London:
A Global Leader in Advanced Digital Technologies

CATAPULT Digital

SUPPORTED BY
MAYOR OF LONDON

This report, written by Digital Catapult, was commissioned by the Mayor of London to project forward, inform and advise on technology research and innovation trends over the next 15 years.

It provides a snapshot of London's strengths in digital innovation, across a variety of technologies and research areas – with the goal of stimulating further thought by industry and policy makers, to realise the full potential of advanced digital technologies for the capital and the UK.

About Digital Catapult

Digital Catapult is the UK's leading advanced digital technology innovation centre. It accelerates the adoption of new and emerging technologies to drive regional, national and international growth for businesses across the economy.

Digital Catapult works with the supply and demand for deep technologies - from startups and scaleups, to established businesses, investors, government and public sector, research and academia - to discover new ways of solving industry challenges, increasing productivity and opening up new markets.

Digital Catapult focuses a new and emerging advanced digital technology stack, that combines:

- Future networks: 5G, the internet of things (IoT) and other next-generation network technologies
- Artificial intelligence (AI) and machine learning (ML)
- Distributed systems (distributed ledger technologies, including blockchain)
- Immersive technologies (virtual, augmented and mixed reality, and haptics)

Digital Catapult (**1**) builds and operates physical and virtual facilities that would not exist without its investment; (**2**) designs and delivers specialised innovation programmes, that drive UK leadership and economic growth; and (**3**) builds combined technology proof of concepts and pilots through collaborative and commercial research and development (R&D) to unlock the economic potential of innovation.

It accelerates practical approaches to adoption – with ethical and security considerations – so that the UK can benefit from these technologies at a national scale.

For more information visit
www.digicatapult.org.uk

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Foreword

Over the last decade technology has radically changed the way Londoners interact with the city and with one another. From social media to wayfinding, the apps and services we use every day were made possible due to advances in the underlying technologies – such as 3G then 4G, the increased computing power of smart phones, the deep learning behind search and recommendation online, and the use of natural language processing in the assistants in our homes.

Now a new generation of underlying technologies are emerging to change the way we live, work and play: the networking of our physical environment, the deployment of artificial intelligence across more and more of our economy, distributed systems of trust and the new forms of ownership they could entail, and the creation of new virtual layers on top of the physical world.

London's tech ecosystem is the envy of the world, with our universities and research base offering expertise and specialisation in the technologies that this paper identifies as key to the future. It is vital the capital builds upon this lead, working with national R&D bodies and Digital Catapult, to ensure London's innovators can capitalise on the next wave of emerging tech and Londoners can enjoy the benefits.

However, it is important to remember, as well as creating economic opportunities and applications that remove the friction from life, technologies have also presented challenges. Just as advances in search and recommendation algorithms and social media have made life richer and more convenient, they have also made it easier to spread hate and misinformation online.

Technology itself is never good or bad, only how it is used and how that use is governed – whether that is technology aimed at public safety such as facial recognition and its impact on privacy, or as yet theoretical applications such as immersive virtual advertising in public spaces.

So alongside this paper I am announcing that London will be developing an Emerging Tech Charter to guide the deployment of new technology in our city and create an open dialogue between innovators and citizens. It is the start of an approach to ensure that the deployment of new technology into London life is well informed, inclusive and by consent.

As advanced technologies become the norm and integrated into daily life, it is more important than ever that we understand what they can do and how they may both augment and challenge life in London.

This paper provides an excellent starting point for this thinking.

Theo Blackwell MBE
Chief Digital Officer

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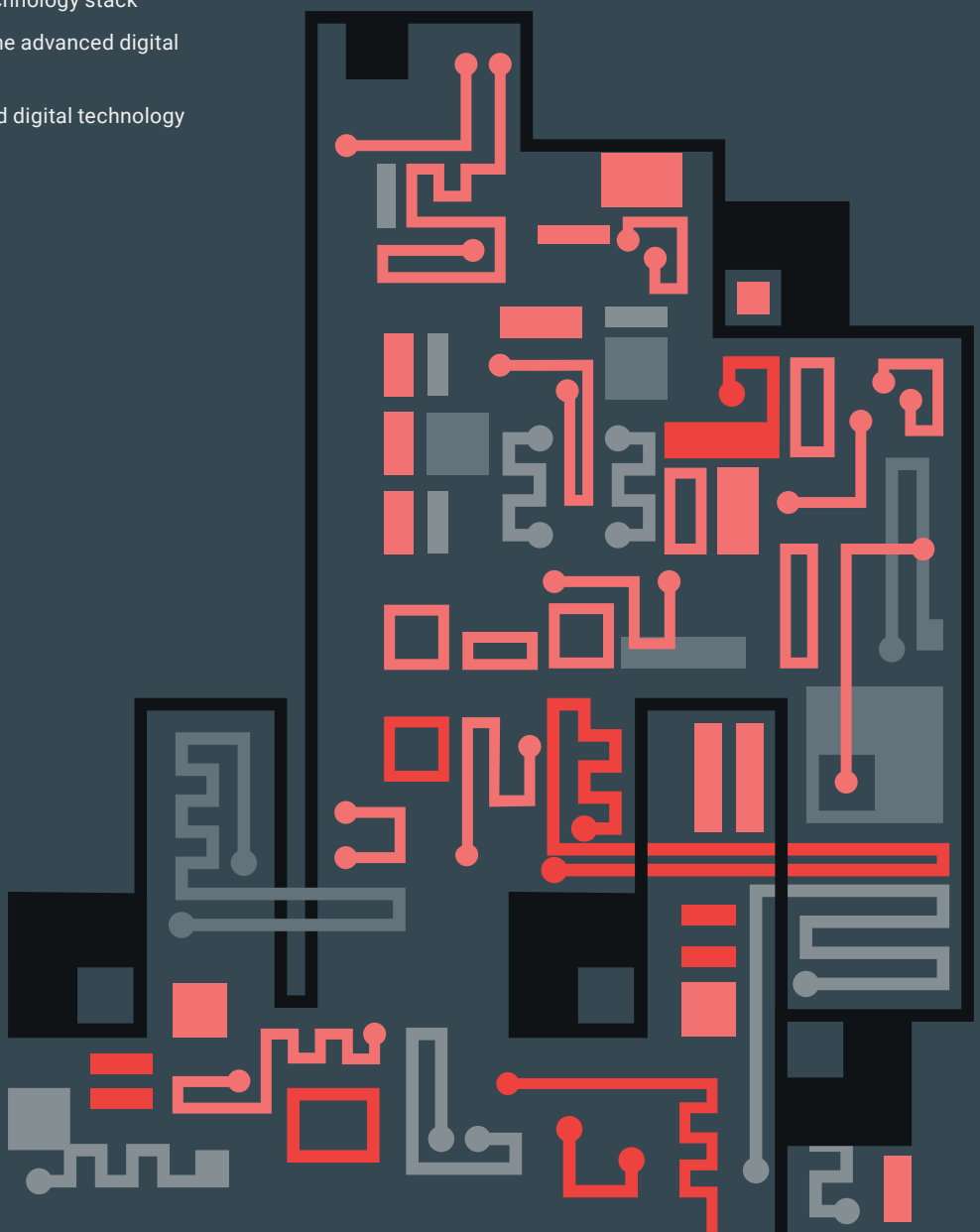


Executive summary

London is fast becoming a global leader in an emerging new advanced digital technology stack. This stack is already starting to enable a number of technologies to combine, forming exciting and transformational changes to businesses of all sizes and driving economic growth. These technologies increasingly blur the divide between the physical and digital world, creating new and innovative ways for us to interact with and use data to solve challenges and realise new possibilities.

The advanced digital technologies

- Artificial intelligence
- Extended reality (virtual, augmented, mixed reality and haptics)
- 5G and future networks
- The internet of things
- Robotics, cobotics and autonomous machines
- Distributed ledger technologies (including blockchain)

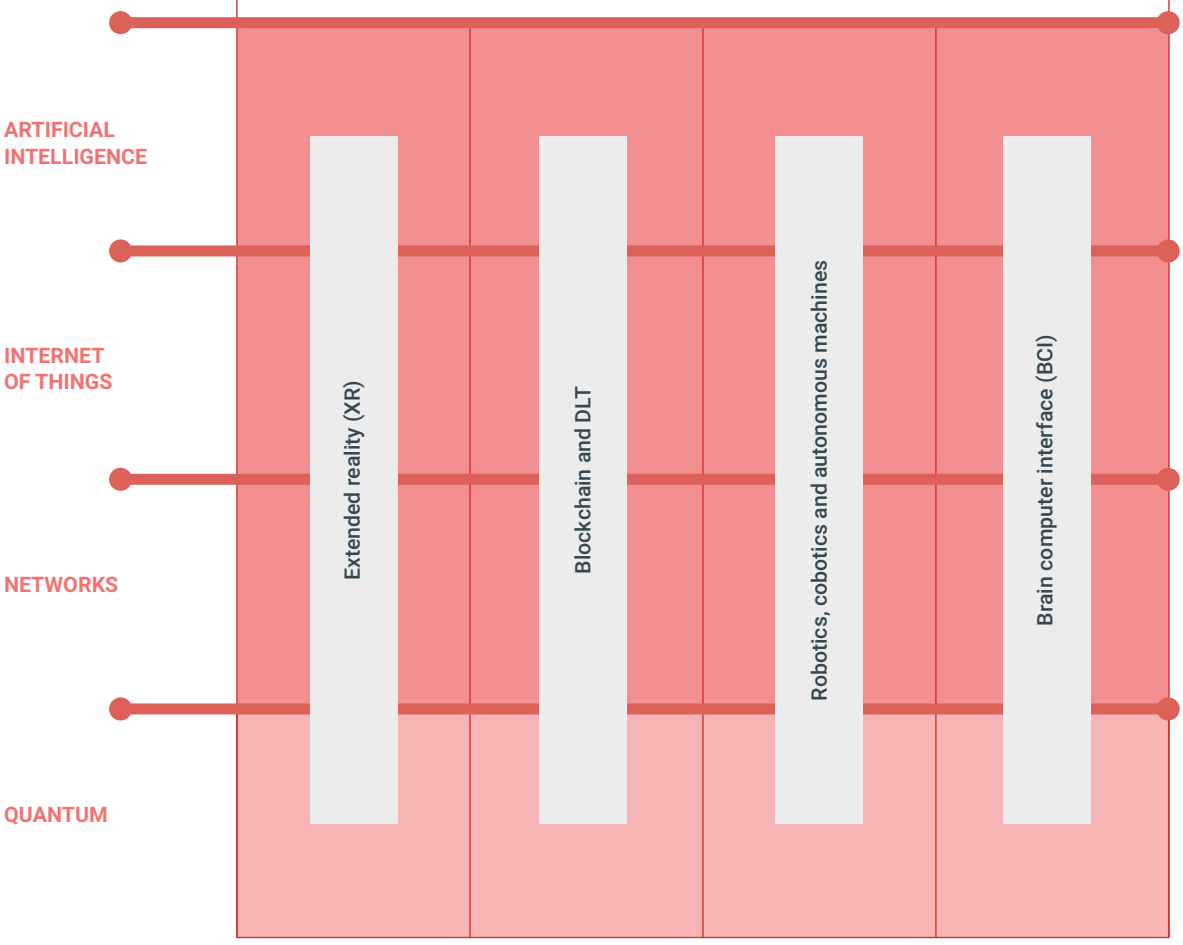
In the future this will also extend to include:

- Quantum computing
- Brain computer interfaces (BCI)

Please see the following page to see how these technologies are applied to **the advanced digital technology stack**

The advanced digital technology stack

The advanced digital technology stack is already starting to enable a number of technologies to combine, forming exciting and transformational changes to businesses of all sizes and driving economic growth. These technologies increasingly blur the divide between the physical and digital world, creating new and innovative ways for us to interact with and use data to solve challenges and realise new possibilities.



Potential use cases of the advanced digital technology stack

There are numerous use cases that this new stack will enable, from autonomous vehicles, to smarter deliveries, to the augmented reality (AR) cloud and AI powered wearable technology. We are entering a new phase of technology, one that focuses on blurring the lines between physical and digital worlds, moving us from fingers on screens to the physical internet. This report covers some of these areas to spark ideas for the future and is not intended to be an exhaustive list. It is from these exciting developments that new products, applications and services will be built, that can be linked to businesses in regions across the country, and exported across the world.

Building on smart city foundations

The introduction of the advanced digital technology stack will transform London. From autonomous vehicles, to remote operated cranes and smarter logistics around the city, this new advanced digital infrastructure will enable numerous startups to access data, connectivity and intelligent AI services and build new products and applications that rapidly transform how we live and work in the city.

Augmenting the physical environment

The evolution and adoption of extended reality (VR/AR/MR), underpinned by real-time data, 5G, IoT and AI, will create the physical internet. This gesture-controlled environment will make what people see around them "clickable" – allowing London to be more interactive and rich with local data. This will enable smart tourism, retail experiences to draw people back to the high street in the light of covid-19, and a transformation of how we all interact with information.

Augmenting the physical self

The combination of the advanced digital technology stack will transform wearable technologies, allowing us all to use technology to augment ourselves. We will see a convergence of London's strengths in design, life sciences and technology to surface lightweight wearable technologies, designed to enhance the way we live, work and interact with one another. This will include haptic feedback, allowing people to click or press buttons in a virtual, touch free environment; through to brain computer interfaces that will help break down barriers for disabled people, for example, the potential to use robotic assistance to aid walking.

Executive summary

London's key statistics

#1

City in Europe for total number of advanced digital technology companies *(source: Crunchbase and Digital Catapult market research)*

£2.3bn+

Total investment in the London-based advanced digital technology companies in the past 12 months *(source: Beauhurst Data since Q2 2019 to the end of Q1 2020 - accessed on 26/05/2020)*

100+

Advanced digital technology spinouts from London universities *(source: Beauhurst Data – accessed on 26/05/2020)*

2,190

Startups and scaleups working with advanced digital technologies with HQ in the capital *(source: Crunchbase, Beauhurst, Companies House and Digital Catapult databases)*

200+

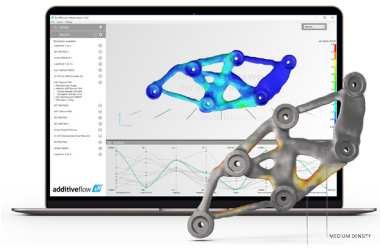
Advanced digital technology companies with a valuation of £10m+ *(source: Beauhurst Data – accessed on 26/05/2020)*

Top 10 London advanced digital technology innovators to watch

In light of the emerging trends for advanced digital technologies, Digital Catapult has identified 10 London-based advanced digital technology startups and scaleups to watch in 2020. These companies are trend setters in the combination of these technologies, have significant growth potential and have headquarters in the capital.

