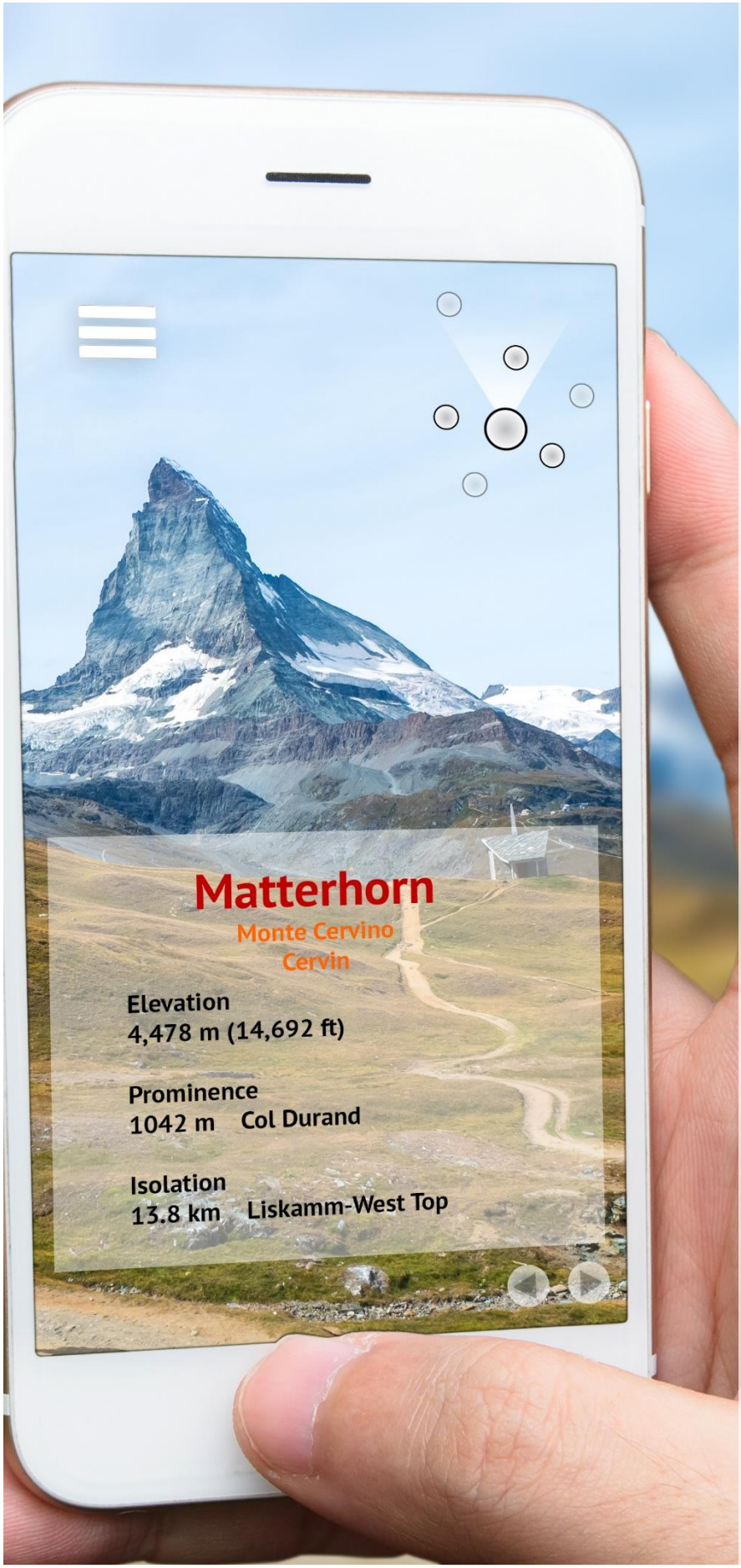

Routes to Market Report

15 - Satellite Technologies for Gaming, Augmented Reality and Simulation

Innovate UK

CATAPULT Satellite Applications

Contents

1. Introduction and Scope

This briefing looks at the potential for Augmented and Mixed Reality Games to be enhanced by satellite data and technology.

The space technologies of relevance to the opportunities described herein include Earth Observation, Satellite Communications and GNSS.

The market described is global and largely focused on populated areas.

An initial piece of research was conducted into the broader games market (including console, PC and mobile games categories, including Virtual Reality) but since we concluded that the major opportunities are in Augmented and Mixed Reality Games, these other games categories are not included here in any detail. We touch on the wider markets that will be opened up by Augmented and Mixed Reality hardware, but the focus primarily on Augmented and Mixed Reality Games, unless otherwise indicated.

The market period the briefing covers is from 2016 to 2025.

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2. Market Overview and Opportunities

2.1. Augmented and Mixed Reality

Augmented Reality ("AR") places digital content on top of the real world by adding graphics onto a display such as a smartphone or a headset that sits between the user and the world. Mixed Reality ("MR") does the same but importantly uses spatial mapping techniques such as infrared and motion tracking to profile a space and allow digital content to sense and interact with the real world. Sometimes portrayed as the next computing platform, some analysts project that dedicated AR/MR devices such as Hololens, Meta2 or Magic Leap could even displace smartphones by the mid-2020s, but this looks optimistic given the current pace of development. For a lengthier introduction to AR/MR, see the Economist article: The Promise of Augmented Reality.

Augmented and Mixed Reality games

AR and MR games layer graphics such as animation, gameplay challenges, metagame data (score, social context et al) that relate to their location onto the world. The technology used to interpret the environment and display digital content varies widely depending on what is available to the user.

AR limitations and impact

The most and, effectively, only materially successful AR game is Pokemon GO which uses forward-facing smartphone cameras to show a user's current view, superimposing digital content based on the smartphone's GPS coordinates and direction its camera is pointing. AR faces to 2 problems. Firstly, the accuracy of GPS is typically not sufficiently high to stop digital content from overlaying (i.e. occluding) a lot of the real world displayed. So, a Pokemon could well sit in mid-air half inside and half outside a building's exterior. Secondly, currently AR games do not access any databases that define where buildings and objects exist as coordinates. Thirdly, although some such databases do exist their resolution is typically between 1-5m and coverage is far from complete. Most AR Games use either no additional sensing, because almost no smartphones have spatial mapping sensors yet, and a small number use camera-based image recognition which requires hand-coding of specific environments

(thus hard to scale). Combined, this lack of accuracy restricts gameplay significantly, ruling out most of the gameplay that you get from Pokemon games on other games platforms.

MR technology

MR is differentiated by using a range of different spatial mapping techniques and sensors to map the actual, but highly localised, real world in three dimensions. They range from relatively unsophisticated techniques like merging GPS data with head tracking via gyroscopes (Vuzix and Sony's Smarteyeglass) to more sophisticated 3D cameras and inertial motion sensors that deliver real-time depth perception using image differentiation algorithms (Google's Tango and possibly Meta) or infrared sensors to map and store the immediate locale in 3 dimensions in real time (Microsoft's HoloLens). The more accurate the spatial mapping, the greater the immersion and 'realism' experienced by the user. All the above MR technologies are head mounted displays apart from Tango, which is smartphone-based.

