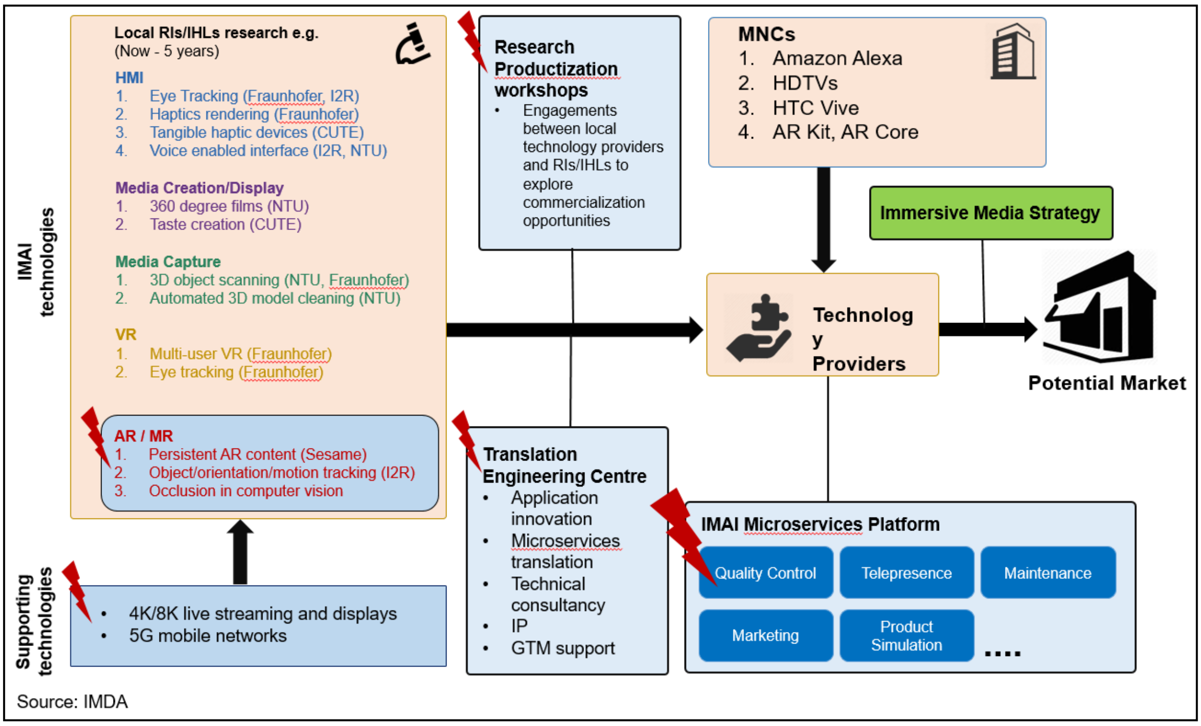


Exhibit 30: Overview of Recommendations

6 SUMMARY

IMAI has the potential to usher in the next big wave of innovations for consumer engagement, business productivity and quality of life. IMAI devices such as VR headsets are improving constantly in terms of visual quality, ergonomics and price point, resulting in increased traction amongst mass consumers and enterprises. Furthermore, supporting technologies such as 4k/8k live streaming and displays and 5G mobile network are developing in tandem with IMAI to support the growing demand. The increasing pervasiveness of IMAI in our everyday lives are corroborated by data gathered on the potential market for IMAI, which projects total global market spending of ~USD$237.8 billion by 2022.

This growing demand for IMAI products and services has spurred the growth of technology providers and research organisations which are venturing into this space. Enterprises and start-ups (e.g. unicorns such as Magic Leap and Improbable) are creating new IMAI solutions that re-define how we interact with and view content. Companies in traditional sectors (e.g. games, advertising, and film) are also exploring new business models and opportunities in leveraging on IMAI to augment their existing businesses. On the R&D front, numerous local research institutes (e.g. Fraunhofer Singapore, Keio-NUS CUTE Centre, A*Star) are actively conducting research into emerging areas of IMAI.

However, there are challenges for the continued growth and development of the IMAI sector in Singapore. For example, more alignment is needed between the enterprises and the research organisations in terms of productising the local R&D works done in IMAI. This will help to address unfulfilled potential in creating new applications and solutions for the market. In addition, many of the products and services offered by our local enterprises are developed in silos and are not interoperable with each other. This lack of integration hinders the creation of a unified, seamless experience for users. At a wider level, the underlying infrastructure to boost the adoption of IMAI (e.g. 4k/8k live streaming and displays, 5G mobile networks) is still in the infant stage in Singapore.

To overcome these hurdles and lay the groundwork for future success of IMAI in Singapore, the following recommendations are proposed:

a) To harmonise the disparate experience enablers offered by our local tech providers, an **IMAI Microservices Platform** could be created to integrate these into a holistic offering for consumers and enterprises.

b) An **IMAI Translation Engineering Centre (TEC)** could be set up, to offer engineering capabilities to translate promising research outcomes into high growth product. This will accelerate the commercialisation of new IMAI products and services for the market.

c) To bridge the gap in enterprises' awareness of the R&D work done by local research organisations, **Research productisation workshops** could be conducted to create more visibility and increase the opportunities for collaboration and co-creation of IMAI solutions.

d) To prioritise investments in **'IMAI Technologies'** which drive Augmented Reality (AR), Virtual Reality (VR) and Mixed Reality (MR) applications e.g. Computer Vision and Human-Machine Interaction, so as to leverage growth potential in sectors utilising IMAI such as Retail, Logistics, Build Environment and Media Entertainment.

e) Singapore should also invest in related **'Key Supporting Technologies'**, in particular communications technologies such as 4k/8k displays and 5G mobile networks, to enable Singapore to lead the proliferation of IMAI technologies.