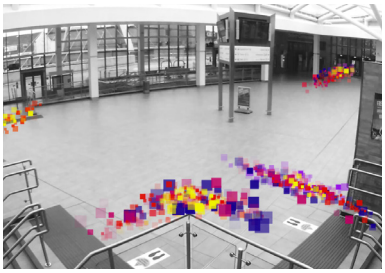
greyparrot

The current low global recycling rate of 14% is partly due to a process that relies heavily on manual labour. Greyparrot offers AI computer vision solutions to power smart systems for waste management. Recognition software identifies different waste types to enable waste monitoring and automation in recycling.



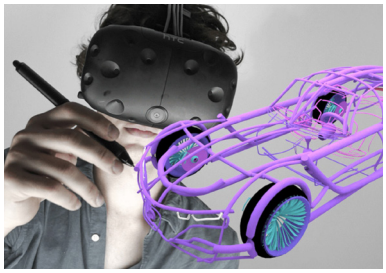
additiveflow

Additive Flow uses machine learning to empower material engineers – alongside a number of users – in additive manufacturing. Additive Flow offers a multi-functional approach to develop holistic, digital tools that consider material properties, geometry and material placement, hardware systems, and build parameters to increase multi-property performance. This optimises the outcomes for any additive manufacturing application.



HUMANISING AUTONOMY

The greatest barrier to automated driving in cities is the unmanageable risk of injury to vulnerable road users. Humanising Autonomy's real-time intent prediction software accurately predicts the full range of vulnerable road user behaviours to improve the safety and efficiency of urban mobility systems and enable automated driving in urban environments – making automated driving at scale a reality. Humanising Autonomy is building the global standard for human interaction with automated vehicles.



gravity sketch

With a re-imagined user experience that puts the designer at the centre of the creation process, Gravity Sketch enables everyone to quickly ideate, visualise and communicate concepts in real-time, from initial conception, straight in the 3D space. Gravity Sketch works collaboratively with creatives across multiple industries including automotive, concept art, architecture and industrial design, to deliver transformative solutions to their creative workflow needs.

mativision
the experience is everything

Mativision offers advanced VR for a variety of use cases, from medical training to live streaming of music and sporting events, with complete synchronisation of headsets using 5G technology. Central to the company's offering is its VR&360° player, which is the world's only turn-key technology for the production of 360° interactive content and experiences, from filming to broadcast across multiple platforms.

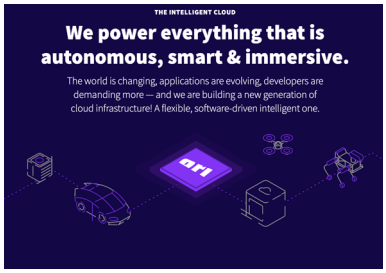
Executive summary

SMARTIFY

Smartify is an application that helps people make meaningful connections with art. Using image recognition technology, Smartify instantly identifies artworks by scanning them on a user's smartphone. Through Smartify, users can unlock the stories behind the art, create and share a digital personal art collection. Smartify is a 5G-ready application that utilises AR to bring art pieces to life.

WILD.AI

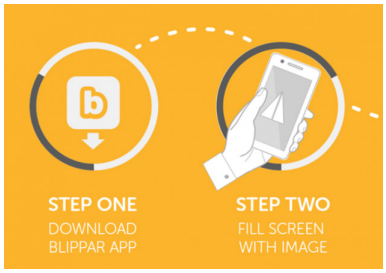
WILD.AI is looking to solve the issue that the medical world has: women are considered as another version of men when they are in fact very different. WILD.AI offers a B2C app, primarily helping women who do sports understand their body, and get the most out of it through an AI app coach. It aims to build the largest database of female datasets across all ages, life stages and ethnicities.



ori

Ori is building a new layer of infrastructure – a flexible, software-driven intelligent one. From smart cities, immersive worlds, autonomous machines and industrial automation, new applications are posing a challenge for global infrastructure. The scale of the challenge requires a more intelligent approach to infrastructure – one which optimises capabilities of geographic distribution, wide area presence and local capabilities. Ori changes the way physical infrastructure interacts with software – paving the way for a more autonomous, smart and immersive future.

Executive summary



Jitsuin

IoT needs maintenance to produce clean and reliable data for enterprise. Jitsuin's vision is to align everyone in the value chain to ensure a safe, efficient and sustainable IoT that creates truthful data for man or machine to act with assured intelligence. The team applies blockchain technology to shared device lifecycle assurance as a foundation for truthful data, which enables autonomous smart contracts and open data markets to realise the true value of IoT.

blippAR

Blippar is a leading technology company specialising in AR, AI and computer vision. Blippar gives access to an AR ecosystem with products and professional services to meet specific business needs – from consultancy to AR creation tools that publish AR content within a client's own app or rich media banners (no app required). Since launching in the UK in 2011, Blippar's technology has been used by world-leading brands such as PepsiCo, Porsche, Nestlé, L'Oréal, GSK, General Mills and Procter & Gamble to create exciting and award-winning experiences.

Key recommendations

01

Enabling advanced digital technology innovation

- The Mayor of London should develop an approach to formalise, structure and inform discussions around the adoption and deployment of advanced digital technologies in London; ensuring that new technology aligns with city principles, that there is a clear and consistent ask of the tech sector by government, and that a diverse range of voices are heard.
- The Mayor of London should work with the UK's regional innovation and research technology organisations to co-design programmes that help London's advanced digital technology startups and scaleups to connect with specialist businesses and local authorities across the country. This will help to support the post pandemic recovery – capitalising on the rapid adoption of digital tools and accelerating the country on its journey towards advanced digital technology adoption.
- Expand and build on the Mayor of London's Civic Innovation Challenge and invest further into specialised acceleration programmes, looking at ways to promote and support broader applications of advanced digital technology for social, environmental and economic good.
- The Mayor should foster collaborations and run consultations with London's innovation ecosystem (including industry, academia, technology giants, investors, policy makers, startups and scaleups) to better prepare the capital for the impact and value that advanced digital technologies will have through widespread deployment over the next 15 years.
- Encourage the showcasing of new and emerging haptic, wearable and biological function products and services to help build trust, and increase adoption and familiarisation with the technology. This will be particularly important with the need to provide touch-free, social-distanced city environments in the future.

02

Establishing world-leading advanced digital infrastructure

- Continue to promote London as a centre for R&D and innovation activity for advanced digital infrastructure.
- Deploy advanced digital infrastructure to help encourage use case explorations of augmented reality and mixed reality for a variety of sectors across the capital. This could also include innovation programmes to explore business applications of extended reality in areas such as retail, design, creative and London's foundational economy.
- The Mayor of London should take a harmonised approach across boroughs in establishing advanced digital infrastructure and 5G – driving the adoption of common standards-based solutions and wherever possible encouraging 5G applications and use cases.
- Approach AI as part of an advanced digital infrastructure capability for the broader ecosystem. This means enabling the city to access AI capabilities at scale, whether through localised (edge) internet of things devices or via mobile edge facilities using 5G.
- Encourage the creation of new specialist facilities in London that celebrate immersive creativity, talent and entrepreneurship and showcase UK content to the world.
- Explore the creation of advanced digital technology-enabled localised manufacturing facilities that connect to the new creative production corridor in the Thames Estuary. This will reduce the burden on the supply chain and waste facilities and increase personalisation of goods, meeting the needs of Londoners.
- Deploy advanced digital infrastructure to help encourage use case explorations of augmented reality and mixed reality for the future of the high street across the capital.

03

Ethical, policy, environmental and social

- All advanced digital technologies will have ethical and policy implications, particularly when used at scale. The Mayor of London should work with all parts of the value chain to encourage the building of practical advanced digital technology ethics programmes, facilities and toolkits for London. This should include the development of an advanced technology charter for the responsible deployment and use of emerging technologies in the city.
- Review and increase diversity and inclusivity for advanced digital technology startups and scaleup programmes – encourage the London innovation ecosystem to foster new engineering, entrepreneurial and business skills across all under-represented groups to create a more balanced and sustainable ecosystem. This includes encouraging more investment into women and ethnic minority-led advanced digital technology companies to help them scale.
- Work with London businesses to map and model the environmental impact that London makes through its current and future consumption of data, to inform future interventions and promote a shared responsibility for environmental sustainability with multinational data centres and technology infrastructure providers.

04

Fostering collaborations, skills and talent

- Upskill and increase awareness of 5G technologies for businesses across the capital and how they will enable future digitalisation. This includes encouraging London-based businesses to invest into 5G R&D to explore new use cases – taking them from the what to the how.
- Continue and expand programmes such as TechInvest, to encourage and educate more London-based investors and Venture Capitalists (VC's) about the convergence of advanced digital technologies, and how this will transform the economy.
- Work with London's universities and leading art and design research institutions to help build a skills base for next-generation immersive content production that will supercharge the London creative sector and create high-skilled jobs of the future.

Introduction

Introduction

The convergence of advanced digital technologies into a new stack, will drive a market worth hundreds of billions of pounds.

London is fast becoming the global hub for research, development, innovation and commercialisation of a new advanced digital technology stack, combining emerging technologies into solutions for multiple industry sectors across the global economy.

This report, written by Digital Catapult, was commissioned by the Mayor of London to project forward, inform and advise on technology research and innovation trends over the next 15 years. It provides a snapshot of London's strengths in digital innovation, across a variety of technologies and research areas – with the goal of stimulating further thought by industry and policy makers, to realise the full potential of advanced digital technologies for the capital and the UK. This is particularly important when looking at the social, ethical, sustainable and economic considerations by decision makers in the Greater London Authority, the UK Government, across industry and the broader UK research and innovation landscape.

Through consultations and research it looks to spark the further development of a comprehensive strategic plan for supporting the combination of these technologies in London, encouraging investment in the advanced digital technologies stack, developing technical and entrepreneurial skills, and driving innovation and R&D investment, to ensure that London can remain at the forefront globally. The delivery of such a plan can be achieved by fostering collaborations between advanced digital technology supply and demand, helping to stimulate new innovations and strengthening existing centres of excellence. This can be achieved through the support of purposeful collaboration between existing activities, linked to the Mayor of London's long-term strategic objectives.

Covering the full spectrum of R&D, innovation, startup and scaleup ecosystems, creativity, design and sector leadership, this report explores the evolution of the advanced digital technology stack. It looks at where the market is at present and where it is potentially heading in the future, highlighting London's strengths and the opportunities already being seen as they come into play. It looks at use cases for advanced digital technologies, and highlights the importance of deploying and testing advanced digital infrastructure capabilities within London, to enable city-scale platforms, capabilities and resulting products, applications and services to be built.

The convergence of advanced digital technologies into this new stack, will drive a market worth hundreds of billions of pounds. It will generate opportunities to transform high-impact economic sectors, while opening doors to new business models and enabling sectors to grow. This will span everything from localised and personalised manufacturing facilities, smart cities, next-generation services, innovative healthcare, immersive entertainment venues, new methods of content distribution and beyond. This report provides insight into how the UK's capital can build on its position of innovation excellence, becoming world renowned for the combination of advanced digital technologies that blur the lines between the physical and the digital world.

Finally, the report acts as a lens through which the Mayor of London, the UK Government, and the broader public and private sector can align their focus and realise this vision. It is intended to drive action, and inform strategic decisions on the ethical, sustainable, economic and social policy drivers for adopting advanced digital technologies at scale, ensuring that London's unique strengths can be leveraged to sustain its position as an economic and innovation powerhouse for the future.

London as a world leader in advanced digital technologies

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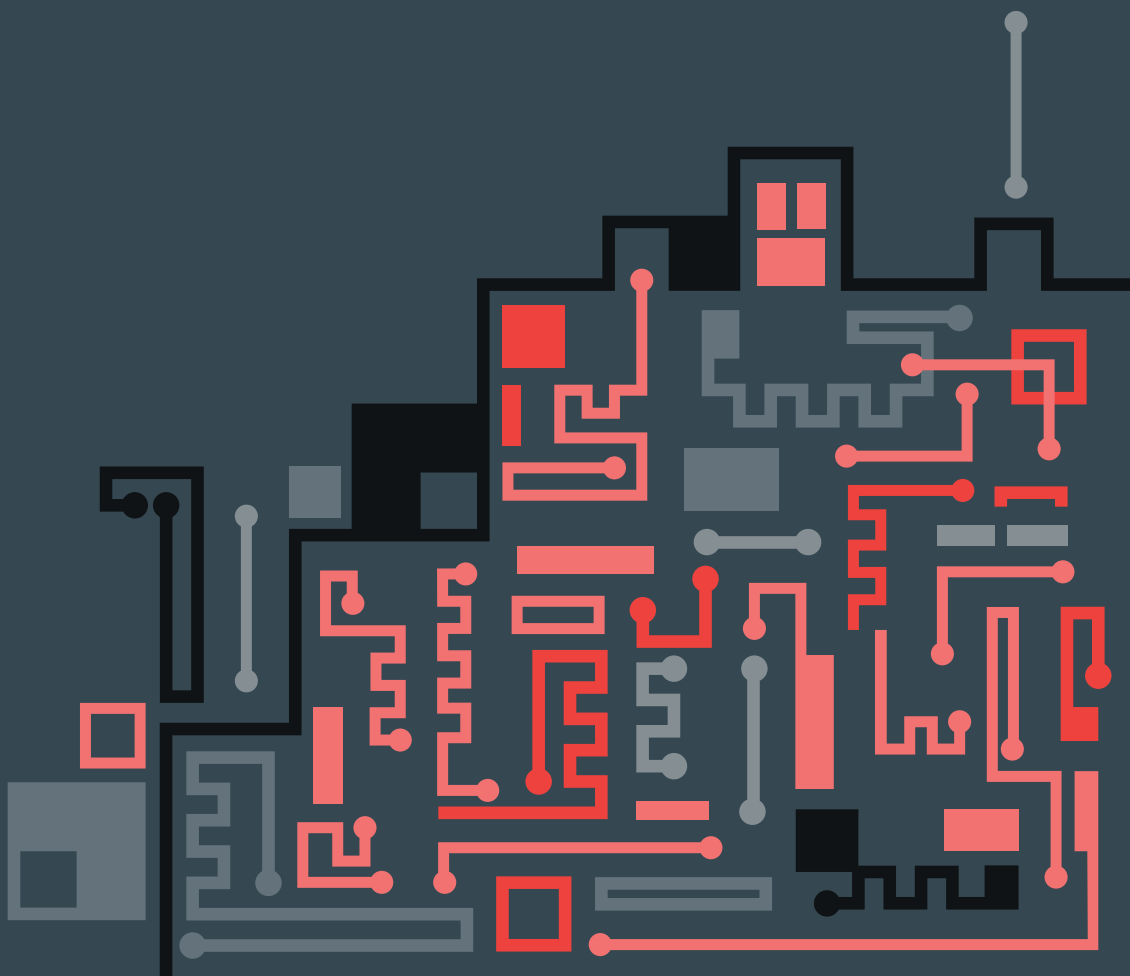


London as a world leader in advanced digital technologies

Over the next 15 years new forms of advanced digital technologies will underpin innovative and disruptive business models, products, services and experiences to fundamentally transform the way we live and work.