MR limitations and impact

All the MR devices currently suffer from range problems. Tango is currently limited to a maximum range of 4m. HoloLens content has a similar maximum range as Tango plus graphics can grow ghostly then disappear when you get too close (under 1m). Remembering locations may assist for future use, but an area will have to be scanned again by the user/wearer to account for any changes. Anything further from camera – almost everything outside – will either need to be mapped by hand, stored and re-used with potential for errors if something has changed, fudged or avoided in interactions. Lighting too can be problematic for some systems like Tango. The impact of MR technology's limitations is that the range of MR games could stay highly localised to a patchwork of small-scale environments centred on the user, which 'break' when you move to too large an environment. Like AR, outdoor MR games must await more accurate x/y/z coordinates from GPS which although planned (Galileo and others) apparently remains well above the sub-10cm range that would prove useful. Currently, MR games do not display any real-world data (such as weather, traffic etc.) due to the data source being highly localised to their sensors.

2.2. Satellite opportunities

The following opportunities that could be open to satellite data are reliant on increasing a user's location accuracy to sub-10cm ranges. GNSS accuracy is increasing and with chips installed in most mobile devices, this will increase in resolution over time without intervention or additional investment. The wider market for AR/MR is projected to grow very rapidly indeed by multiple analysts (see 7. Revenue Projections) and for both of these opportunities, gaming represents a subset of a greater market with commercial potential for satellite companies choosing to invest early. However, gaming is the first mover in AR that has triggered significant investment by the world's largest technology companies. Games always test the boundaries of a new technology, often spearhead the commercialisation of new technology and typically are exciting enough to be the poster child for the most compelling new consumer applications.

Permanent structure scanning

A solution delivering centimetre-accurate coordinates in three dimensions of permanent structures would be a significant step forward to enabling pervasive AR and MR outdoors, with gaming being just one of many potential use cases. Whether this is an opportunity for satellites is speculative but appears to be an EO opportunity, either using existing stereo satellite imagery to extrapolate 3D structures and coordinates or perhaps new cubesats fitted with sensors with the appropriate sensitivity. These small satellites could use cameras (possibly light field or other 3D cameras) or infrared sensors, after which the data could be processed and sold to 3rd parties. An American 3D map project, accurate to between 1-5m, has been working to increased resolution and coverage across a greater area of the US, and is thought to use a mix of data from light detection and ranging (lidar) and interferometric synthetic aperture radar (ifsar) data from aircraft with satellite data and

data from other sources. Ordnance Survey is creating a similar 3D map but how accurate it will be, its cost, and its timing is not clear. Google has used Tango to map buildings through a highly manual process, such as that required to deliver Streetview. British 3D mapping company eeGeo has metre-level accuracy outside and 3D rendering capability on any device (probably using the EO technique above) but to scale down to the sub-10cm accuracy required may need additional data. Further investigation is needed to understand eeGeo's coverage, availability and potential for partnership. It is understood that SAC has used optical imagery and a digital terrain model to produce a 3D image of an open cast mine in Chile, but the goal is to make the process less manual and more automated, which eeGeo's procedural 3D map generation appears to have achieved.

Solution elements:
This analyst's estimated requirements for such a system would include satellite (possibly cube sat constellations) mounted with 3D scanning sensors flying over populated areas, high capacity data feeds to ground processing facilities, 3D image processing and positioning algorithms which procedurally generate high resolution 3D maps of environments that are then available for sale as a service to customers as a medium-high value service (estimated contract values of between $50,000-$500,000 depending on coverage and update frequency)

Time frame: 2-5 years, depending on the resolution of the cameras or sensors.

Strength of opportunity:
Medium. The availability of other solutions reduces the opportunity strength, but static object coordinates for population centres will have a market and involve irregular or one-off data purchase by a wide range of companies, amongst which gaming is assumed to be a small part.

Games partners: Google, Microsoft, Magic Leap, Oculus

Temporary or moving object scanning

The 3D scanning of outdoor environments for coordinates of temporary and moving objects with the above centimetre accuracy in real-time or near-real-time could represent a vital step in the progression of AR/MR that's sought by many global companies such as Google and Microsoft, who have made significant investments in AR/MR. However, the technical challenge will be very significant. I assume it would require massively parallel image recognition for even a small area with prodigious computing capability and would require deep and seamless integration with multiple different local data sources (such as 5G and the Internet of Things) to deliver viable solutions in remotely real-time. This medium-term opportunity is probably one in which other companies will be investing in already, but only a few of which will be from games, which could be one of the first consumer-driven MR applications. The availability of this data would represent an explosion of information on our real-world environments and would have a huge range of potential applications from commerce[1] (personalised promotions accurately augmenting store frontage), insurance[2] (metadata superimposed on buildings being assessed for cover or risk warnings on construction sites), transport[3] (incoming/outbound train/bus data for consumers), security[4] (real-time crowd movement data and instructions for police forces), military[5] (real-time threat assessment and environment data in combat

[1] See eMarket Services 2012 report on AR in ecommerce http://www.emarketservices.com/clubs/ems/prod/E-Business%20Issue%20-Augmented%20reality%20for%20eCommerce.pdf
[2] See http://blog.adsensa.com/how-is-augmented-reality-going-to-change-the-insurance-industry amongst many others
[3] See Appearition article on AR/MR in transport https://www.appearition.com/industryar-augmented-reality-transport-improving-daily-life/
[4] See FBI article on AR/MR's impact on security https://www.fbi.gov/file-repository/stats-services-publications-police-augmented-reality-technology-pdf/view
[5] See article on ODG's roots in military AR/MR http://www.forbes.com/sites/aarontilley/2016/12/01/military-tech-company-odg-raises-58-million-to-grow-its-augmented-reality-business/#140d79ce557c

areas), public sector[6] (real-time flood threat assessment and management, or accident site enhancement for emergency services), advertising[7] (interactive billboards with purchasing or vouchers), with concomitant requirements for legislation to protect privacy as the resolution gets down to human level detection.

Solution elements:
As above Opportunity A but requires real-time data processing and low-latency feeds (possibly via a data processing intermediary) to platforms or direct to devices (as they become more powerful in parallel with rising mobile bandwidth) sold as an always-on high value service to customers (estimated contract values of between $50,000-$5,000,000 per month depending on coverage).

Time frame: 4-10 years, depending on how real-time the data gathering, processing and provision becomes.

Strength of opportunity:
Strong commercially (ongoing data provision contracts with games and many more industries could be a multi-billion dollar industry) but long term, since this capability is not available yet, and with the downside that the less real-time the data, the less valuable it becomes in this context.