APPENDIX A: GLOSSARY

TECHNOLOGY	GLOSSARY
4K	4K resolution, also called 4K, refers to a horizontal display resolution of approximately 4,000 pixels. There are several different 4K resolutions commonly used in the fields of digital television and digital cinematography. In television and consumer media, 3840×2160 (4K UHD) is the dominant 4K standard.
8K	8K resolution refers to any screen or display with around 8000 pixels width. 8K UHD is the current highest ultra-high definition television (UHDTV) resolution in digital television and digital cinematography. 8K in 8K UHD refers to the horizontal resolution of 7,680 pixels, forming the total image dimensions of (7680×4320), also known as 4320p, which refers to the vertical resolution.
360-degree Videos	360-degree videos', also known as immersive videos or spherical videos, are video recordings where a view in every direction is recorded at the same time, shot using an omnidirectional camera or a collection of cameras.
3D Audio	3-D audio usually implies the perception of point sources in 3-D space (could also be 2-D plane) whether the audio reproduction is accomplished with loudspeakers or headphones.
Augmented Reality (AR)	AR overlays digital information on real-world elements. Augmented reality keeps the real world central but enhances it with other digital details, layering new strata of perception, and supplementing your reality or environment.
Biometrics	Biometrics is the measurement and statistical analysis of people's unique physical and behavioral characteristics. The technology is mainly used for identification and access control, or for identifying individuals who are under surveillance. The basic premise of biometric authentication is that every person can be accurately identified by his or her intrinsic physical or behavioral traits.
Haptics	Haptics (pronounced HAP-tiks) is the science of applying touch (tactile) sensation and control to interaction with computer applications.
Media Capture	Media Capture is defined as technologies capable of digitally encoding non-digital information. This does not include the encoding of human input.
Media Display/Creation	Media Creation or Display is defined as technologies that produce output that can be understood and processed by human senses. By default, these technologies do not require human input to function but they can incorporate them if designed to do so.

Mixed Reality (MR)	MR brings together real world and digital elements. In mixed reality, you interact with and manipulate both physical and virtual items and environments, using next-generation sensing and imaging technologies. Mixed Reality allows you to see and immerse yourself in the world around you even as you interact with a virtual environment using your own hands – all without ever removing your headset. It provides the ability to have one foot (or hand) in the real world, and the other in an imaginary place, breaking down basic concepts between real and imaginary, offering an experience that can change the way you game and work today.
Photogrammetry	Photogrammetry is the science of making measurements from photographs, especially for recovering the exact positions of surface points. Photogrammetry is as old as modern photography, dating to the mid-19th century and in the simplest example, the distance between two points that lie on a plane parallel to the photographic image plane, can be determined by measuring their distance on the image, if the scale (s) of the image is known.
Simultaneous Localisation and Mapping (SLAM)	Simultaneous localisation and mapping (SLAM) is the computational problem of constructing or updating a map of an unknown environment while simultaneously keeping track of an agent's location within it.
Smartglasses	A pair of glasses that contain computer technology so that, for example, they can be used in a similar way to a smartphone, or you can get information added to what you are seeing as you look through them.
Smartwatch	A smartwatch is a digital watch that provides many other features besides timekeeping. Modern smartwatches include several apps, similar to apps for smartphones and tablets.
Smartphone	A smartphone is a cellular telephone with an integrated computer and other features not originally associated with telephones, such as an operating system, web browsing and the ability to run software applications.
Spatial Audio	Spatial audio is broader than 3D audio, more inclusive in scope and includes the possibility of environmental sound, multi-loudspeaker systems, etc.
Speech Recognition	Speech recognition is the ability of a machine or program to identify words and phrases in spoken language and convert them to a machine-readable format.
Virtual Reality (VR)	VR is fully immersive and it tricks your senses into thinking you are in a different environment or world apart from the real world. Using a head-mounted display (HMD) or headset, you will experience a computer-generated world of imagery and sounds in which you can manipulate objects and move around using haptic controllers while tethered to a console or PC.

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APPENDIX C: WORKGROUP MEMBERS

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Mr. Glen Francis (Co-Chairman of Workgroup 2)	Chief Technology Officer, Singapore Press Holdings
Mr. Leong Yong Shin	Senior Development Engineer, Advanced Remanufacturing and Technology Centre (ARTC), Agency for Science, Technology and Research (A*STAR)
Mr. Sridhar Sunkad	Managing Director, EON Reality Singapore
Mr. Roy Koo	Founder, Ignite VR
Mr. Seow Kwan Heng	Pre-Sales Specialist, Lenovo Singapore
Mr Parminder Singh	CCDO, Mediacorp Campus
Mr. Richard Koh	Chief Technology Officer, Microsoft Operations Pte Ltd
Ms. Teo Chor Guan	Senior Research Fellow, Keio-NUS CUTE Centre, Smart Systems Institute
Mr. Barry Wong	Vice President, ST Electronics (Training & Simulation Systems) Pte. Ltd.
Mr. Ng Teow Koon	Founder, SideFX Studios Pte. Ltd.
Mr. Wilson Ang	Director, Business Development – DSLC, Infocomm Media Development Authority
Ms. Keh Li Ling	Director, Media Industry Development, Infocomm Media Development Authority

Mr. Adrian Chue	Deputy Director, Media Industry Development, Infocomm Media Development Authority
Mr. Chua Chee Cheng	Senior Manager, Digital Services Lab, Infocomm Media Development Authority
Mr. Jeffrey Lim	Manager, Media Industry Development, Infocomm Media Development Authority
Mr. Christopher Weidya	Assistant Manager, Intelligent Computing Labs, Infocomm Media Development Authority