Step-changes in connectivity, hardware and computation power, data generation and real-time data processing, physical and virtual interfaces, and AI will converge to create significant economic opportunities and shape a modern economy.

Most new technologies go through an initial phase of significant attention, hype and high expectations, before then facing a drop in interest and investment. Taking nascent technologies through this "trough of disillusionment"[1] by creating more tangible industry use cases and challenge-led innovation helps to support the business case for further investment across an economy, and drives adoption to achieve commercial maturity through supply and demand.

Disruptive digital technologies, which reach that level of scale and commercial maturity, have created today's biggest businesses and rapidly-growing new markets. The platforms that now dominate the digital technology landscape are built on technology 'stacks': each with an underlying networking layer, a computation layer, and an interaction or interface layer. Today, these three layers are typically seen as internet networks and the web, with computation delivered by databases and software engineering, accessed via touchscreen and browser interfaces.

The convergence of technologies within the advanced digital technology stack will have a significant impact on industry, creating economic and societal benefits at scale. There are already an increasing number of use cases for products, services and platforms that offer glimpses of how the advanced digital technology stack will evolve, combining emerging technologies in new and disruptive ways. Over the next 15 years, the convergence of these technologies will be commonplace within the products, applications, services and experiences built by the next generation of innovators.

London is well-placed to lead the global market, seize the available opportunities and to drive economic growth across the wider UK economy.

There is currently a race for global leadership and competitive advantage within each of the technologies that form this new stack, which already includes artificial intelligence and machine learning; extended reality (the collective name for immersive technologies, including virtual, augmented, mixed reality and haptics); 5G and future network connectivity; the internet of things; robotics and cobotics, additive manufacturing and distributed ledger technologies. Quantum computing and brain computer interfaces (BCI) are also not far behind. This race is being felt at a local, regional, national and international level.

Future versions of the stack are already evolving rapidly. Since 2016, Digital Catapult's analysis has shown how the economic potential of advanced digital technologies for UK businesses has grown from nascent exploration to commercial adoption. Within the next five years it is expected to have reached wider deployment, with increasing commercial maturity leading up to 2035. For example, next-generation internet initiatives are looking at how networking infrastructure will meet future requirements for privacy, reliability and availability. Connectivity technologies, including 5G and its multiple iterations over the next five to ten years will enable a new generation of businesses to build better connected, transformative and distributed applications. Such networks will depend on AI to operate efficiently and securely, while the data flowing across these networks will enable AI computation to supplant and exceed today's hand-coded software to provide more intelligent services. At the same time, fully immersive interfaces, rather than today's fingers on glass screens, will form a more direct human connection to these new applications.

London is well-placed to lead the global market, seize the available opportunities and to drive economic growth across the wider UK economy[2]. The capital's academic and research institutions are exceptionally strong, it is home to a world-class digital technology ecosystem and a growing investor landscape, it leads in high impact sectors of the global economy – such as life sciences – and sits at the forefront of creativity, innovation and design. In 2019, the European Regional Innovation Scoreboard (RIS) ranked London as an innovation leader in Europe, with its performance at more than 20% above the EU average.[3]

Academia, research and skills

London is already well-positioned as a global leader in advanced digital technologies. The capital's top tier academic and research institutions will play a critical role in developing a strong advanced technologies ecosystem, with the city having one of the highest concentrations of leading universities in the world conducting research across policy, economics, engineering and biomedical life sciences, as well as art, architecture and design.

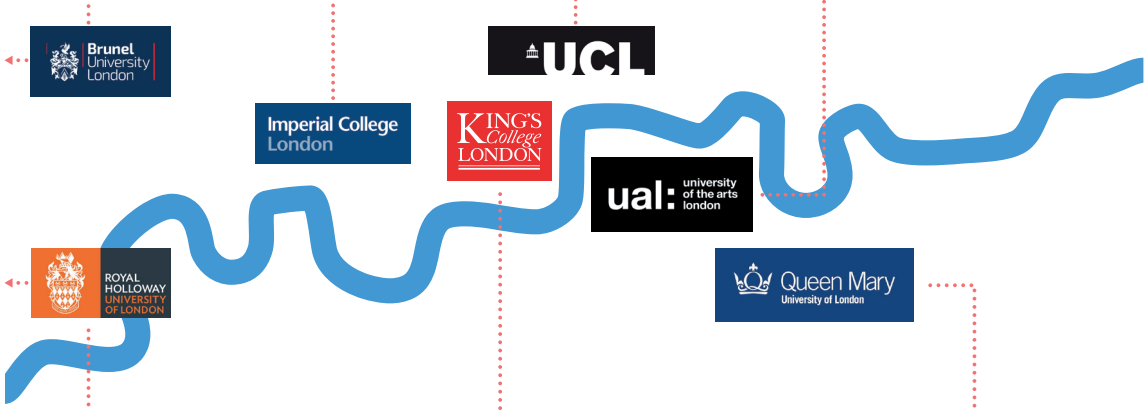
London as a world leader in advanced digital technologies

Brunel University
Human Machine Interaction Department, with recent research on 'Smart Money, an application of Distributed Ledger Technologies to Central Bank issued Digital Currencies' looks at the power of data to improve policy making around controlling money supply for public good, and the development of new fintech services in the UK.

Imperial College London
- The UKRI Centre for Doctoral Training in AI & Healthcare focuses on making healthcare provision more efficient and effective by increasing the productivity of nurses, and developing AI-based diagnostics and monitoring that can detect disease earlier and monitor health with more precision.

University College London
- CDT for AI-enabled Health-care Systems, combining UCL's excellence in AI, computational science and biomedical research to train future leaders to solve the most pressing healthcare challenges.
- CDT for Foundational Artificial Intelligence, training students to create new algorithms for next-generation AI technologies. Incorporating knowledge about the real-world and human culture into AI agents themselves.

University of the Arts London
- UAL's London College of Communication in 2019 launched Europe's first Virtual Reality MA course – providing the opportunity to explore and develop the application of VR technologies across filmmaking, visual effects (VFX), animation, games and immersive augmented reality (AR) experiences.
- Central Saint Martins has a focused MA on the convergence of Science, Technology and Creative design - Material Futures.
- The London College of Fashion in partnership with Polytechnic University of Milan & the Swedish School of Textiles at University of Boras, has been developing interdisciplinary curricula for better higher education within the fields Smart Textiles, Wearable Technologies and Digital Manufacturing.



Royal Holloway University of London
- EPSRC Centre for Doctoral Training in 'Cyber Security for the Everyday', established in 2013. With cohorts of multi-disciplinary researchers with a broad understanding of cyber security and the interplay between technical and social issues.
- StoryFutures Academy, the UK's National Centre for Immersive Storytelling. Delivered with the National Film and Television School developing cutting-edge creative training and research programmes to ensure the UK creative workforce is the most skilled in the world in the use of VR, AR and MR.

King's College London
- The UKRI Centre for Doctoral Training in Safe and Trusted Artificial Intelligence (STAI), is led by a team of renowned experts from King's College London and Imperial College London. It aims to train a new generation of scientists and engineers who are experts in methods of safe and trusted AI.
- Leading researchers in the development of 5G technology, collaborating with Digital Catapult to showcase the world's first fully synchronised concert using 5G low latency, connecting three separate physical locations in Bristol and London.

Queen Mary University of London
- UKRI Centre for Doctoral Training for AI & Music: artificial intelligence, machine learning and signal processing with a cross-disciplinary approach has the potential to deliver ground-breaking original research and impact within the UK creative industries and cultural sector.
- The Media & Arts Technology CDT has facilities for real time motion capture, 3D positional audio capture and other state of the art immersive technologies.

With so many relevant world-leading universities and businesses in close proximity, London provides the perfect environment for collaboration.

University College London (UCL) and Imperial College London both rank in the top ten of the world's universities, with the London School of Economics (LSE) and King's College London also in the top 50[4], London also has leading universities in the design and creative industries, including the Royal College of Art – ranked number one in the world for art and design for the past five years[5] – Central St Martins, University of the Arts London and the London College of Communication. It has world class facilities and research centres for immersive technologies such as the StoryFutures Academy at Royal Holloway, in combination with the National Film and Television School.

In the field of AI and ML, London is home to the Alan Turing Institute and the National Centre for Data Science and Artificial Intelligence, and is the birthplace of DeepMind. UCL, Imperial and King's are all in the top ten universities for AI research in the UK[6], while UCL ranks in the global top 20 for computer-human interaction and Imperial is twelfth in the world for robotics – both scoring more than 50% 4* ratings in computer science and information technologies in the most recent Research Excellence Framework (2014).[7]

With so many relevant world-leading universities and businesses in close proximity, London provides the perfect environment for collaboration. The Knowledge Quarter, near Kings Cross, has one of the highest densities of knowledge-based cultural and scientific organisations and businesses anywhere in the world. According to the 2019 Science and Innovation audit of the Knowledge Quarter, it contributes an economic output (£43.4 billion) similar to that of the City of London (£46.7 billion).[8]

London's world-leading innovation ecosystem for advanced digital technologies

London's research and academic strengths are exemplified by the number of startups and scaleups working with transformative advanced digital technologies in the capital. Through ongoing ecosystem mapping research for advanced digital technology startups in the UK, it has been identified that the country has approximately 1,200 immersive startups and scaleups, 1,200 AI startups and scaleups, 1,000 IoT startups and scaleups and 400 blockchain/DLT startups and scaleups.[9]

London as a world leader in advanced digital technologies

The following figures provide estimated numbers of startups and scaleups for London's advanced digital technology ecosystem, as shown by Digital Catapult's ecosystem mapping activities. This data is based on active companies headquartered in the city that are working with advanced digital technologies. The comparisons of company numbers are taken from Crunchbase and Beauhurst; are all for profit and were founded between January 2010 and December 2019:[10]

London as a world leader in advanced digital technologies

~770+

AI startups and scaleups

London is a global leader for AI startups and scaleups with ~770+ companies working with AI and machine learning based solutions. San Francisco has ~700+, while San Francisco Bay Area combined has ~1,500+. London is ahead of New York (~490+), Berlin (~150+), Paris (~190+), Boston (~100+), Tokyo (~81+) and Dublin (~35+).The capital on its own has more companies than the country counts for Germany[11] (214, according to German site Applied AI), France[12] (338, according to France is AI) and Canada[13] (685, according to J F Gagne 2019 Canadian AI Ecosystem Report).

~250+

blockchain and distributed ledger technologies startups and scaleups

There are more DLT and blockchain startups in London than other large European cities such as Berlin (~60+), Paris (~30+) and Dublin (~15+). London is also not far behind the total number of blockchain startups and scale-ups in San Francisco and the San Francisco Bay Area combined (~350+), and ahead of New York (~170+) and Boston (~20+). London has a larger number of DLT startups and scaleups than Tokyo (~25+) and Hong Kong (~100+).

~550+

internet of things startups and scaleups

London has more IoT providers than New York (~165+), Tokyo (~95+), Berlin (~70+) and Boston (~47+). San Francisco (~230+) and the San Francisco Bay Area (~590+) had the largest number of IoT companies of any city. London has a greater number of IoT startups and scaleups than France (~150+), Germany (~180+), Canada (~210+) and Japan (~130+).

~620+

extended reality immersive technology startups and scaleups

London has a larger number of VR and AR startups than New York (~135+), Boston (~20+), Berlin (~40+), Paris (~35+) and Tokyo (~70+). San Francisco (~165+) and the Bay Area (~382+) had the closest number of immersive startups to London. London contains the most immersive startups when compared to Germany (~110+), France (~65+), Japan (~75+) and Canada (~135+). However, the US has the largest number of immersive startups and scaleups in the world (~1280+), with a similar number to the UK.

There are significant opportunities for London in applying transformative technologies to sustainability and 'technology for good' uses.

London is also home to a rich innovation ecosystem, including incubators, accelerators, venture capitalists/ investment funds, research technology organisations (RTOs) such as the National Physical Laboratory (a world leader for metrology) and the Catapults (including Digital, Connected Places and Cell and Gene Therapy Catapults, part of the internationally recognised Catapult Network), numerous innovation centres and hubs of support such as Plexal, the London Office of Technology and Innovation (LOTI, based at London Councils) and the Transport Innovation Team at TfL, along with specialist acceleration programmes such as DigitalHealth.London led by MedCity and CreativeXR led by Digital Catapult and Arts Council England.

With this underlying world-leading deep technology research environment, London is uniquely positioned as a hotbed of economic activity, talent, innovation and research, all of which are vital to its current and future success. The research and development environment for advanced digital technologies has combined with high levels of investment and a highly evolved startup and scaleup ecosystem, positioning the capital on an upward deep tech trajectory that matches or even outweighs the potential of other global centres, such as San Francisco and Silicon Valley. In 2019, London was listed as the third most innovative city in the world, marginally behind New York (first) and Tokyo (second), and ahead of Los Angeles (fourth), Paris (6th), Boston (8th) and San Francisco (9th).[14] In the 2020 Startup Genome Report, London was also named second in their ranking of tech startup ecosystems in the world.[15]

London's thriving innovation ecosystem is growing in each of the key areas of the advanced digital technology stack. As these technologies continue to converge further, cross-pollination of skills, talent and innovation within the capital will generate significant economic opportunities, with huge potential for regional engagement and international exports.

Net zero, sustainability and ethical leadership

There are significant opportunities for London in applying transformative technologies to sustainability and 'technology for good' uses. The ecosystem can build on the ambitions of the Mayor of London and his strategy to ensure that London becomes a zero carbon city by 2050: for London public transport systems and infrastructure to become carbon neutral, enabling businesses and Londoners to generate as much renewable energy as possible, and planting more trees to enrich greenery and biodiversity within the city.[16]

The Mayor of London has launched a number of initiatives to drive forward the CleanTech ecosystem and its economy in London, including the flagship £1.6 million Better Futures project, launched in 2017 and part-funded by the European Regional Development Fund[17], and the ultra low emission zone (ULEZ) implemented in April 2019.

The Mayor of London and UK Government aim to prioritise ethical approaches to AI and establish the UK as a leader in its trusted application. This has been at the heart of many of the policy activities and conversations that underpin the UK Government's AI and data initiatives. For example, the GLA has appointed an independent ethics panel to advise the use of facial recognition software throughout London, demonstrating its awareness of both the risks and the benefits that the technology can generate for the city.

London is an economic, social, and cultural epicentre, with a concentration of exceptional talent across a range of industries.

Both sustainability and ethics are imperatives for the advanced digital technology stack, over both the short and long term. It is essential for London to become a champion for products and services that help to tackle global and local challenges and lead the way in exporting solutions out of the capital.