Partners: Google, Microsoft, Magic Leap, Oculus

Minor opportunities

- **Sale of other satellite data:** AR/MR games played in real-world environments might be enhanced with real world data such as weather to add realism (e.g. lighting, wind, rain) and gameplay (e.g. wet/dry/snow-covered Pokemons). This is believed to be a nice-to-have, as opposed to a core requirement for the AR/MR games market, which could mean a long sales cycle with low returns and low pricing. Almost all other games categories (console, PC, mobile) take place in virtual game worlds which are entirely under the developer's control (day/night cycles, weather effects, geography, car/foot traffic levels and so on) which means that at best A small handful of games make cursory use of real world geography and data (from free sources but at relatively low resolution[8]), and usually no use at all. We do not see any market demand for more accurate satellite data from the main games categories. For a tiny sub-category (rail/flight/fishing simulation games which provide ultra-realistic simulations) dominated by a British games company (Dovetail Games), satellite data could add weather, road and water traffic, wind speed and so on. Hence, we suggest it's a target of opportunity only.

- **Business model education:** The games industry has pioneered the use of new digital business models, particularly in Asia, producing a $60bn global market from games that are 'free' to play. A very wide range of commercial techniques whereby consumers access free product (often costing developers millions to tens of millions of dollars to develop) then pay to upgrade may be of educational value to the Space sector.

2.3. Online games delivery models

The games industry's long migration to online delivery and service provision started in the late 1990s and is still in progress. Games companies have developed sophisticated technology to deliver high

[6] See Deloitte paper on Augmented Government 2013 https://www2.deloitte.com/us/en/pages/public-sector/articles/augmented-government.html
[7] See VE Interactive's article on AR advertising https://www.veinteractive.com/blog/is-augmented-reality-the-future-of-interactive-advertising/
[8] Examples include The Division, the Watch Dogs series and the thinly disguised real world locations found in the Grand Theft Auto series

quality content to clients and consumers on a wide range of devices, which could be repurposed to assist the satellite industry in migrating from massive data downloads towards the more efficient and localised delivery of data to clients and consumers.

3. Customer or End-User

3.1. Customer

The customers for both opportunities are global companies delivering AR and MR games hardware and software. Not listed here are companies investing in AR but without released product details such as Samsung (light field technology for AR), Qualcomm (processors for AR in smartphones) and Intel (processors and potentially headsets):

- **Microsoft (HoloLens)**: Microsoft fast followed Google into the AR headset space with a much more powerful device, a wearable windows PC requiring no tether that projects graphics onto a visor using waveguide. HoloLens is a powerful solution built using games technology (a motion sensing system for Xbox called Kinect, since retired) that features spatial mapping (using infrared sensors), motion tracking (accelerometers), visual tracking (cameras that sense movement including gestures) and speech recognition (user configurable commands and system level commands via Cortana). Developers can access a development suite which supports Unity and Visual Studio, and the technology is highly malleable or trainable for users. HoloLens's battery life is 2.5-3 hours with intensive use. It is currently priced at $3,000, and is being sold to enterprises (architects, engineers, doctors and so on) not to consumers. Its origins ensured that some games have been developed, some via a small number of third parties, but its processing power and memory restrictions currently mean games are relatively basic compared to state of the art console titles. HoloLens uses a dual display system which enforces a minimum range (holograms will not appear closer than 1m). Consumer versions are planned for much lower cost but they will be tethered to mid-power PCs. Whether untethered HoloLens devices targeting consumers at consumer-friendly pricing will be released soon is currently unknown, but Moore's Law should work favourably and rapidly to bring more powerful untethered devices within range of consumers within 3 years. **Knowledge of Space sector**: Microsoft utilises EO and GNSS for a range of mapping services but whether teams working on MR have connected with mapping teams in such a huge company is unknown. Their ambitions for HoloLens as a consumer gaming device are medium-term, but for enterprise they are actively investing which makes them a strong potential partner.

- **Google (Tango)**: Although Google canned its Glass device following multiple failures, it is still heavily investing in AR and MR. Tango is an open-source initiative to bring MR to Android devices by means of a sensor array and image processing software built into powerful new phones. The platform consists of motion tracking (accelerometer-based inertial motion sensors combined with image difference tracking algorithms), area learning (location memory and drift correction) and depth-sensing (3D cameras and infrared sensors plus markerless augmented reality[9]). Area data is thought to be being gathered by Google for future use for advertising and commerce. Developers can use C, Java and Unity (very popular development tools and/or game engines), a freely available UX framework and community support to develop software, and a small but active group of developers, some funded by Google, are working on applications, a small subset of which are games. Currently lacking any kind of

[9] Markerless AR refers to an earlier technology called marker-based AR which used hand-made reference images to ascertain the exact position of objects in a 3D space, which would then be augmented with data. Markerless AR, sometimes called "dead reckoning", uses cameras, sensors and algorithms to map objects and local environments in real-time without reference images,

headset (although it is compatible with some high-end VR headsets), it is not yet known whether Tango will be integrated into a headset by Google, whether Google's daydream VR headset will support video pass-through AR (where a VR headset shows you what's in front of you by a camera, superimposing graphics on the screen), or whether Glass will re-emerge (now called Project Aura). There is an outside chance that Google will relaunch its Glass AR system but no announcements have been made. **Knowledge of Space sector**: Google has deep experience in mapping, as well as machine learning/AI, machine vision and to some extent games. Google has demoed Tango being used to map inside and outside spaces so there is a clear ambition to overlay data on all the world, which makes them a good potential partner.

- **Magic Leap**: Magic Leap is a technology start-up that has received over $1.4bn in funding from Google and some of the world's biggest venture capital companies. It has yet to produce a consumer product and while it does do demos to interested companies, its NDAs are so severe that no-one has yet leaked information on precisely how it works. Patent applications suggest that it employs light field technologies similar to those found in 3D cameras such as a Lytro to project graphics directly onto the eyeball. How it undertakes spatial mapping, motion detection, area learning, gesture controls and so on is unknown, but all are suggested to be supported. Analysts have hinted that the headset technology is currently tethered to a PC but it has said it aims to be untethered, will be able to handle well-lit environments and has released a number of frankly astonishing videos including outdoor MR at a distance. The company has come under fire for hyping the opportunity and the company has responded that it has taken longer to develop solutions than planned. Some analysts think a consumer release is possible in 2017, others not for 1-3 years. Patent applications also show a longer term ambition to build MR contact lenses. Games are one of the first areas Magic leap is focusing on, and it has been actively recruiting developers and studios in ways that suggest a consumer device and not an enterprise device will be unveiled for launch. **Knowledge of Space sector**: Unknown.

- **Oculus**: Facebook acquired the virtual reality headset manufacturer Oculus in 2014 for $2bn, and since then the device has been developing relatively quickly into one of the market leaders in VR, with 2.7m headsets in the market[10]. VR is quite distinct from AR/MR but Oculus acquired a British spatial mapping company called Surreal in 2016 which maps the real 3D world into the digital world using image recognition. Although Oculus has not yet announced any uses for the technology, it signals an intention to bring VR closer to the real world. Facebook announced[11] in 2016 that it was working on merging virtual and augmented reality into "normal looking glasses" over the next 10 years. **Knowledge of Space sector**: Unknown, probably minimal so far.

- **Apple**: Apple has announced[12] it is "high on AR for the long run… great things for consumers and a great commercial opportunity… it will be huge", acquired an AR pioneer (Metaio in 2015) but has not announced any devices, nor will it leak anything until they are shortly to be available for purchase. **Knowledge of Space sector**: High. Apple Maps uses EO imagery for route planning and other applications, so their knowledge of today's satellite data capability will be high.

- **Meta**: Meta is a VC-backed American MR headset manufacturer which has live product in the market (priced at around $1,000) targeting enterprise clients. Its technology is under wraps

[10] Source: Superdata Dec 2016 This figure includes 355,000 of its proprietary Oculus Rift headset and 2.3m Samsung Gear VR, which is powered by Oculus.
[11] http://www.theverge.com/2016/4/12/11415366/mark-zuckerberg-facebook-f8-virtual-augmented-reality-glasses
[12] http://www.theverge.com/2016/7/26/12290920/apple-augmented-reality-ar-tim-cook

but comprises a tethered MR visor featuring spatial mapping, depth perception and naturalistic gesture recognition (all using cameras). It has a small developer base, and no games as yet developed beyond simple demos. **Knowledge of Space sector**: Unknown, probably minimal.

- **ODG**: Another AR visor company which has until now specialised in military applications (and sold some technology IP to Microsoft), ODG announced 2 products for release in 2017, the R9 for enterprise ($1,800) and the R8 for consumers ($1,000), both of which use light field technology to project images onto glasses. Spatial mapping is an optional extra for the R8 (which keeps the form factor small) so its use as a games device will be limited, despite ODG having a more entertainment focused strategy, working with OTOY's Vuforia AR platform (which has licensed films). No games partners have so far been announced. **Knowledge of Space sector**: Unknown.

- **eeGeo**: eeGeo is a British 3D mapping company founded by games developers and built using games technology (Unity). It processes a variety of data including EO imagery and Ordnance Survey data to process and deliver 3D maps of the world, all procedurally generated and rendered as malleable digital objects with what it describes as semantic geometry. Its accuracy is based on source data, which is accurate to around a metre, which suggests that eeGeo's procedural 3D mapping technology could be enhanced with more accurate static and near/actual real-time moving object data of many kinds. eeGeo also provide a route to market including customers such as Qualcomm, IBM, Tencent and mapping companies. **Knowledge of Space sector**: High. eeGeo processes EO imagery so their knowledge will be high.

3.2. End users

The end-user for the services will be consumers playing games on their AR and MR devices. The consumer profile of the end user will vary very widely depending on the type of game played but the classic early adopters will be young adults, skewing male, playing action, roleplaying and sports games. If MR hardware is not pigeon-holed as Glass was but instead sees the same adoption curve as mobile games, the young males will be followed fairly swiftly by middle aged females playing social and casual games, before braking into true mass market status – all of these dependent on 'killer apps' – games with massive consumer appeal.

4. Value Proposition to Customer or End-User

4.1. Permanent structure scanning

Customer: MR device manufacturer customers would purchase a database of building and other permanent structure coordinates in 3D enabling them to pinpoint their users' locations within a 3D environment outside. This database will enable a range of benefits:

- **Outdoor MR**: The primary benefit of permanent structure scanning is that MR applications including games, currently limited to small-scale indoor environments up to 4m from the user, will be accessible and viable outdoors, although applications will fudge many if not all moving objects.

- **MR realism**: Increased accuracy of MR applications will stop digital content from overlapping real-world objects in unrealistic ways (as currently available in AR games such as Pokemon GO). This raises the bar for visual fidelity to allow for a range of new functionality such as being able to accurately overlay digital content onto the side of a building without it looking clunky.

This new level of realism will be broken by passers-by and moving objects, which will need to overcome in application design.

- **Gameplay opportunities**: A significant increase in the types of gameplay that developers can create. Currently they can slap graphics over the real-world using cameras but they are crude and cannot utilise their environments at all. With permanent structure coordinates in 3D, games can be set around objects, which releases a huge diversity of gameplay and interaction types to developers.

- **MR device power**: Availability of cloud-based historic data on 3D coordinates of permanent structures in fine detail could reduce the need to utilise the resource and battery-intensive real-time spatial mapping functionality built into devices for big objects already mapped, resulting in longer battery life or, more likely, focus on processing more realistic or exciting graphics.

End-user: End users will get more realistic MR experiences that knit more pervasively with the real world outside and in. The gameplay will become dramatically more diverse, closer to that available on other games devices, and quite possibly better quality from devices that last longer and can deliver better graphics.

4.2. Moving object scanning

Customer: MR device manufacturer customers would purchase a live stream of temporary or moving object coordinates in 3D enabling them to pinpoint their users' locations within a richer 3D environment outside. This stream will enable a range of benefits, in addition to opportunity A's benefits above:

- **Outdoor MR**: Real-time moving object data will enhance opportunity A's ability to play MR apps and games outdoors at or closer to ground-level including moving objects.

- **MR realism**: Realism for MR games will go up a notch with larger moving objects included in the field of play.

- **Gameplay opportunities**: Moving objects will further increase the diversity of gameplay and interaction types to developers and players, reducing the need for fudging of objects that cannot be tracked.

- **MR device power**: This should bring another level of power and resource-saving by preparing devices to render moving objects in 3D, or actually rendering them in the cloud then providing them as a stream.

End-user: End users will get richer, more realistic MR experiences, wider gameplay, on better devices.

5. Market Competitiveness and Alternatives

The alternatives to both opportunities described above appear to be:

- **3D world processing**: The (US) National Map, eeGeo, Ordnance Survey and possibly other providers (more research is required to ascertain this) appear to either have this data at 1-5m resolution scales or, like Google Tango, be moving slowly towards acquiring it at sub 10-cm resolution. eeGeo's capability needs more investigation but it could provide cost-effective but less accurate competition to a satellite-based Opportunity A. eeGeo has mature technology,

market access, is well-funded and has global coverage but lacks the requisite resolution and data sources for either Opportunity, which suggests there is a clear partnership opportunity with eeGeo. For both Opportunities, a satellite-based solution could be a more thorough, wider-scale and potentially cost-effective way to gather this data.