London has an influential international position, well-developed infrastructure and top talent, which, if capitalised upon and leveraged correctly, can create significant opportunities for foreign direct investment into the UK's innovation ecosystem, ensuring that trust and sustainability within technology sits at the heart of the city's USP.

London's industry strengths

London has a number of world-leading sectors and industry strengths, and numerous potential use cases for combined advanced digital technologies are explored in this report. The sectors where London is particularly strong can have a broad impact for the UK. They include:

- Financial and business services
- Creative industries, media and entertainment
- Hospitality and retail
- Industrial/transport and logistics/supply chain and manufacturing
- Health and life sciences

The example use cases contained in this report shine a light on how the future of these sectors might look and on the steps that can be taken by industry, the Mayor of London and the UK Government to ensure London maximises on its potential in this space to become a powerhouse for innovation. It will also touch on nascent areas of capability that may grow to be influential within the London economy over the next 15 years.

The importance of London to the UK economy

London generates 22% of UK GDP while only accounting for 13% of the population.[18] At the same time, the UK's capital has the eighth largest economy in Europe; larger than many other national economies, such as those of Austria, Belgium, Norway, and Sweden.[19]

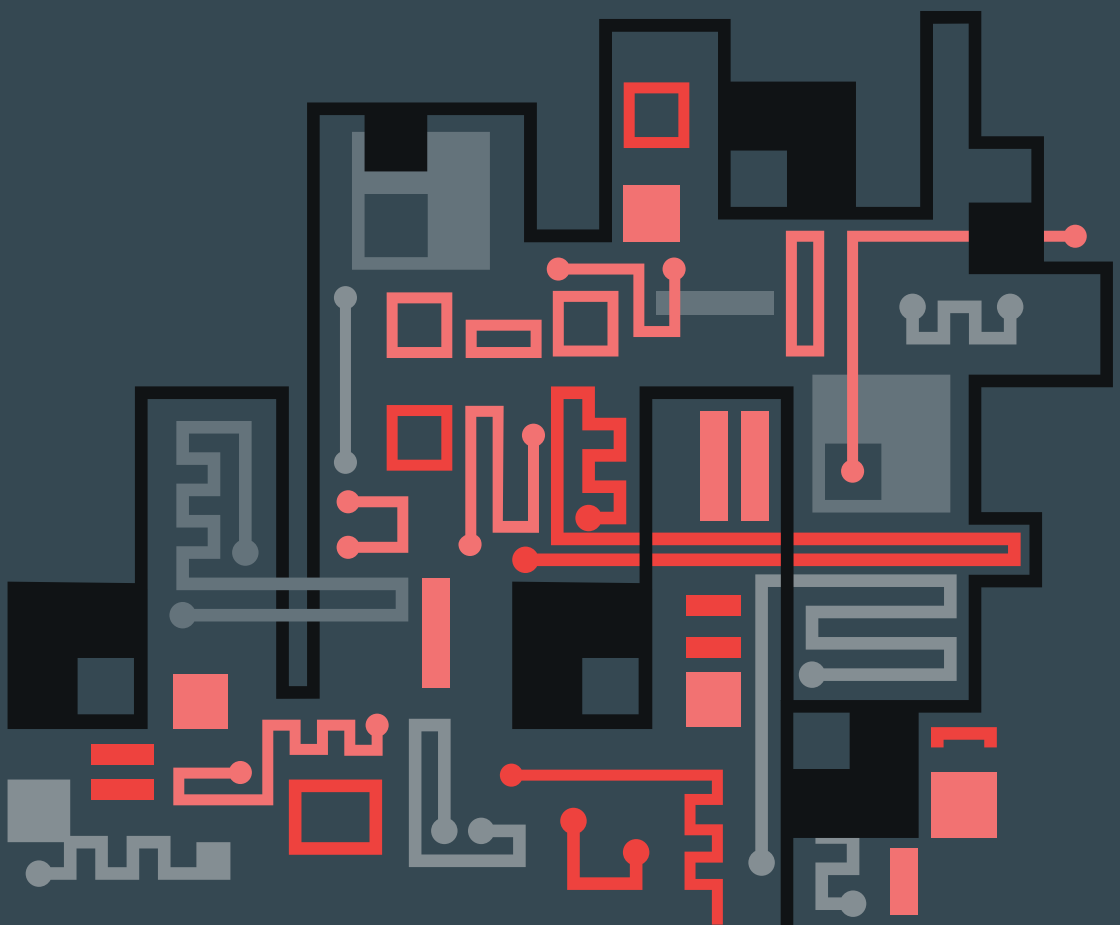
London is an economic, social, and cultural epicentre, with a concentration of exceptional talent across a range of industries. The close proximity of multi-sectoral expertise, research institutions, entrepreneurs and national and international investment – alongside its favourable regulatory environment, central and local government support and innovation centres – has led London to become a national and global hub of economic activity that makes the capital unique in Europe, and one of the leading cities in the world.

London's breadth of sectoral expertise, with high population density and cluster-like emergence of sub-economies, has enabled the city to benefit from 'agglomeration effects', that is, productivity enhancements from dynamic knowledge transfers. This offers significant opportunities in the development, commercialisation and growth of advanced digital technology applications, products and services that can be exported to meet growing regional, national and international demand.

If the right approaches are taken over the next five to ten years, London's strengths, capabilities, and strong relationships with other regions, coupled with specialised innovation and acceleration programmes, will drive the convergence and adoption of the advanced digital technology stack described in this report. This will provide greater socio-economic opportunities, and help accelerate the adoption of these technologies at a transformational pace for the entire UK economy.

The advanced digital technology stack

Contents

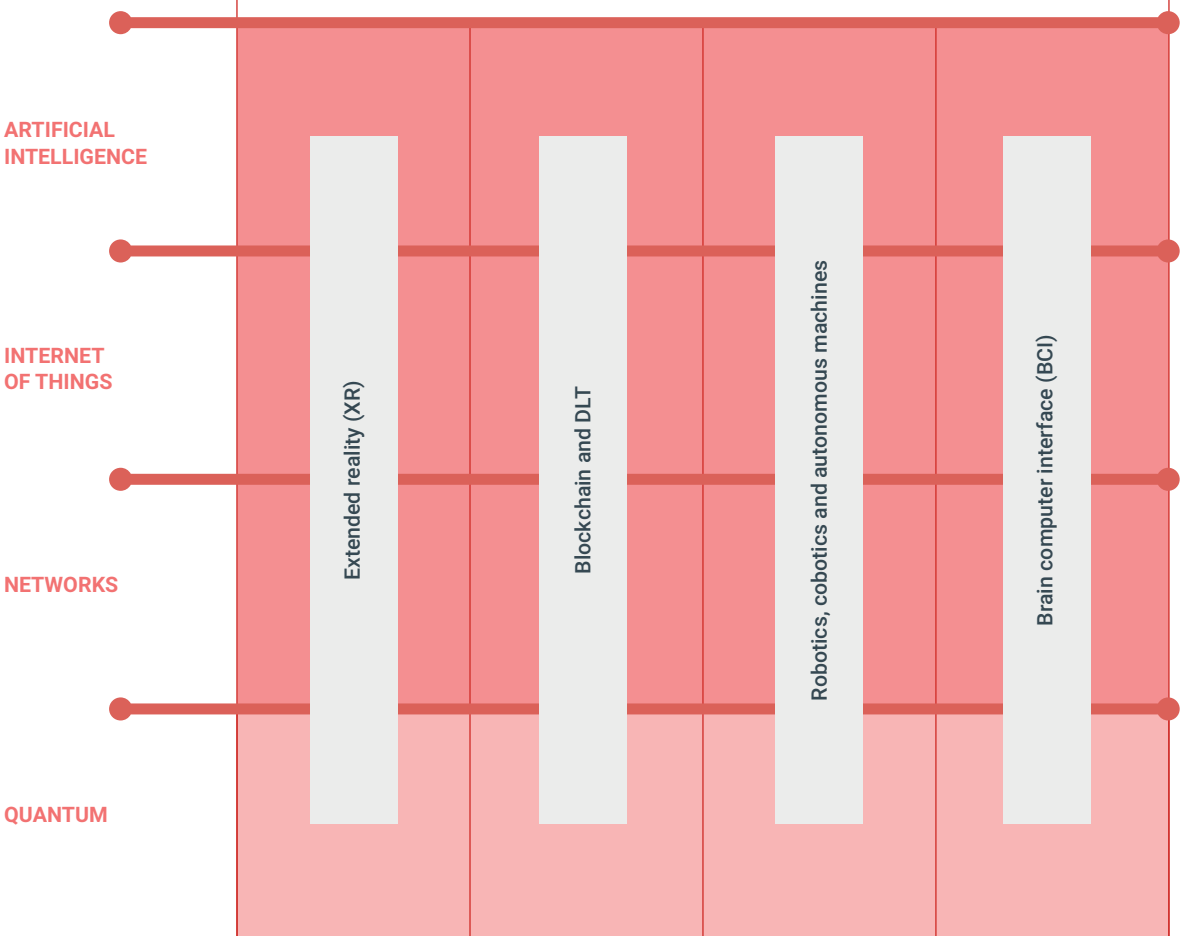


The advanced digital technology stack

The technology stack diagram below illustrates the broad convergence of advanced digital technologies.

The advanced digital technology stack

The advanced digital technology stack is already starting to enable a number of technologies to combine, forming exciting and transformational changes to businesses of all sizes and driving economic growth. These technologies increasingly blur the divide between the physical and digital world, creating new and innovative ways for us to interact with and use data to solve challenges and realise new possibilities.



Good quality and useful data is still the fundamental driver for innovation.

Over the last two decades, digitalisation and trends in technology have led to an exponential increase in the amount of data being collected, stored and processed across the UK and globally. Using and unlocking the value in this data is often crucial to innovation and increases in productivity. The Mayor of London has already responded by creating the London Datastore, a valuable tool for businesses and policy makers that shares data publicly and privately. This online service shares over 6,000 datasets, and provides an API that companies can incorporate into their products, applications and services for regular updates.

The current landscape

According to a report by Seagate and IDC in January 2019, the global datasphere (a measure of how much new data is created and replicated each year) will grow by more than five times over the next seven years. By 2025, it is projected that the amount of new data created globally will rise to 175ZB – in comparison to 2018, which generated 33ZB (one zettabyte is approximately equal to a billion terabytes). The report suggests that Europe, Middle East and Africa (EMEA) will increase from 9.5ZB in 2018 to 48.3ZB in 2025.[20] The explosion of data generation and collection is fuelled by vast quantities of sensor devices and internet of things, video surveillance, metadata and entertainment. In particular, user-created and user-consumed data (such as online video from YouTube) is a big driver in this trend.

Data lies at the heart of the digital ecosystem, and as its use and volume increase, so will the demand for next-generation products and services. Yet large volumes of data on their own are not useful and too often we see companies collecting and storing data with the view that it will be worth something in the future. In reality, good quality and useful data is still the fundamental driver for innovation – and deploying advanced digital infrastructure that has standardised approaches, security and interoperability considerations in its design, will be critical to how data can be collected, processed and used ethically, accurately and in ways that extract value for businesses.

The diagram below illustrates the underlying technologies that form what we call advanced digital infrastructure.

Advanced digital infrastructure

Advanced digital infrastructure is the combination of sensors and devices that collect data, future networks such as 5G that connect data with greater speed, accuracy and reliability, artificial intelligence and data science capabilities to analyse and intelligently action that data and computation that helps to process data. In the future this may evolve to include quantum computing capabilities. These are the foundations that will underpin business applications and services across the global economy in the future.

ARTIFICIAL INTELLIGENCE

The ability of a digital computer to perform tasks commonly associated with intelligent beings. This includes everything from machine learning (which includes predictive analytics, deep, reinforcement and federated learning), Speech recognition, computer vision (including image recognition and machine vision), Natural Language Processing (NLP) and expert systems (a computer system that emulates the decision-making ability of a human expert).

INTERNET OF THINGS

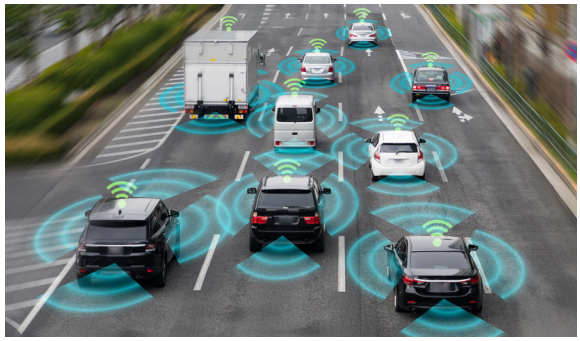
The Internet of Things includes industrial and smart city sensors (spanning sectors and use cases including healthcare and manufacturing); wearables and on person connected devices (such as smart watches and clothing); and smart home devices for monitoring and automation (such as lighting and energy systems). This will increasingly offer actuation (triggering an action from the device) and edge devices (providing inbuilt data analytics capabilities).

NETWORKS

Spanning the full scope of network technologies, the future networks in the stack will be underpinned by greater control, reliability and flexibility. This will include everything from 5G, to future iterations of mobile connectivity, as well as cloud-based connectivity through fibreoptic internet, as well as NB-IoT and other related technologies such as Low Powered Wide Area Networks.

QUANTUM

Quantum computing will develop further and may in the future form part of the stack as the use of quantum-mechanical phenomena such as superposition and quantum entanglement enables new approaches to computation. a quantum computer will offer new capabilities allowing for parallel calculations at speed impossible using current computers, with huge potential in chemistry, optimisation problems and unstructured search.



Considering this background of data generation and the need for better data quality, it is important for the London ecosystem, the Mayor of London and the UK Government to set out clear plans for an advanced digital infrastructure, encouraging and de-risking private sector investment into R&D and building specialised challenge-led innovation activities to help accelerate adoption. This will allow the capital's advanced digital technology providers and important industry sectors to test and explore how such an infrastructure will enable innovations that can transform the London economy and have a broader impact across the UK as a whole.

While much of the narrative around productivity and economic growth in London and the UK tends to focus on products, applications and services and the challenges they solve for industry, there is less focus on the connectivity that enables them to be built and used at scale. Furthermore, AI and ML capabilities are often seen as being out-of-the-box products or applications, when they should be viewed as an integrated technology that underpins the ability of other products and services to work autonomously and intelligently.