- **Local mast scanning**: Dedicated 3D camera or infrared sensor scanning of environments, while possible, is a capital expenditure-intensive route to this data. Ordnance Survey have announced[13] a major public/private funded 3D mapping project for UK that will provide a digital replica of the UK. No information on resolution levels has been released, and an initial trial in a single city suggests that this is likely to be highly resource intensive, slow and time-consuming, as well as UK only. There is the potential for smaller IoT devices to deliver some data, but it can only be partial, unless they are dedicated to the task, as above. A quality satellite-based solution should easily leap-frog local scanning in cost, efficiency and coverage, but the short life spans of small satellites may limit that competitive advantage to the medium term, given that a local mast can have a productive life measured in years not months, and can be upgraded more easily.

- **Drone scanning**: The use of drones or long-flight aircraft to provide platforms for scanning services appears to be a major competitor to satellite data. This could provide alternative solutions to both Opportunities which are both increasingly cost-effective and faster to implement and upgrade with new technologies. Lower flying drones may provide a better platform for 3D cameras than cube satellites for closer proximity to scanning targets. As drones are developed, they can stay in the air longer and could provide real-time scanning data. However, restricted use of airspace over heavily populated areas is assumed to be a continued barrier, with some drone companies receiving record fines for unauthorised flights.

- **Device scanning**: Google Tango's building scan project is not yet a formal plan to map the world in 3D, only a by-product of some early-stage use cases for Tango. Tango or HoloLens's mapping by individual device will be highly detailed but have the same cost, efficiency and time downsides as the OS project, but with the challenge of needing to go global. Tango's and HoloLens's ability to scan moving objects in real-time is not clear but their capability to map objects at greater distance will only increase with time. Both satellite opportunities may allow Tango and/or HoloLens to quickly in-fill the significant gaps in their data more efficiently than device scanning alone.

6. Role of UK companies

The UK is home to globally-important industry clusters in the Space industry, the games industry and image recognition research and most of the major global AR/MR technology companies.

6.1. AR/MR:

Although no major UK-owned companies are making AR/MR devices or platforms, Google, Microsoft and Facebook have large, sometimes growing (Google) UK facilities. Of these, Microsoft has UK-based AR/MR talent since Kinect, one technology on which HoloLens is based, was developed here. The core AR/MR hardware and software platform are being developed in the US, but partners being actively sought from UK technology companies, especially games (who are winning development funding for these companies' VR/AR/MR hardware).

[13] https://www.ordnancesurvey.co.uk/about/news/2016/uk-leading-way-5g-future.html

6.2. Image recognition:

If Opportunity A is tackled by machine vision using existing high resolution EO images, then the UK has a good track record of research and commercialisation of new techniques from universities to companies. Groups and companies include Oxford's Visual Geometry Group, Digitalglobe, Orbital Insights, Descartes Lab, RS Metrics and Vinesight. One of the most appropriate UK companies could be an AR game developer with proprietary image recognition technology. Gamar's proprietary image recognition software runs in real-time on smartphones and can map 3D environments very accurately. Gamar was founded by an image processing expert with experience in satellite image processing, so should be a good candidate for partnership discussions.

6.3. Space:

The Satellite Applications Catapult has clearly demonstrated the UK's capability in terms of companies manufacturing satellite technology and providing data services for EO, secure GNSS and Satellite Comms. This combines with the Government's willingness to invest in the sector and the Satellite Applications Catapult's initiatives to bring new investment into the British Space sector to provide a strong foundation for innovation in partnership with games and AR/MR companies. The envisaged roles, in which fields the UK has strong capability, are as follows:

- **Instrument manufacture**: 3D scanning sensors or cameras capable of delivering sub-10cm accurate scans from orbit may need to be developed if existing satellite imagery is not sufficient.

- **Satellite manufacture**: The above sensors would need to be mounted on satellites that could include constellations of small satellites (e.g. from SSTL or Clyde Space).

- **Data processing and provision**: Either existing EO imagery or data from the above new sensors on new satellites will need to be processed procedurally into high-resolution 3D objects, segmented according to client demand then made available as close to real-time as possible to clients on a 'Software as a Service' platform. British 3D mapping company eeGeo already has such a procedural 3D map generation platform and clients, but currently delivers a lower level of accuracy, which makes them a good partnership candidate.

6.4. Games:

The UK games development and technology sector is one of the world's largest games clusters, the 5th-6th largest producer of games by revenue globally depending on the year. With over 1,000 development companies, 12,000 development staff and an economic impact of over £1.25 billion per annum, the UK's games companies are located nationwide across every games category, including some early Pioneers in AR/MR and geo-gaming. The main role in this opportunity is:

- **AR/MR games development:** A range of UK games companies could provide games that demonstrate the potential for high accuracy AR/MR games. 3-5 UK games studios with roughly 50 staff are working almost exclusively on AR/MR games today, but perhaps 50 studios with perhaps 750 developers are working part-time on the adjacent market of VR games, experience of which would be very pertinent in developing AR/MR games once the market matures. Potential partner candidates are Climax Studios (making AR/VR games for HoloLens and Tango), Gamar (making location-based games for museums and theme parks using a proprietary smartphone-based AR platform), Preliminal (that has developed a Unity plug-in that imports Open Street Map data into games requiring real world environments), New Moon Games and Starship (both dedicated AR/VR studios). Improbable is also worth a mention, since they have developed the capability to provide unsegmented virtual worlds for millions

of concurrent users, a cloud-based function AR/MR may need to replicate given data loads and potential numbers of concurrent AR/MR users.

7. Revenue Projections

	2016	2017	2018	2019	2020	2025
AR/MR total market (all sw / hw)	$1bn	$3bn	$10.5bn	$29bn	$57bn	$136bn
AR/MR (games sw only)	$800m	$944m	$2.4bn	$5.9bn	$10.4bn	$22.9bn

GIC is a games analyst firm that has produced market data for 14 years, conducting our own market surveys and benchmarking against other analysts' output where possible. AR/MR total market and AR/MR games software market data is a synthesis of 2016-2021 projections by 2 analyst groups, projecting out to 2030 using a declining scale. Digi-capital (a San Francisco-based analyst, advisor to major VCs that specialises in games and VR/AR/MR, whose projections are based on company and investor data) and Superdata (a New York based analyst group that specialises in games and entertainment media including VR/AR/MR, whose projections are based on company and consumer spending data). These companies' projections are relatively bullish, but all analysts see AR/MR market values rocketing over the next 5 years. IDC projects VR/AR/MR market value of $162bn by 2020, while ABI foresees $100bn. Goldman Sachs see AR/VR as the main driver of digital markets over the next decade, forecasting between 100 and 300 million head mounted display shipments by 2025. Gartner foresees 100m AR shoppers by 2020. The most bullish is Citi which predicts a trillion dollar market for AR/VR by 2035.

7.1. Opportunity projections

	2017	2018	2019	2020	2021	2025
Opportunity A	$0.8m	$0.9m	$2.2m	$9.7m	$13.6m	$21.4m

For Opportunity A I have estimated company revenues for static object 3D scanning at $750,000 this year, then used the same growth rate for the AR/MR markets above to project growth. The key assumption is that the opportunity is competitive from 2017, with companies such as eeGeo selling 3D scanning services, which can only grow as AR/MR device manufacturers and services see the need for broader coverage. The market doesn't grow faster than the AR/MR market because clients will probably be satisfied with irregular data drops, as opposed to live feeds. I note that the market value might start under games, but provide clients with functionality that will serve multiple other markets.

	2019	2020	2021	2022	2023	2025
Opportunity B	$5m	$12.5m	$21.9m	$36.1m	$55.9m	$110m

Opportunity B commences later (assuming there will be significant but soluble technical hurdles to overcome to deliver real-time 3D scanning data to devices without noticeable lag) but it grows much faster due to providing services for the much larger and wider market for AR/MR services (of which games is but a small proportion) that most analysts see developing in the coming decade. Real-time scanning of moving objects could power a substantial portion of this new and wider market for AR/MR in areas such as commerce, advertising, entertainment, navigation, enterprise, consumer (e.g.

scheduling, social networks) and other sectors, as well as Games. The market value rises more rapidly because this will consist of much more valuable live data feeds delivered to populated areas.

8. SWOT Analysis

This analysis relates to both Opportunities unless explicitly mentioned.

Strengths	– AR/MR is projected by many to be one of the fastest growing digital markets of the next 2 decades, reaching over $100bn by 2020 – The market is led by the world largest technology companies (Microsoft, Google, Facebook) or companies funded by them (Magic Leap), with Samsung, Apple and Intel claiming interest – To progress, the market needs highly accurate positioning, building and moving object data – Satellite data could represent a strong and ongoing solution – Revenue potential by selling to the above AR/MR platform providers is strong – At least 1 British company already leads in the area of 3d mapping, but lacks resolution that might be possible from satellite data – British strength in satellite technology is a competitive advantage – British strength in games development and technology is also world class (global top 5)
Weaknesses	– A lack of consumer devices with the right brand, price point, battery life, graphical performance and bundling – Many devices are tethered to PCs today – Consumer awareness is low due to device issues and lack of marketing – Market projections for VR/AR/MR vary widely and are still highly speculative – Inflexibility in business models and delivery mechanisms in Space sector
Opportunities	– Device issues above are being heavily invested in ($1bn in new investment in AR/MR head mounted displays in 2016 alone) and manufacturers hope to solve issues in 2018-2019 – Develop 3D scanning capability to deliver historic, near-real-time and real-time data on objects in populated areas – Develop a platform using the 'Software as a Service' model that can add a rich stream of data to other data streams already being aggregated by the world's largest technology companies – Sell high value services (historic 3D data on static objects) and very high value services (near/actual real-time 3D data) to a wide range of clients – Accurate 3D scans of environments will provide an explosion of data and opportunities for games as well as many other higher value applications – Games will be at the forefront of the AR/MR revolution and currently dominate revenues
Threats	– AR and particularly MR technology is highly novel, and despite bullish projections and a possible investment bubble, one real scenario is that consumers and then industry may see it as a fad, as uncool as Google Glass, limiting the opportunity to enterprise

	– There have been no mass-market MR games, due to the lack of devices, and whether traditionally sedentary or commuting gamers will adopt MR games en masse remains to be seen. No major games title owners have announced MR game plans. – The analyst is not a specialist in satellite technology and the opportunities identified herein are speculative and may not be exploitable by satellite technology, but instead smaller, faster, cheaper alternatives like drones. – Technical issues around imaging technology at a distance, 3D scan accuracy and data latency from satellite to ground processing to device may rule out some or all of these opportunities – The resolution of any scanning system to include passers-by is a long way off, which means the field of play is limited to vehicle or possible head height – Privacy and legislation – AR/MR providers' vision of profiling people and activity increases the potential for corporate or governmental intrusion and damage to privacy as well as the potential for crime. Legislation is inevitable to set reasonable limits on the availability, accessibility and accuracy of personal data in AR/MR. – Major technology companies will be investing in fixing this issue, which means other solutions will arise (drones possibly the strongest) – No/low understanding of games and SaaS business models in Space sector

9. Barriers and Enablers

9.1. Barriers

Disconnect between Space and Games sectors: The games industry has yet to identify a pressing need for satellite data, due to most games currently being only loosely, if at all, connected to real-world locations, geography and data. As a result, games companies have had almost no contact with the space industry. The advent of AR/MR games played outside should change that, whereupon games companies will either try to recreate limited-scale AR/MR environments by hand or local device, superimpose data from existing open data sources such as Google Maps or the US 3D Map project, or access solutions developed as a result of this briefing.

Inflexibility of current satellite data solutions: This analyst understands that currently satellite data and imagery is being sold at high price points and distributed as huge files covering large areas with permanent usage licences. The transition from this to cloud-based platforms capable of selling tiny chunks of data at far lower price points possibly using freemium business models or with timed rights expiry or other 'consumable' business models could be challenging. A solution would be the creation of new companies (or joint ventures) to exploit this opportunity. The Satellite Applications Catapult has informed the analyst of a start-up offering lower cost, more flexible EO imagery and satellite data, which is an indication of increasing flexibility amongst satellite data providers.

Vision: This report assumes that billions of dollars being invested in AR/MR will result in mass-market devices and multi-billion dollar markets with a huge range of commercial opportunities that crystallise 3-5 years down the line. The relative scarcity of such devices and the many weaknesses/threats identified in Section 8 above could easily create scepticism about an opportunity which requires investment soon to investigate feasibility, develop market-ready solutions and avoid being late to market.

Funding availability and location: To exploit these potential opportunities requires risk capital of a kind that is scarce in the UK but much less so in the US and Asia (where there are several dedicated VR/AR/MR funds[14] as well as VCs that invest in this space). Public sources of finance in the UK may or may not be able to fund the investigation phase of these opportunities, although institutional funding for the commercialisation phase is assumed to be more available assuming the investigation phase yields positive results. The availability of funding may ultimately define whether the opportunity is captured by UK or US companies.

Legislation: In February 2017, a New York court rejected a class action against games publisher Take-Two for retaining facial scans of players used inside games. 3 US States have biometric privacy laws which could easily be used to deny AR/MR services and/or providers access to a range of data augmenting views of the real world. Also, Milwaukee County has demanded Niantic gets a permit to include any of its parks in Pokemon GO. How and when legislation and regulation affects AR/MR remains to be seen.

9.2. Enablers

AR/MR device launches: 2017 is expected to see a number of new device launches which will start to realise the potential for AR/MR. Expected are new devices supporting Tango, HoloLens partnerships (tethered) and more announcements from Magic Leap. This will add to momentum behind existing devices, generate more interest in the AR/MR field and no doubt lead to funding availability from device manufacturers for cutting edge AR/MR projects using their devices.