The importance of 5G and next-generation connectivity

As the advanced digital technology stack evolves, the network infrastructure – including 5G – acts as the backbone on which products, services and applications are built. Over the next 15 years, we will expect to see 5G and future iterations of mobile connectivity become common currency in different use cases: industrial applications that can benefit from cellular mobility, security and low latency; remote healthcare solutions, such as digitalised assisted living; and enhanced city-wide transport systems, including the use of connected autonomous vehicles.[21]

The importance of 5G (and the future networks it currently represents) is in its transformational nature. It not only provides faster connectivity – thanks to its reliability, accuracy and enhanced reach, it also enables use cases and processes that have previously been impossible, or were under-performing. For example, through wearable technologies, patients could feed real-time data on their health back to their doctor for monitoring, or other healthcare services; and doctors could use ultra-high definition telemedicine feeds or AR for consultations; and even conduct surgeries remotely. In industry, 5G can facilitate the remote control of robotic tools in hazardous environments, or the tracking and monitoring of geographically distributed industrial assets to improve sustainability and efficiency across the supply chain, reducing the loss of perishable goods and creating greater resilience in the face of shocks (as has been seen with COVID-19).

5G is expected to contribute up to £173 billion to the UK economy over the next ten years.[22] This is largely due to the scalability it provides for advanced digital technology services, as well as enabling businesses to create entirely new business models, products and services. Network function virtualisation (NFV) and software defined networking (SDN) – two of the differentiating capabilities of 5G – allow seamless scalability and control of a network, with reduced overheads and operational costs. As businesses grow, they no longer need to add more hardware to improve their connectivity – they can use virtual software to upgrade instead.[23]

The Mayor of London's ambition, through the Connected London initiative and team, is to help make London the best-connected city in Europe.

Despite its huge potential, 5G is often mistakenly perceived as being similar to 4G, only faster. The "network operators can build it, and we'll then see if we want to use it" approach limits the potential of 5G to consumer-centric business models and services only, whereas the reality is that 5G needs co-investment from different industry sectors to explore what its capabilities will mean for other emerging technology applications. While these other applications (such as AI, immersive and DLT) are at the forefront of private sector R&D investments and exploration, 5G and next-generation network connectivity are not. In order to accelerate adoption of 5G by both supply and demand, there is a significant need for all parts of the value chain to collaborate (that is, network providers, system integrators and industry working together on solutions with technology innovators). To make this happen faster and accelerate adoption, exploration must be de-risked and incentivised to bring innovations to market faster in the UK.

Initiatives and investments from the UK Government, such as the Department for Digital, Culture, Media & Sport's 5G Testbeds and Trials Programme (2017-2022) have helped to kickstart co-investment, with competitions such as Urban Connected Communities, Rural Connected Communities, Industrial 5G and future competitions being launched as a result. However, more can be done by both industry and the Greater London Authority to encourage London to be a centre for R&D activity, and to help and inspire those startups and scaleups developing products and services across the advanced digital technologies stack to explore what 5G will mean for them.

The Mayor of London's ambition, through the Connected London initiative and team,[24] is to help make London the best-connected city in Europe through broad availability of full fibre connections and continue to extend 5G coverage. The Connected London team, established in 2017, works with London's local authorities to help share information and coordinate with digital infrastructure providers to enable investment into fibre and mobile infrastructure in underserved areas in London. The programme includes working with Transport for London (TfL) on its Connected London network[25] and harnessing public sector assets to enable digital infrastructure rollout. 5G use cases are also being explored in six Creative Enterprise Zones in London, with the Mayor of London's Chief Digital Officer kickstarting work to identify civic use cases launched in March 2020.

To drive increased use of the city's growing advanced digital technology infrastructure, Digital Catapult recommends that the Mayor of London encourages London-based businesses to join the UK Government's 5G Testbeds and Trials Programme and connect to the UK5G Network. Businesses should also be encouraged to engage with Digital Catapult (the Catapult Network lead for 5G), and conduct strategic activities, such as workshops and roundtables, to encourage London's startup and scaleup ecosystem to explore how 5G can help the development of their future products and services.

Digital Catapult already provides 5G access through the 5G Testbed Accelerator programme and the Industrial 5G Accelerator with Ericsson. Further collaboration between the Mayor of London and Digital Catapult can help to align ambitions, benefiting businesses in the capital and maximising on existing innovation and acceleration activities.[26] Industry should also be engaging with local authorities and the Mayor of London, particularly through the Sharing Cities initiative[27], to gain a better understanding of balancing borough responsibilities for service delivery and residents' needs with infrastructure design.

Furthermore, it is also recommended that the Mayor of London participates in ongoing discussions (such as by the European Commission) on international standards for future mobile deployments, and evolutions of mobile connectivity. This may be 6G, but may also focus on the ongoing evolution of advanced digital infrastructure, as it is upgraded iteratively, rather than through large-scale deployments. Enabling businesses to regularly explore what these iterations mean for them will put London ahead of the market and help to drive further growth.

The evolution of AI, machine learning and deep learning

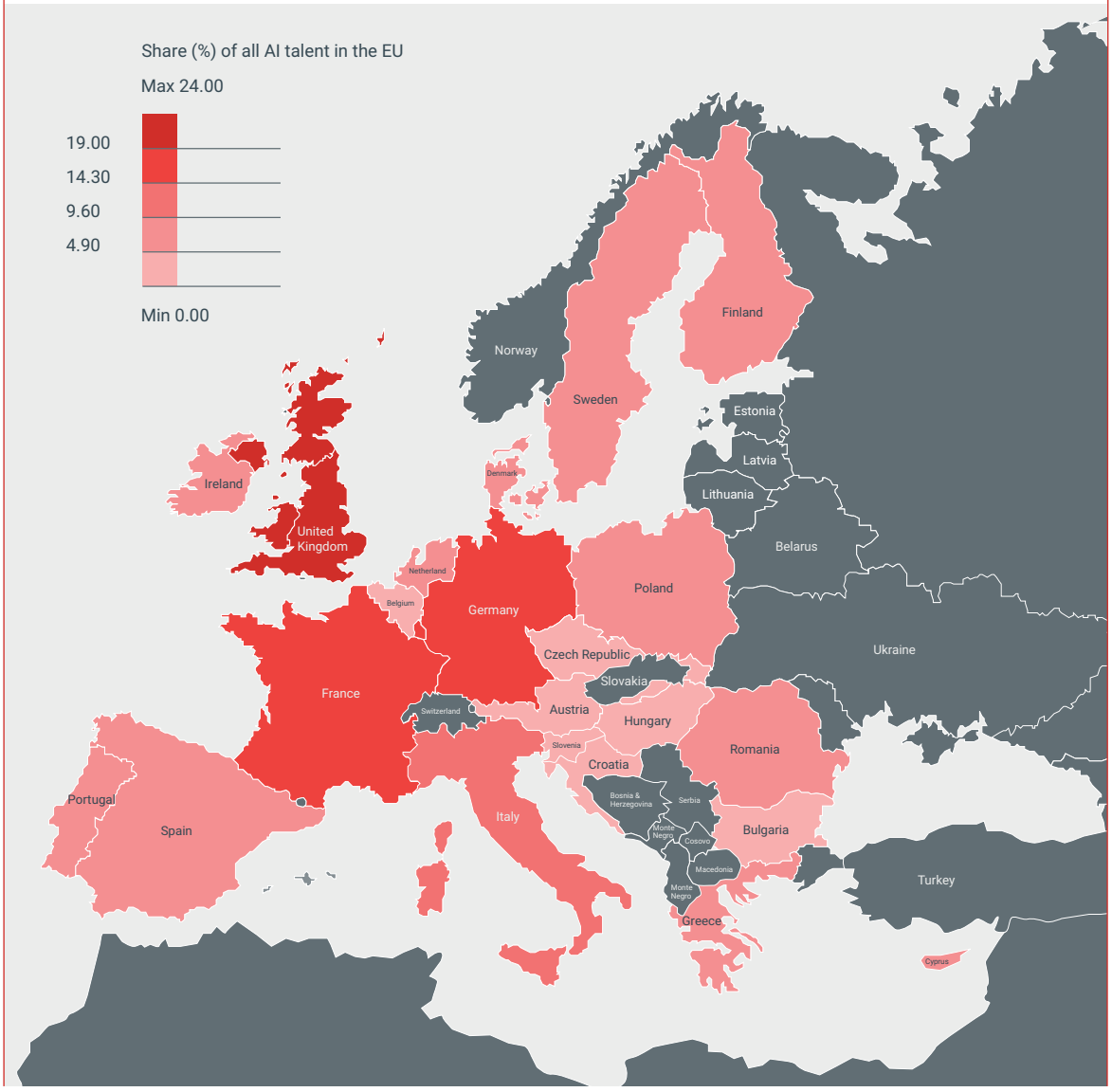
Today's AI, ML and deep learning has been made possible through wide-scale improvements to computation power, and the use of internet-scale datasets for training ML models. Improvements in computation power include developments in central processing units (CPUs) and the application of graphic processing units (GPUs), new specialised ML chips, and developments in smartphone technology. Enhanced compute power is essential for handling the large volumes of data used by AI algorithms in machine learning and deep learning.

With the development of new research and approaches in deep learning in 2006-2009 , there has been an exponential increase in new deep learning techniques for commercial and consumer applications. Deep learning systems can discover features and make predictions using diverse data sets. However, it's an inefficient process that requires large volumes of training data and computation, and is less accurate when used beyond these original data sets. Deep learning models often lack interpretability, with many 'black box' challenges – there are inputs and outputs, but the end user has little to no knowledge of how the system works in practice.

New approaches to AI applications will enable deep learning to evolve and develop architectures that can better understand the relationships between data points, and then represent them in ways that are useful for downstream processing. London's strengths in the research and innovation of combined artificial intelligence approaches will offer exponential growth and scalability to AI startups and scaleups in this space over the coming years, providing early access to solutions that will decrease compute power inefficiencies, and increase the number of products, applications and services that can be built using AI technologies. It will also have the potential to greatly improve the explainability of AI and deep learning decision making.

The advanced digital technology stack

The UK is home to 24% of European AI talent (see map below)[28] with a large percentage of this talent based in London. The capital is home to global leaders in AI research, namely Turing, Imperial College and UCL and benefits from spillover effects of the 'golden triangle' (London, Oxford and Cambridge). (Map source: AI Talent in the European Labour Market, LinkedIn Economic Graph, 2019.)



Enabling AI startups to bridge the gap between proof of concepts and enterprise adoption will create the perfect market conditions for widespread industry application.

London is a world-leading commercial AI hub, and home to companies such as Deepmind. The success of ML companies is not only predicated on having in-depth technical knowledge for the development of ML solutions, but also on in-depth domain-specific knowledge to be able to frame the technology's application.

London has significant potential to adopt AI more quickly and on a greater scale than many other cities in the world, as it is already home to leading industry expertise. Data scientists and AI companies can work with challenge owners from specific sectors and sub-sectors, to curate and label data sets that solve defined problems by applying the correct specialist knowledge to the types of data needed to solve a particular challenge.[29]

As part of London's strategy for adopting advanced digital technologies and AI more effectively across the digital ecosystem, steps should be taken to help provide opportunities to engage directly with university departments and become closely connected to AI master's programmes to those startups and scaleups that do not have access to data science capabilities and cannot compete with tech giants for data science talent. As highlighted in the AI sector deal, it would be advantageous to utilise MSc programmes and skilled postgraduate students to bridge any talent gaps.[30] London has a multitude of acceleration programmes that can be leveraged to enable the next generation of technologists to gain industry experience and build products and solutions with exciting young startup businesses.

The Mayor of London also needs to help bridge the gap between the end of early stage AI startup support and the scaleup phase, to help build additional sales pipelines for AI companies and provide a more collaborative environment for industry to adopt the technology. This approach could also work with the Catapult Network and connect the London innovation ecosystem with the UK regions, to help overcome capability failures. This will also overcome the lack of business cases for AI technologies, which can be a barrier to investment and adoption. By encouraging and enabling AI/ML startups in London to build sales pipelines and bridge the gap between proofs of concept/pilots and enterprise adoption, the Mayor of London and the UK Government will create the perfect market conditions for widespread application. This was highlighted by the 2019 evidence briefings from the House of Lords APPG on AI.[31]

According to Digital Catapult's research, 60% of ML startups interviewed stated that they were limiting their growth and ability to train AI algorithms because of the high costs associated with computation power.

The need for compute resources to train the newest algorithms is rocketing, with AI developers hoping for the creation of new AI chips that harness more computation power and better cost-efficiency, cloud and edge computing architectures to better support deep learning and neural networks; and the ability to leverage faster insights. A number of acceleration programmes have already been set up to mitigate this need. Digital Catapult's Machine Intelligence Garage provides early-stage machine learning startups with access to computation power and cutting-edge AI hardware. Tech Nation's Applied AI programme supports later stage AI/ML companies (post series-A funding) by delivering six-month sprints that create opportunities for under-represented and diverse innovators, and providing access to mentorship and courses.

Dependency on the availability of relevant, clean and appropriately voluminous and broad datasets is another challenge for AI solution developers. Without access to adequate data relating to their subjects of interest, startups are unable to make significant breakthroughs in their application of AI. The Mayor of London can help to broker data sharing agreements with the private sector, technology

Over the next ten to 15 years, the maturity of the IoT market will bring significant improvements in how AI and IoT are used, working in concert with other parts of the advanced digital technology stack.

innovators and local government bodies – extending the remit of the London DataStore and directly connecting its capabilities and challenges to the Mayor of London's Civic Innovation Challenge, which offers an opportunity for start-ups to work together with leading corporates and public organisations to tackle some of London's most pressing problems. Its first iteration focused on challenge-led innovation for start-ups to develop innovative solutions to democratising planning, tackle congestion and counter violent extremism online.

The Mayor of London and the organisations co-funded by the Mayor, such as London & Partners (the international trade, investment and promotion agency for London), will greatly benefit from connecting more closely to existing AI innovation and acceleration programmes (such as Digital Catapult's Machine Intelligence Garage and TechNation's Applied AI programme) in the capital and across the UK, building a deeper policy and innovation understanding of the constantly evolving nature of the technical and business challenges and opportunities facing advanced digital technology startups. These connections can also help to plug these startups into various Mayor of London initiatives and schemes. This will help to ensure a sustained supply of AI innovations coming to market, and better future policy planning to stay ahead of the curve.

Establishing and building a practical AI Ethics testbed in London will help to ensure that its AI developers are well equipped in the ethical considerations required for sustainable solutions that can be used at scale by the public and private sectors. This has been indicated through a number of reports, including the work from NHSX[32] and the consultation undertaken by the Centre for Data Ethics and Innovation in 2019.[33] Digital Catapult is taking active steps to establish this testbed, based on the work of its independent AI Ethics Committee, chaired by Professor Luciano Floridi from the Oxford Internet Institute.[34] This stronger understanding of practical ethics in AI will be crucial to London and the UK achieving global leadership in the field of sustainable and ethical approaches to AI.

Building on the Mayor of London's Civic Innovation Challenge, the Mayor of London should also focus on how to promote and support broader applications of AI for social good: to facilitate access for AI startups and scaleups to advocacy groups and social purpose challenge owners, while exploring the development of AI-powered solutions based on ethical frameworks and approaches.