Business model changes: Changes in the flexibility of satellite data providers' business models could enable this market to flourish.

Funding sources: A small range of funding sources such as the new Seraphim Fund, Innovate, Company funding or other (global) venture capital funding focused on VR/AR/MR could be used to fund pilots, joint ventures or new companies in this space. Device manufacturers could also start funding app development, as they have in Virtual Reality to plug content gaps.

R&D and Manufacturing: The usual steps (international patent searches and registration, copyright, legal safeguards such as NDAs) to protect new IP developed during research, piloting and deployment should be undertaken to ensure that the IP is defensible and owned by UK companies, and the supply chain develops in the UK.

9.3. Recommendations

The analyst proposes the following steps to realise these Opportunities, if the appetite exists.

Research phase

The research conducted in this briefing is deliberately arm's length and conducted by a games industry specialist. A next stage of research could deepen the understanding of the opportunities presented here, in the following areas:

1.1. **Market feasibility:** A deeper study of the market feasibility of these opportunities, with closer engagement with stakeholders and technical experts, is recommended to ascertain whether the opportunities described in this short study are as viable as they first appear. This should include discussions with AR/MR device manufacturers (Microsoft, Google and Magic Leap) to explore their current and planned capability, as well as games and potentially other sectors

[14] The US-based VR Fund has raised $50m https://www.crunchbase.com/organization/venture-reality-fund#/entity, while Japan's COLOPL is investing $50m http://coloplnext.co.jp/en/coloplvrfund/, amongst many others http://virtualrealitytimes.com/2016/11/30/list-of-vr-investment-funds/

investing early in AR/MR. We recommend these be billed as fact-finding as opposed to partnership discussions (to keep powder dry).

1.2. **Technical feasibility (Space sector):** We recommend more research into the current and future capabilities of satellite data providers in this area, especially whether EO, GNSS or Satellite Communications will provide partial or complete solutions to deliver sub-10cm resolution imagery and/or positioning and how real-time the data can be.

Technical feasibility (image processing):

After the above technical feasibility research, research should investigate the technical feasibility of existing and forthcoming image processing solutions to exploit the Opportunities for both historic and real-time image processing using machine vision. This should include Gamar's image processing algorithms.

1.1. **Technical feasibility (3D mapping)**: Finally, we recommend that research investigate the capability and resolutions of current 3D mapping platforms. A priority should be eeGeo, since it has already developed a procedural 3D mapping platform, albeit probably at a lower resolution. Their platform should be scrutinised as a potential market-ready solution (with appropriate delivery, device support and commercial models) to exploit new data. Research should also be conducted into alternative data sources for historic or real-time 3D scanning of static and moving objects in outdoor environments to understand how satellite data could merge with other data sources in future.

Pilot Phase

If the research phase above indicates viable opportunities, a pilot covering a medium scale target such as a large town or small city would be the natural next step. The city of choice could a connected city such as Bristol (in that it would be receptive to integrating new data sources) or a less connected city. The pilot could focus on Opportunity A and/or B depending on 1.2-4 above, and consist of:

1.2. **Satellite data provider(s)**: 1 or more satellite data providers may be required for a pilot, depending on which would provide the appropriate imagery or data. This could include launching a small constellation of cube satellites.

1.3. **Image processing provider:** Commercial or academic image processing capability will be necessary to generate the appropriate data

1.4. **3D mapping provider**: Again, a commercial or academic image processing capability will be required to procedurally generate the relevant semantic geometry for a platform.

1.5. **AR/MR device manufacturer**: A pilot should involve and integrate with either Google or Microsoft, and access xx devices in the pilot.

1.6. **Games developer**: A games developer would be an optimal partner for a consumer-focused application trial which could showcase the pilot.

Go to market

The pilot phase should clearly indicate whether there is a good opportunity in this or adjacent areas. If so, a joint venture could be established between parties in the pilot to take the product to market.

10. Market Dynamics

10.1. Games market overview

Sales: The global games software industry will have had turnover of $75bn in 2016 and is growing at nearly 5% per annum through to 2020, comfortably outstripping almost every other entertainment medium[15]. Combined with hardware, the market value is around $90bn.

End users: 47% of adult Americans[16] and 41% of adult Britons play games[17], and the most accessible category – mobile gaming – has an estimated 1.5 billion players globally[18]. Player gender is between 40-48% female depending on the territory[19], and all ages play, albeit in diminishing proportions.

Developers: 12,000 developers make games professionally in over 900 games development companies in the UK[20]. 52,000 develop games in 5,000 US studios[21], up to 75,000 developers in over 1,000 studios in China, 20,000 in 500 Canadian studios[22], 22,000 developers in 400 South Korean studios and with other significant development clusters in Japan, France, Germany, Scandinavia, Poland, Eastern Europe and Brazil. Roughly 200,000 professional staff are making games worldwide (plus well over a million amateurs[23]), and this number appears to be growing by between 7-10% per annum[24], bolstered by around 15,000 graduates from specialist video game development degree graduates.

10.2. AR/MR Games

Description: Games played by interacting with digital content overlaid on top of the real world, typically seen on screen using a mobile phone's camera (AR), or games played with digital content that interacts with the real world, as seen through visors, sometimes tethered to PCs or mobile phones (MR).

Market scale and growth: $1.1bn (hardware and software) in 2016 (<100,000 hardware units), growing at est. 155% CAGR to $13.6bn by 2019 and 46m hardware units[25] by 2020.
End users: Biggest demographic groupings are young people (AR) and young and middle aged early adopters (MR).

Business models: Free to play with microtransactions[26] for a wide range of functional and cosmetic digital goods, power-ups, time savers, consumables and subscriptions. A small proportion of the market remains premium (single purchase, open access). Undefined for MR.

Value chain: AR games – Studios or hardware manufacturers can fund development of software by games studios, hardware manufacturers curate stores and share revenue (30% of gross revenue). MR Games are yet to be defined, but likely to adopt AR Games' value chain.

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[15] Source PWC Jun 16 http://venturebeat.com/2016/06/08/the-u-s-and-global-game-industries-will-grow-a-healthy-amount-by-2020-pwc-forecasts/
[16] Source ESA Apr 16 http://www.theesa.com/wp-content/uploads/2016/04/Essential-Facts-2016.pdf
[17] Source Ofcom Apr 16 http://stakeholders.ofcom.org.uk/market-data-research/other/research-publications/adults/media-lit-2016/
[18] Source Eedar Nov 15, 1.5 billion mobile gamers http://stakeholders.ofcom.org.uk/market-data-research/other/research-publications/adults/media-lit-2016/
[19] Source ESA Apr 16 http://www.theesa.com/wp-content/uploads/2016/04/Essential-Facts-2016.pdf
[20] Source GIC/TIGA Aug 16
[21] Source GIC Jan 17, ESA 14 http://www.theesa.com/article/u-s-video-game-industrys-economic-impact/
[22] Source ESAC 15 http://theesa.ca/resources/essential-facts/
[23] GIC estimate. Unity has been downloaded 5.5 million times since its launch 11 years ago
24 UK headcount has been growing at 7% CACG since 2011 (Source GIC/TIGA 2016), Canada at 10% between 2012-2014 (Source ESAC)
[25] IDC AR/VR forecast 2016-2020, Apr 16
[26] Transactions of $0.99 or more

Development budget range: $5,000,000 (medium).