The growing importance of the internet of things

On a global scale, industry has been gradually adopting the IoT over a number of years. In 2014, 13% of businesses worked with IoT, but by 2019 this figure had risen to approximately 25%.[35] McKinsey estimates that between $4-11 trillion a year could be added to the global economy by 2025 through the use of IoT devices.[36] The internet of everything (IoE) is considered a superset of the IoT, and while the premise of connected devices remains the same, the IoE takes the connection to the next level, with almost all hardware and devices being connected to networks. While the IoT may connect a railway track, signals and junctions, the IoE will also connect trains, ticket machines, staff, and customers, while factoring in variables such as the weather conditions.[37] The IoT is a transformational technology capable of creating opportunities for businesses to develop new products, services and solutions, while improving efficiency, productivity and organisational performance through IoT-enabled devices that can also harness AI's predictive capabilities[38].

Over the next ten to 15 years, the maturity of the IoT market will bring significant improvements in how AI and the IoT/IoE

are used and how they work in concert with other parts of the advanced digital technology stack – for example, how a device is implemented to capture richer or more relevant data, or how it is visualised, as currently, most IoT data is not used. For example, on an oil rig that has 30,000 sensors only one percent of the data collected may be examined, mainly because the unused information is used to detect and control anomalies rather than make optimisations or predictions, which is where IoT can be most valuable.[39] Other trends include the advancement of more sustainable and 'green' hardware, and edge computing that allows data to be processed locally, resulting in cheaper operational expenses. Better availability and cost efficiency will enable more applications to be made, including large scale monitoring and detection.[40]

The IoT market will continue to grow as new and existing devices, software and capabilities will be linked with IoT sensors and help to address systems issues, including interoperability. Connected with ultra-reliable ultra-low latency communication that may be provided by future 5G networks, actuation (the ability to make a machine take a particular action) will become a much stronger aspect of the IoT – its current predominant use is data gathering. Reliable and timely actuation will allow many more real-world processes to be autonomously influenced and made adaptive to real-world events, for example, industrial processes, supply chains and logistics, energy management, water flow and traffic management.

Over the next ten years it will be imperative to enable better data visualisation and management of the large volumes of data being collected by the IoT in order to extract value from data silos. Recognising that 60 billion devices will be connected by 2022, and understanding the landscape of IoT challenges, GeoSpock, a Cambridge and London-based startup, has capitalised on this opportunity and developed a data visualisation platform that enables users to leverage better insights from IoT-collected data. GeoSpock will power future mobility applications, including the management of autonomous vehicle fleets, and help businesses across the automotive, marine, media and retail sectors. This platform is an example of how the IoT can be used to make better evidence-based decisions to support safety, sustainability and increased profit margins. By the end of 2019, GeoSpock had raised a total of £19.25 million in funding.[41]

IoT deployments in London

The value of the IoT is well understood across London. The insights to be obtained from large amounts of data collected in real-time through 5G networks are significant.

A number of London boroughs are already engaged in IoT pilot projects. Sutton, Croydon and Watford have put forward local challenges as part of Digital Catapult's Low Powered Wide Area Network Testbed programme[42] and are now using IoT solutions to improve the way that the pollution impact of large construction sites is managed, to provide increased visibility of taxi services and residential parking for citizens, and increase travel independence for young adults with learning disabilities. The South London Partnership is in the process of procuring a multi-purpose IoT platform, as part of the InnOvaTe[43] project, to enable further use cases that help Londoners to live better, healthier lives and to generate economic growth in their boroughs.

London Bridge station is installing IoT sensors to help prevent delays and train cancellations.[44] The information collected will be processed using machine learning to anticipate potential faults in advance. Inputs to this predictive maintenance system will come from a number of sources, including camera feeds from the front of trains, satellite imagery and weather forecasts.[45] Mass deployment of this technology will tackle the more than 233,000

The Mayor of London should consider the deployment of edge IoT devices as a crucial enabler for AI solutions.

cancelled rail journeys a year in the UK, saving the economy thousands of lost hours.[46] This kind of optimisation is not exclusive to 'smart cities': manufacturing sites and retail sectors (among many others) are already benefiting from IoT powered predictive maintenance and other use cases.

With more such IoT deployments emerging over the next decade to underpin private sector and public service delivery all over London, it is important that investment in standards-based technologies and harmonisation takes place across all the capital's boroughs. This will ensure that new London-wide services can be effectively realised through increased interoperability, while being able to freely leverage the latest innovations and the benefits of economies of scale. International alignment with peer cities, such as through Open and Agile Smart Cities[47] represents an important first step in this direction.

IoT will also play a key role in the emerging urban data economy by providing a rich set of real-time data that can be used beyond the initial application or service for which IoT infrastructure was initially deployed. London has taken the lead in making data available for urban innovation through its world class open DataStore[48]. Such capability can be further augmented to support more efficient sharing of IoT data between different London boroughs and other private and public sector stakeholders.

IoT as an enabler for localised AI capability

Over the next five to ten years, a significant amount of the data required by future AI-enabled services will come from IoT devices deployed as part of the advanced digital infrastructure in factories, buildings and public spaces, or from those being worn by or attached to people, animals, assets and goods.

IoT is a core element in the advanced digital infrastructure required for businesses, public services and the built environment. It will deliver accurate real-time information on real-world occurrences and conditions (such as temperature, air quality, vibration, images and video) for analysis by humans, or to be intelligently processed and actuated by machines. At present, most IoT data flows into cloud platforms, where other service layer technologies make use of it. As the number of IoT devices being deployed across the capital increases, the result will be an explosion of data, making its centralised processing through cloud platforms increasingly challenging.

This is one of the factors behind IoT data processing being moved to 'the edge': a local facility or even on the IoT device itself. Being able to conduct analysis locally or even in situ avoids a great deal of unnecessary data communication and transfer. New IoT and edge processing hardware devices that are smaller and require less energy are being developed, enabling the use of AI without having to first transfer data to the cloud.

The Mayor of London should consider the deployment of edge IoT devices as a crucial enabler for AI solutions, and as part of the broader advanced digital technologies stack and advanced digital infrastructure. The deployment of these devices will be made possible when combined with networks such as 5G, enabling high speed data throughput, accurate measurement and processing of real-time data, and improved security and greater flexibility through private 5G networks, isolated network slices, and 'network of network' capabilities. The Mayor should also consider the security and ethical implications of using AI at the edge, to ensure that data privacy is considered.

Edge IoT is a crucial component of the advanced digital infrastructure of a modern and innovative city. London will

The capabilities of quantum computing offer huge potential for the London economy by opening up new frontiers in drug discovery, material sciences, smart cities and possibly in AI algorithms themselves.

have a significant opportunity to create economic opportunities for businesses across the capital by connecting innovators to shared data through a data marketplace or by extending existing platforms such as the London DataStore. This will provide access to the data being generated by IoT devices in real-time, making it possible for startups and scaleups to integrate artificial intelligence capabilities into their products, applications and services of the future. For example, AI capabilities coupled with 5G can enable the processing of large volumes of image data for computer vision or autonomous vehicles. A localised London-based edge mobile compute facility would help to drive this forward and serve the needs of the capital, so should be considered alongside large-scale IoT deployments.

Future potential through quantum computing

When looking at infrastructure within the advanced digital technology stack, it is important to give consideration to quantum technology and its potential commercial impact. Quantum computing may still be a number of years away from consumer and commercial maturity, but it is increasingly under a global spotlight due to recent advancements (see latest announcements from IBM Q and Google).[49] In 2019, high growth potential quantum startups emerged from London-based universities. Rahko, for example (which originated from Conception X at UCL, and recently raised seed funding of £1.3 million led by Balderton Capital) is building 'quantum discovery' capability for chemical simulation, which could enable ground-breaking advances in batteries, chemicals, advanced materials and drugs.[50]

To understand what quantum is, it is useful to understand what it is capable of. Current electronics process data using the binary values one and zero ('bits'). All values are either one or another, like an electrical switch. In quantum technologies, information is processed as quantum bits, or 'qubits'. Like bits, qubits can also be in a state of one and zero, but in addition they can be both at the same time, creating a continuum of possibilities. Thanks to an additional quantum effect known as 'entanglement', it is possible to link two qubits together, so that when changing the state of one, the other will be automatically affected. This may have a profound impact on how data is stored, processed and used in the future – offering significantly faster and more complex systems, applications, algorithms and mathematical models to be created with greater efficiency – opening up vast possibilities for society and the economy.

A report from Government Office for Science in 2016 titled 'The Quantum Age: Technological Opportunities'[51] broadly characterises quantum technologies into three areas:

- **Quantum widgets**[52] – a set of technologies that will improve the way we sense things (for example, using 3D vision, underground materials/objects, biomedical markers) and measure time
- **Quantum communication** – technologies that will improve communication security and enable large distributed computing
- **Quantum computing** – technologies that use large sets of qubits to perform complex calculations, mainly relating to drug discovery and complex optimisation problems

The capabilities of quantum computing (such as being able to easily simulate complex quantum molecular dynamics) offer huge potential for the London economy by opening up new frontiers in drug discovery, material sciences, smart cities and possibly in AI algorithms themselves. London already plays a world-leading role in each of these areas, making it likely that quantum-enabled products, applications and services will play a significant part in its economic and industrial future.

Enabling startups and scaleups to develop products and services that meet industry demand, helps to move beyond short-term proof of concepts to adoption of solutions that can transform whole businesses across multiple sites.

London's strengths in this space have already led to the launch of the UCL Centre of Excellence for Quantum Technologies, incorporating the UCL Quantum Science and Technology Institute and the EPSRC Centre for Doctoral Training in Delivering Quantum Technologies at UCL. Amazon's AWS platform now hosts three North American startups: Rigetti Computing, DWave Systems and IonQ, and although Amazon's quantum offering is currently based in the US, it is expected to evolve and work closely with London's research community through UCL, where its Director for Quantum, Professor Simone Severini, is also a professor.[53] UCL has also partnered with Plantagenet Systems, D-Wave, BT and the University of Bristol through a 12-month Innovate UK grant to explore the commercialisation of quantum technologies and how they can be used in the logistics and planning space.[54] The Imperial Centre for Quantum Science, Engineering and Technology (QuEST) draws on a diverse selection of world-leading engineers and scientists who share an excitement for the potential of the quantum domain, and their research will also undoubtedly improve the innovation landscape for quantum computing technologies in London.

While quantum computers will not become portable systems, like current digital technologies, within the foreseeable future, it's possible to imagine scenarios of digital-quantum hybrid clouds (an approach being pioneered by Rigetti Computing), where quantum hardware investments and quantum software will be essential to success. Indeed, a recent analysis from Nature[55] indicates investments are growing globally across each of the bulleted quantum technology areas above. In 2017 and 2018, companies globally have received a minimum of $450 million in private funding — more than four times the $104 million disclosed over the previous two years. This trend has similarities to the early years of AI investments, demonstrating that quantum technologies are maturing towards commercial applications.

Getting London's advanced digital infrastructure right

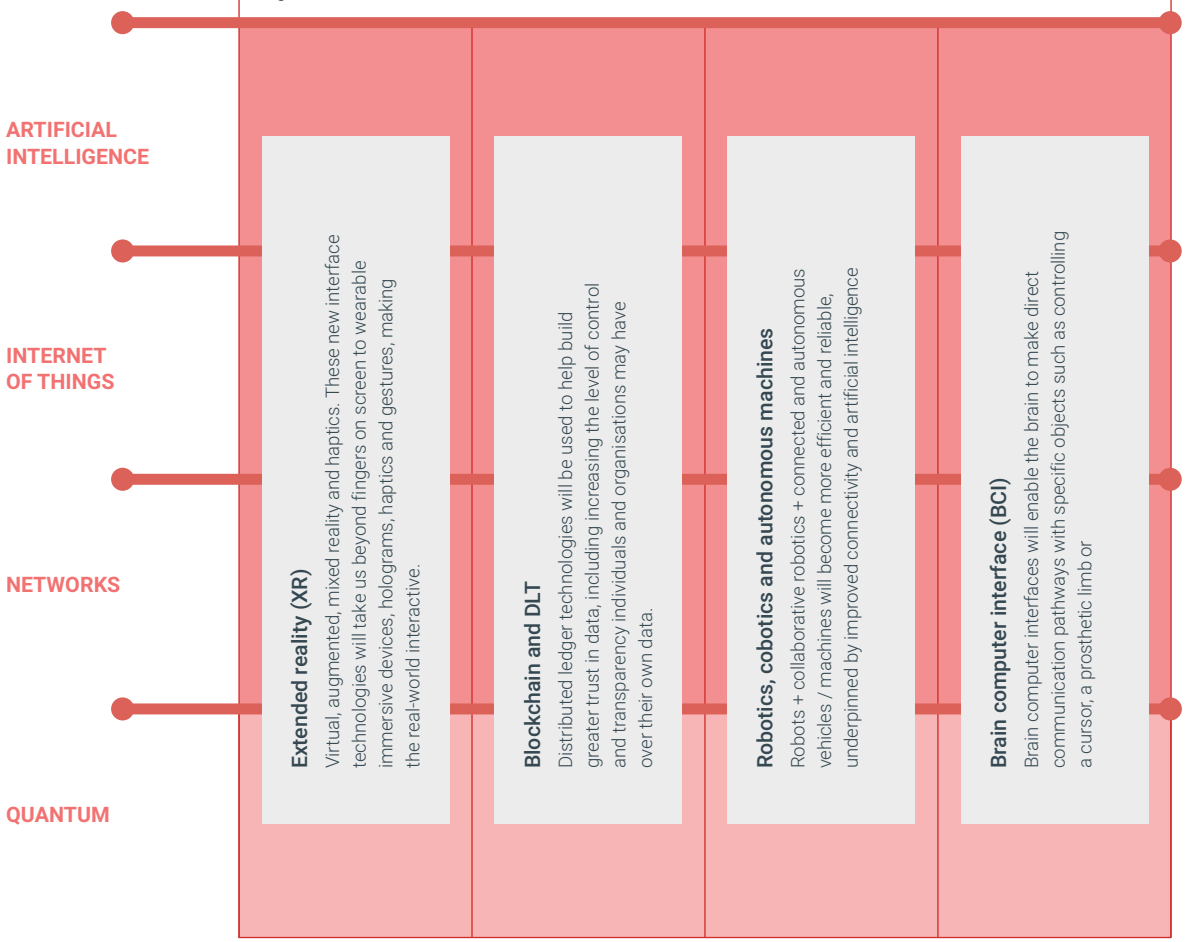
Establishing the foundations and capabilities that most future services and applications will be built on is fundamental to London's future economic success and global leadership in advanced digital technologies. It is also vital to the spillover effect for the broader UK economy.

By enabling innovative digital startups and scaleups to develop products and services that meet the needs of industry demand, it will be possible to move beyond short-term proof of concepts and pilots to the adoption of solutions that can transform whole businesses across multiple sites. This will evidence the business case for investment into advanced digital infrastructure by industry.