Locations: Global – largest regions by software sales are Asia, North America, Western Europe. Apart from Microsoft, no other AR headset manufacturer is based in the UK, but there are a handful of AR games developers.

Major companies: Niantic (developer/publisher of Pokemon GO), Microsoft (Hololens manufacturer), Magic Leap (unreleased hardware), Google (Tango), CastAR (HMD manufacturer).
Market structure: AR: Apple/Google dominate handsets and therefore App Stores. Only a few developers/publishers make AR games as yet. MR market structure not yet defined but likely to closely resemble or substantially overlap that of AR games.

Highly nascent sub-sector, no clear manufacturers nor routes to market yet.

Biggest selling title of 2016: Pokemon GO by Niantic (est. gross revenue $780m), free to play highly simplified AR game.

11. Market Trends

11.1. AR/MR Games trends

Nascent but rapidly growing market: The AR/MR games market is forecast by many analysts to grow rapidly to 2020. Superdata found that the AR/MR games market (for software and hardware) was worth $1.1bn in 2016 (from next to zero in 2015) and have forecast the market to grow substantially to $13.6bn by 2019, which represents growth of 155% each year[27]. New investment in AR and MR games developers by venture capital companies totalled around $100mn in 2016[28], sourced almost entirely from American and Asian funds.

Pokemon GO opened doors: The global success of Pokemon GO, an AR game which imposes graphical assets on top of a smartphone's outward facing camera, in 2017 was a perfect storm. This huge consumer brand carries a substantial pre-existing audience which combined with simple but innovative gameplay, accessibility on almost every available smartphone and massive press coverage to create a global hit. In turn, this will tempt larger companies to try to replicate the success of Pokemon GO with other mainstream brands. We do not expect any games, including sequels or follow-ons from Niantic, to approach the same revenue levels, but a rash of AR titles is expected in 2017 which will grow the market modesty. The next growth spurt will come when true MR games with the right consumer hardware are launched, probably in 2018-2019.

Google Glass spoiler: The first consumer AR device was Google Glass which was released to real people in a large-scale trial in 2013. The only novel use identified by Google not already available on smartphones was its ability to record video or photos from a user's eye perspective. During the trial, users were singled out for wearing headsets with an obvious camera, in part because they could record video without asking permission. Glass wearers also drove which was deemed illegal in California. This led to some degree of social stigma (colourful soubriquets for users). Glass was an under-powered, over-hyped experiment that got a lot of bad coverage and was withdrawn by Google in 2015, but is still apparently a work in progress. Pokemon GO avoided that stigma completely, despite involving groups of people walking around glued to their phones; indeed it was seen as cool by all Pokemon fans, helped by massive download levels.

[27] Superdata expects growth to be slow in 2017, then rocket up to 2019
[28] Source: Digi-capital Oct 2016 http://www.digi-capital.com/news/2016/10/mainstream-vcs-bigger-checks-drive-record-arvr-investment/#.WHZqk1w55aQ

Where's the AR/MR hardware? The biggest obstacle to the AR/MR games market growing rapidly is the lack of sales volume of any high-end head-mounted AR/MR devices targeted at consumers to date. Microsoft's HoloLens is an enterprise (not a consumer) device designed for professionals such as engineers, architects, surveyors and surgeons, priced at over £2,700 for a development version. Cheaper versions (£299) are coming, but they are not designed for outside use, since they are tethered to high-end PCs (>£800). Other AR/MR device manufacturers have also been targeted at professionals, not consumers. Investment in AR/MR head mounted displays is easily the largest focus on investment activity across the VR/AR/MR space, taking 40% ($1bn) of total investment in the 12 months to October 2016[29], signalling that investors are bullish about the maturation of this market in the next few years. Magic Leap, which raised $1.4 billion from Google and Alibaba, is the most ambitious, promising but over-hyped technology currently being developed. Tango has launched and demonstrated powerful functionality in 2016 but only on a small number of handsets. Apple has been linked to optics manufacturer Zeiss and AR/MR but as usual advance no product announcements have been made.

Major technical hurdles for gaming on AR/MR devices: Most analysts believe that the hardware needs to mature to be untethered, with much longer battery life, better graphics processing ability, intuitive user interfaces and much lower consumer pricing, quite possibly subsidised by mobile operators (like tablets). Until then, it is unlikely that games and other app developers will produce content in the quantities found in other markets, nor that formal routes to market will be established, although it is likely that MR will simply adopt AR games' route to market which is basically via mobile app stores. Currently only a subset of games companies is working on games for the adjacent market of VR. AR/MR games developers are a subset of this subset. HoloLens has had the most success in recruiting developers, perhaps a score worldwide, one or two of which are UK-based. This will change in 2017/2018 once projections for consumer adoption of viable devices improves.

MR struggles outdoors: Several blockers exist today for MR outdoors. Rendering objects with realistic light and shade is difficult without identifying every light source. Some head mounted displays do not have a wide enough field of vision to avoid the user looking through a porthole. A more thorny problem is that visor-based MR such as HoloLens or Meta struggles to handle pure black (which is the absence of light) which is why demos are shown in low-light indoor environments. With visors, the eye is tricked to believe something is black but get close and it's grey. Visor providers will solve this with incoming technology such as transparent liquid crystal displays, but outdoor MR is hard to render in daylight. We expect to see solutions in 2018.

MR interactions are short-range: Most head mounted MR devices try to spatially map the local environment to support the 'realism' of the digital content that interacts with the real world. HoloLens and Tango's spatial mapping and visual tracking are naturally limited to 4m in range, which means outside environments will appear blank and be mostly inaccessible from an interaction point of view unless very close to the target. Just as a film or television programme requires the suspension of disbelief to achieve viewer engagement but can be broken by bad dialogue, unrealistic events, poor visual effects and so on, games have a similar but slightly different set of triggers, with immersion and realism being key for MR games. An MR game which superimposes digital content on the real world can be punctured if the digital content appears to respect some but not all physical rules in the real world. For example, an MR space invaders game played in Trafalgar Square could be ruined by a digital target flying unrealistically straight through Nelson's Column, but will be significantly enhanced by the target ducking behind Nelson's Column. These real-world environment opportunities for players could lend a massive expansion in gameplay opportunities for developers.

[29] Source: Digi-capital Oct 2016 http://www.digi-capital.com/news/2016/10/mainstream-vcs-bigger-checks-drive-record-arvr-investment/#.WHZqk1w55aQ