However, to get to this point the Greater London Authority should work with UK Government (in particular the Office for AI and the DCMS 5G Testbeds and Trials Programme), to encourage collaboration between the digital innovation ecosystem in London (including startups and scaleups), universities and research institutions (such as KCL for 5G, UCL and Imperial for AI), telecoms providers and network operators, industry players and system integrators. This will help to overcome any lack of awareness of relevant R&D activities and funding and collaboration opportunities for advanced digital infrastructure across the value chain, and enable a fragmented ecosystem to come together and build scaled demonstrations of London's capabilities and expertise in this space.

The advanced digital technology stack

Advanced digital technology service layers will transform the way we live and work, providing new ways of interacting with data and moving us beyond 'finger on screen' applications to new possibilities. By utilising extended reality for an interactive layer of information over the physical environment, distributed ledger technologies for better trust, provenance and transparency of data, robotics, cobotics and autonomous machines to power a new generation of vehicles and hardware, and brain computer interfaces to explore new medical applications and enhance human cognition - these layers will create new types of human machine interaction, powered by intelligent, accurate and reliable data in real time through advanced digital infrastructure.



Within five years major technology companies will launch first iterations of augmented reality glasses, leveraging hand and gesture tracking, computer vision, and voice interfaces to solve user experience challenges of smartphone-based AR.

As advanced digital infrastructure evolves, it will enable a wide range of potential service layers. These service layer technologies will transform the way we live and work in the capital, providing new ways of interacting with data and moving us beyond 'finger on screen' applications to new possibilities, as the divide between the physical and digital world becomes more and more blurred. The service layers included in this document provide a snapshot into some of the most impactful technologies that will enable new products, applications and services to be built.

Extended reality (XR)

Extended reality – the umbrella term for immersive technologies – is expected to add £62.5 billion to the UK economy by 2030.[56] London is a hub for immersive technologies in the UK. Its population density fosters varied and experimental audiences, and enables niche communities – such as immersive audio experiences[57] – to thrive. This diversity is essential in enabling businesses to produce cutting edge content and has helped to make London a pioneering immersive city, already generating revenue of approximately £660 million a year.[58] It is home to the world's leading volumetric capture studios, including Dimension Studio in South London (Earlsfield) – Europe's most advanced volumetric and 3D capture facility – and one of the first of its kind in the world.[59] London's prominence in immersive is also reflected in the advanced research into immersive technologies and their applications taking place in institutions such as University College London and Goldsmiths, University of London.

Over the next five years, it is expected that major technology companies will launch their first iterations of augmented reality glasses, which will leverage hand and gesture tracking, computer vision, and voice interfaces to solve user experience challenges of smartphone-based AR. This shift to what is termed the 'AR cloud' will enable real-time, persistent and shared experiences (such as augmented reality social media information and events) that will allow users to create large volumes of new AR content. As a consequence, AR content creation will skyrocket, driven by personal and commercial interests (such as marketing and wayfinding). However, the potential hyper-personalisation or customisation of public spaces through augmentation with commercial and/or personal content, will result in unforeseen privacy and property rights issues. This decentralised metaverse or 'mirror world' would require open data standards and file formats, alongside ethical approaches and regulation to ensure it is sustainable. This is discussed in further detail in section three of this document.

VR technologies will continue to develop incrementally and have significant potential for consumer-facing solutions (for example VR cinema and arcades) – with Apple already filing a patent that combines AR and VR capabilities in the same device.[60] Content creation and design software for VR will increasingly attract both existing and new practitioners, steadily changing workflows and paradigms in creative practices. Virtual production techniques and facilities, and consumer-facing software (such as Tilt Brush by Google and London-based Gravity Sketch) are already leading the way in making immersive commercially viable. VR's adoption in forward-looking educational institutions will influence the pace of new developments and tools. The new generation of creators will be empowered in ways far exceeding the reach of their predecessors, and their community will be far more diverse. Proliferation of real-time 3D content will feed into 3D printing applications, but also into so-called 4D printing solutions, where physical objects are given qualities that can transform over time[61].

Future VR headsets will feature eye-tracking and expression tracking, both of which are features that enable an increasing number of enterprise and medical use cases. These solutions are also tangible examples of immersive technologies and AI working in concert. Training applications are already having traction within VR, and it is expected that training will increasingly move to this domain. To be able to facilitate specific use cases, it is likely that requirements to combine virtual and physical spaces and objects for such purposes will need more mature technologies for tracking, mapping, and synchronisation. For AR and VR to fulfil their potential, solutions for accurately navigating and mapping space will be milestone technologies.

Other relevant technology developments in the immersive space include haptics, which will advance beyond current capabilities and enable the grabbing and holding of virtual objects. More granular interaction and feeling weight and contours are on the roadmap, examples of which are featured later in this report – companies working in ultrasound and computer vision present the current most likely routes to these advances. VR and AR will contribute to changes in remote working practices through virtual meetings, even before hologram technology reaches a point where cost and production methods have matured and begin to scale.

Related to these developments, 'virtual humans', an amalgamation of real-time 3D and AI, are likely to become commonplace, and future networks will enable streaming of immersive content in real-time. More and more means of communication and social interaction will become virtual or synthetic, with the help of algorithmic, AI-supported production methods.

Robotics, cobotics and autonomous vehicles

Robotics are consistently being adopted into service economy processes, such as baggage handling and loading inventory into warehouses. The robotics industry has received exponential investment growth, with the subset of cobots (small, mobile machines that can collaborate with humans) enjoying considerable attention from the UK manufacturing and logistics industries.[62] The potential for robotics and cobotics within the manufacturing and logistics industries is vast: there is a general trend towards robots becoming cheaper yet capable of performing increasingly complex tasks.

For example, Starship, based in London and San Francisco, is building a network of battery-powered autonomous robots to deliver goods. It has already partnered with numerous retailers, such as Plenish, Co-operative and JustEat.[63] With the demand for manufactured goods rising globally and increasing pressures on the 'last mile', the advent of such technologies over the next five to ten years will help to ensure that processes are optimised and can be made more sustainable over the long term.

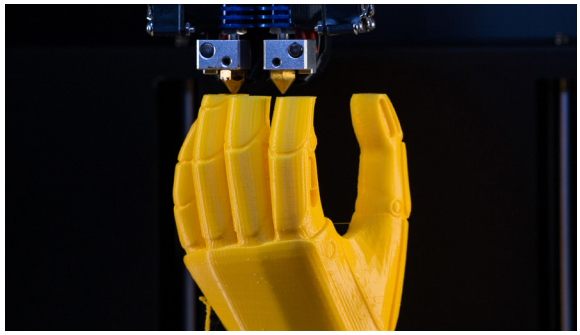
Ocado's warehouse in Andover, Hampshire uses over 1000 robots [64]

UK-based online retailer Ocado already has a warehouse with thousands of robots to pack up groceries. It is pertinent to consider this application in a context that includes COVID-19 and other harmful diseases. Automation in warehouses, coupled with reliable data tracking, can create resilience and safety within our food supply chains. This allows key food distribution centres to keep their workers safe, (for example maintaining social distancing guidelines), with data tracking to better understand the provenance of goods to localise and manage potential contamination.[65] Furthermore, more efficient deliveries and autonomous operations using the advanced digital technology stack will create better efficiency and capability to cope with shocks to food and drink sector deliveries. This could occur through spikes in demand that could arise through pandemics, but also in the future may include climate change. Currently, the Ocado warehouse uses a private 4G network with a traffic control system, and the robots move along a grid system several times larger than a football pitch. This has streamlined its online supermarket operations, making the process and delivery – from warehouse to consumer – significantly more efficient, while reducing overheads.

Robotics research is strong in the UK, involving a number of academic centres, such as Bristol Robotics Laboratory and Imperial College London – considered one of the best global institutions in the field. The Edinburgh Centre for Robotics includes the National Robotarium, a £21 million government-funded robotics research hub, which is a partnership between Edinburgh University and Heriot-Watt University[66]. While London has the potential to become a central global hub for robotics, as highlighted by BEIS in 2019, the UK Government and the Mayor of London should take proactive steps to ensure this national and local research excellence translates into commercialisation.[67]

As a subset of robotics, the UK is also home to pioneering work with connected autonomous vehicles (CAVs). It is predicted that by 2030, 20% of the miles travelled by UK consumers will be automated, the highest such figure globally.[68] Four major CAV testbeds and three additional test sites for highways, rural and parking are taking place in the UK, setting the country on the right path to becoming a global leader. CAVs will also have monumental potential for the UK economy, with projections showing an extra £62 billion in economic growth, due to enhanced productivity enabled by in-car connectivity, reduced mobility-related expenses and improved travel efficiency. CAVs are also estimated to create 420,000 new jobs in the UK, for example, in the automotive industry, logistics, telecommunications and content production. Commuters will enjoy better journeys, saving an estimated 42 hours of travel per annum, and tens of thousands of serious accidents will be precluded every year. Mobility strategy and technology, including CAVs, will change the nature of transport within urban environments; according to recent research by McKinsey, robotaxis in cities are expected to become cheaper than using private vehicles by 2030.[69]

London is also leading research in miniaturised robots (nano-robots or micro-robots), which can be used to improve early diagnosis and monitoring of medical conditions. Earlier diagnosis will also increase the proportion of procedures that are minimally invasive, such as targeting small lesions. Nano-robots will have a significant impact on the future of medical procedures, including neuro, cardiac, and endovascular surgeries.



3D printing/additive manufacturing

Imperial College London's Hamlyn Centre has launched a new research programme looking at further development in 3D printing. The London-based research centre includes precision 3D printing for rapid prototyping, with a range of diverse materials and direct metal laser sintering.[70]

The Mayor of London is already aware of the potential of 3D printing, with long-term plans (completion in 2050) to create a state-of-the-art facility and foundry for manufacturing large-scale artworks and sculptures, including the UK's biggest 3D printing centre in Silvertown, West Ham.[71] Innovate UK is also driving innovation for additive manufacturing (another term for 3D printing) across the country. This includes various research projects in association with the University of Nottingham and the University of Sheffield, and London-based startups are also capitalising on the opportunity. London company, Additive Flow, harnesses machine learning techniques to improve materials engineering selection for 3D printing. Users can upload their 3D CAD models and define specific functional requirements. Smart algorithms will generate different solutions, based on heat resistance, geospatial requirements, cost effectiveness, and even sustainability. The company says that users can increase sustainability by 90% through reduced CO_2 emissions from the entire lifecycle component.[72]

Blockchain and distributed ledger technologies (DLT)

Alongside New York, Berlin, Singapore and others, London has emerged as one of the global hubs for blockchain/DLT activity. Recent market research by Digital Catapult has identified approximately 250 companies headquartered in the capital, including large DLT-specific companies, such as R3 and ConsenSys.

Alongside the small businesses and corporations in the sector, London has two major universities undertaking activities in blockchain/DLT: University College London and Imperial College London. Other leading UK academic groups, at the University of Surrey and Oxford's Saïd Business School, are also nearby. These institutions provide access to a ready resource of highly trained young graduates entering the workforce. It is therefore understandable that most UK DLT activity currently takes place in London, where entrepreneurs can rapidly access meetups, offices, skills, capital, and potential customers for their technologies.

The UK's pragmatic common law provides a generally permissive environment for disruptive technologies. Indeed, the UK briefly led the world with its 2016 government report analysing the potential use of blockchain/DLT[73]. This report was translated into five languages and directly influenced national DLT strategies elsewhere, and its work has been continued by Lord Holmes of Richmond. Another world-first was achieved in November 2019, when the UK Jurisdiction Taskforce[74] published work examining the applicability of common law to crypto-assets[75] and smart contracts[76].

Within five years we expect to see a number of successful early demonstrations of how DLT streamlines inter-organisational processes that currently involve paperwork to create trust.

While most current UK DLT activity is focused on fintech applications, use cases are likely to expand beyond this sector in the near future. For example, when multiple parties need to interact, lengthy legal or contractual processes can be digitised to protect them from failure or disruption. As well as de-risking legal arrangements, the reliability, security and transparency of DLT eliminates the time it usually takes to establish trusted working relationships.

Within the next five years we can expect to see a number of successful early demonstrations of how DLT has streamlined inter-organisational processes that currently involve paperwork to create trust. Beyond fintech, involvement is likely to be in diverse sectors such as farming, aerospace, and fine art, ultimately to improve business productivity and provide cost savings across much of the economy. Such process optimisation and cost reduction will have significant impact for the quality control and distribution of goods, which may contribute to better sustainability and help London to become a green city. It is hoped over this period there will be a national discussion for engaging with data valuation, exchange and sharing from both a personal and industrial point of view: DLT could be one of the key underlying technologies used to ensure usage behaviours match the intentions of data holders.

Looking ahead ten years, we foresee a broader uptake of DLT in an enabling role by multiple industries, creating process efficiencies for accessing and exchanging information between organisations. Everyday actions that currently require an abundance of trust and entail lengthy verification processes, such as setting up a bank account or renting through a car-sharing app, could be completed in a single click using data made available through shared ledgers. This is also an opportunity for the everyday person to be more in control of their digital and personal data identity, with DLT ensuring full visibility of who has requested their data, when, and why. In the financial sector, digital pounds (sterling) may even be made available for use on distributed ledger-based systems to value and pay for goods and services.

By 2035, London and the UK may see some of the original drivers for the invention of blockchain being realised, creating more trust in data sharing and usage through clear data ownership, reducing reliance on intermediaries. For example, taxi services where the processes of offering and finding taxis are regulated by algorithms, healthcare applications where all GPs and hospitals are interconnected but the patient remains in control of their records, or local energy trading services to incentivise green behaviours.

Brain-computer interfaces

Brain-computer interfaces (BCIs) are placed inside or outside the brain or other parts of the body to interact directly with the nervous system. They leverage computational power and artificial intelligence to support the cognitive power of the human brain. There are a number of exciting use cases for BCIs emerging in the healthcare space, including life-changing therapies for patients with stroke, epilepsy, paralysis, and Parkinson's tremors, as well as enhancements to memory and the use of cochlear implants. In the future, it may be possible to see these use cases extended, providing humans with the ability to directly interact with digital data and information, as well as communicating with and controlling computers.[77]

London's strength in this field is due to the convergence of a number of areas of research capability and the underlying business environment:

- Academic strengths in disciplines such as electrical engineering, neuroscience and behavioural research
- Funding bodies to support the spin-outs from research, such as The Medical Research Council, the Royal Society, Wellcome and Innovate UK
- Life science leadership
- The NHS and its high quality of care for all citizens

Furthermore, UK regulation is internationally renowned, scoring the highest of the OECD countries, meaning that advancement and use of the technology has the potential to be conducted thoughtfully and ethically, fostering sustained economic development.

It is expected that the innovation and investment ecosystem in London will facilitate the development and widespread usage of BCIs. While they may raise a number of ethical questions (including how to overcome perception barriers around mind control and monitoring), London has the perfect ecosystem to tackle the challenges and plan ahead in terms of regulatory and policy planning.

The Mayor of London should take proactive steps and build upon the UK's ambition to be a global leader in the ethical applications of AI – extending this to BCI – and taking the lead at developing a policy evidence base in partnership with the capital's leading technology ethics centres, such as the Ada Lovelace Institute, the Alan Turing Institute, and the office of the Centre for Data Ethics and Innovation.

Using advanced digital technologies in London's key industry sectors

The ability for innovators to seamlessly pivot into different domains is one of London's key strengths, due to agglomeration, dynamic knowledge transfers, and its diverse sectoral strengths. This cross-sector influence is an important aspect of London's innovation ecosystem, value chain and economic growth potential.

Financial and business services

Financial and business services underpin the workings of London's economy. In 2018, financial services contributed £132 billion to the UK economy, with 49% of the sector's output being generated in the UK's capital.[78] London has more banking head offices than any other city in the world[79] and was ranked second in the global financial index survey, after New York.[80]

Advanced digital technology innovations for financial services are already being used, for example, building infrastructures to enable alternative payment methods, and using machine learning for enhanced decision making.[81] In large banks, AI is being used for automated customer enquiries, streamlining processes and efficiencies.[82] London is at the core of fintech innovation on a global scale, with 44,000 people working specifically in fintech roles in London – more than in Silicon Valley or New York.[83] Venture capitalists are consistently attracted to London, with London consistently securing more investment deals for fintech than any other city worldwide.[84]

Virtual production techniques that combine advanced technologies will create game-changing new immersive consumer experiences.

After fintech, London's next largest professional service is its thriving legal sector. The UK is the largest legal services market in Europe, and is ranked second globally, employing over 306,000 people, almost a third of whom are based in London.[85] London's legal sector contributes £9.6 billion in GVA to the UK economy. Use of advanced digital technologies is emerging, with some London law firms having dedicated smart contract divisions, and more beginning to develop smart contract digital platforms. Finally, London has a leading insurance sector, with Lloyd's of London being the world's biggest insurance market, reporting a pre-tax profit of £2.5 billion for 2019.[86] London has a strong foothold in developing the insurtech ecosystem and hosts Europe's largest insurtech conference. London-based insurtech startup, Zego, also recently secured £42 million to expand globally.

Creative industries, media and entertainment

The UK has one of the world's largest creative industries, with billions of pounds of creative products and services being exported. For example, the UK has the largest games development sector in Europe, generating £2 billion in global sales each year.[87] There are creative clusters located across the UK, with London being the largest hub. London's creative industry is at the epicentre of this economic development, where over £40 billion per year is spent within its supply chain. Over 267,000 individuals work in London's creative industries, with more than 203,000 employed in the creative supply chain.[88]

Two thirds of UK immersive companies are based in London, where the creative scene has already capitalised on the adoption of immersive technologies (such as virtual, augmented and mixed reality) to offer users new experiences. Approximately 80% of immersive companies operate predominantly in the creative market (with most also working in other sectors). This intersection between creative and leading edge technology is significant, as immersive generates a turnover of around £660 million in the UK, estimated to represent around 9% of the global market share in the sector.[89] The UK Government has identified this potential across the advanced digital technology stack, with the UK Government's Department for Digital, Culture, Media & Sport (DCMS) launching 5G Create in February 2020, an open competition within the 5G Testbeds and Trials Programme with up to £30 million of government funding available to industry to explore how 5G can be used by industry. This is a welcome step to exploring how 5G will enable use cases in the creative sector. Furthermore, the significant potential of how AI can be used in the sector from computer vision capabilities, AI-generated content, bespoke characters and more efficient operations for production will enable a future content sector in London and the UK, underpinned by virtual production techniques that combine technologies to create game-changing new immersive consumer experiences.

Smartify is a London-based startup that provides an AR platform for some of the world's best art and cultural institutions.

London-based startup, Smartify, leverages augmented reality and advanced image recognition to enrich cultural experiences across the capital and internationally. The company's founders recognised that museums and galleries often distribute information in an outmoded manner, typically through audio guides, which often don't engage users or provide the museum with any measure of the popularity of their exhibits and installations. Smartify allows users to scan the exhibit or artwork and read curated content on the piece, and gives them the ability to 'save' their favourites, prompting smart suggestions of other exhibitions or galleries globally. Smartify's partner institutions, such as the National Gallery, have found that repeat visits have increased, and that they are increasing accessibility and enriching cultural experiences for their visitors. The company is also currently working to provide museums worldwide with a way to reach audiences at home and to prepare for buildings re-opening with safe social distancing, transforming opportunities for virtual engagement of global audiences.

It is important to consider the impact of one industry on another. Some creative London companies that traditionally worked in leisure and entertainment, for example, are now using creative experiences to deliver training and facilitate collaborative manufacturing activities. For example, Gravity Sketch was initially a creative startup and is now working with engineers and architects who are using its VR platform for collaboration. Just as Google Drive enables teams to work together on online documents, Gravity Sketch enables design teams and architects to get to market faster through XR collaborative design.

As we begin to move into the recovery phase of post-pandemic London – production studios are increasingly needing to explore "virtual production" techniques – underpinned by a number of advanced digital technologies coming together. Virtual production is a new approach and set of tools that allows for production companies to establish their content in a digital environment before going on a physical set. This includes defining things like lensing, set dimensions, asset placement, and exact camera movements and can be undertaken in an immersive environment using VR-ready game engine platforms such as Unreal and Unity.

This radical new approach to making films, television, games and audio will enable a new era of real-time content production using 5G, with the global race for leadership in this new form of content production being defined by sovereign capabilities such as facilities, talent and a supply side of content creators who can utilise them. Upskilling and building capacity in virtual production techniques will be critical as we move into a touch free/remote operations/ social distanced content production environment.

Hospitality and retail

In 2018, there were 37.9 million visits to the UK, adding £68 billion to the UK economy, 6% of total UK economic output. London is the UK's most popular destination, attracting 50% of all visits – nearly four times the number to Scotland, Wales and Northern Ireland combined.[90]

There is significant potential for retail to use immersive technologies to enhance and transform the experiences offered. Building capacity in virtual production techniques will be critical as we move into a touch free and social distanced environment.

Repeat visits are the most profitable, as visitors average more spend per night and stay for longer. London offers many attractions for international tourists: heritage sites, performing arts, museums, galleries and a plethora of restaurants that offer international cuisines from renowned chefs. London-based startups are leveraging rich cultural epicentres in the UK and using extended reality technologies to attract and engage users.

London's many retail specialist centres also attract local and international visitors: Hatton Garden for jewellery, Saville Row and Jermyn Street for tailoring, Bond Street and Harrods for luxury purchases, and Oxford Circus for high street fashion. Given fashion and retail's prominence in London, this is an ideal sector to benefit from the growth in advanced digital technologies. While retail has low productivity, it has high employment and is vital to the economy.

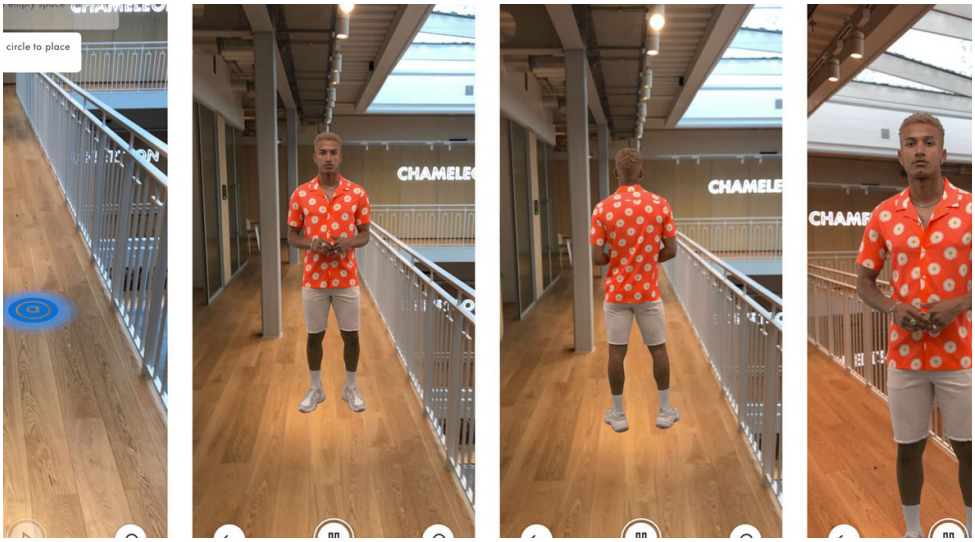
In 2019, the total value of UK retail sales were worth £394 billion, contributing 5% of total GVA.[91] E-commerce is more popular in the United Kingdom than in any other European country, so it's unsurprising that digital technologies already play a key role in UK retail. Innovations in advanced digital technologies will be central to its continued success, with further structural shifts taking place. For example, disruptive transformations in the manufacturing of clothing and other goods creating a shift towards more localised and personalised manufacturing facilities (possibly building on the ambitions of the Thames Estuary production corridor) that could harness 3D printing, distributed ledger technologies, 5G and AI for on-demand production.

Immersive technologies are being used to promote and facilitate sales in London, online and in store. HoloMe, a startup founded in London, enables retailers to promote and communicate their messages using augmented reality. Consumers can use their smartphones to experience AR catwalks, giving them a better idea of the size, scale and detail of clothing items. The combination of enhanced and immersive user experiences with smart logistics supply chains, and seamless distribution for just-in-time deliveries, will enable London's retail businesses to continue to thrive online in the face of pandemics, and changes that may come as high streets are transformed post COVID-19.

There is also significant potential for the retail sector to use immersive technologies to enhance and transform the experiences offered by bricks and mortar stores, and drive the future of the UK shopping experience. With high street stores seeing a decline in footfall, the New West End Company (the trade group that represents Oxford Street, Bond Street and Regent Street) is working with the Mayor of London and Westminster Council to change planning for the area to permit the growth of a broad range of experiential and engaging spaces to attract consumers. These could include showrooms, cultural spaces, food and leisure activities, and venue spaces for community events and evening attractions.

The details of this transformation – an investment of £2.9 billion in investment – are laid out in the New West End Company's report, Oxford Street 2022: The Vibrant Future.[92] To maximise this potential, additional focus on retail experiences through immersive technologies, particularly AR, should be explored – making Oxford Street and Regent Street a broad testbed for the convergence of future networks, and consumer-centred immersive experiences that enhance the retail experience and encourage further learnings, use cases and content for high streets across the country. This shift will be crucial to maintaining London's leadership as the retail capital of the world, and enable the exploration of new business models and activities.

ASOS Virtual Catwalk with HoloMe



In July 2019, UK fashion retailer ASOS worked with London-based AR innovators HoloMe to launch an experimental new augmented reality feature on its app, called Virtual Catwalk.

The AR solution, developed in partnership with HoloMe, is available now through the ASOS app on iOS 11.3 devices and above globally, trialled across 100 ASOS design products. It enables customers to point their smartphone camera at any suitable flat surface and click the 'AR' button on the product page in-app, and they will be able to view models as if they are walking in front of them.

Janosch Amstutz, chief executive at HoloMe, said in a statement: "By allowing the consumer to bring mobile shopping into their own physical space, we can create a more intimate buying experience. We are excited to see how our technology can be used as a new way to communicate to the customer."

ASOS are continuing to explore and experiment using advanced digital technologies, such as using AI for fit assistance, to help customers get the right size, as well as trialling other AR features, such as a tool that allows customers to view products on different size models so they can see how it will fit their body shape.[93]

Innovative solutions to monitor, optimise and make logistics more efficient is an imperative for London and the wider UK.

Industrial, transport and logistics, supply chain

Logistics contributes £121 billion in GVA to the UK economy. Across the UK, 2.5 million individuals work in the wider logistics industry, with 10% of these workers concentrated in London, which is also base to the highest number of logistics enterprises compared to other UK regions. London was ranked second in the UK for the amount of tonnage handled in 2018.[94] Unsurprisingly, London's roads are among some of the most congested in Europe. London's road users endured an average of 227 hours a year being idle in traffic, consequently reducing their productivity and generating harmful vehicle emissions.

With more restrictions on goods vehicle access and increasing regulation of air quality, innovative solutions to monitor, optimise and make logistics more efficient is an imperative for London and the wider UK. Key logistics players and the UK Government have placed a priority on the reduction of emissions, as outlined in its Industrial Strategy, with the UK's clean economy being estimated to grow at four times the rate of GDP.[95] This trend has been accelerated by the Mayor's plans for a vehicle free centre of the city, allowing for only cycles and pedestrian traffic in light of COVID-19.[96]

In terms of transport infrastructure for public use, London has a globally recognised system, and was placed fourth globally for urban mobility in 2018[97], and second in Europe for effectiveness of public transportation systems.[98] London continues to prioritise productivity and inclusivity, and with (pre-pandemic) 26.8 million journeys already being made in London every day,[99] TfL is estimating that the demands on transport infrastructure will continue to increase over the next 15 years. Connectivity in this context is strongly correlated to agglomeration and improvements in local productivity,[100] as well as an established relationship between transport systems and welfare. London's public transport network, particularly its rail network, helps to support agglomeration by connecting businesses and people within London. This is important to ensure that people living in London's boroughs can easily access jobs (especially in less well-connected areas), and to avoid delays and overcrowding, to minimise losses to economic output while maximising welfare.

London is already home to global scaleup technology companies that are leading the way in helping to tackle transport challenges. Citymapper, a scaleup that was developed in London (now with over £40 million in funding), gives users real-time transport information at their fingertips. London information was provided by the Mayor of London via TfL, which cleaned and published the data to enable this first use case to be developed. Citymapper is now leveraging insights from data points to help create alternative transport systems for under-connected areas, those areas of London identified as being under-served by public transport. The company has also developed additional functionality, so that users can now select either the fastest route or main roads only, providing the best option for users who feel unsafe walking along less populated roads.

Future data gathering - provided by the convergence of machine learning, IoT and 5G - will help optimise traffic flows, reduce congestion and reach net zero.

Citymapper is well integrated and used, and may appear to be 'old news' in the context of the advanced digital technology stack. However, it does highlight and contextualise two main trends: data-driven development within cities, and personalisation. Leveraged correctly, the technologies that can make both happen offer huge potential for the future of transport in London. The potential for future data gathering - provided by the convergence of machine learning, IoT and 5G - will provide key information for optimising traffic flows, reducing congestion and reaching net zero. It will also facilitate the improvement and development of existing and new transport links, with travellers being able to decide which kind of commute or journey they prefer, whether time-efficient, or well-lit with safer routes, or cleaner air are prioritised. The food and drink sector across the UK - in the light of COVID-19 and the need for food supply chains to cope with shocks - are already exploring how this combination of technologies will enable real-time data, combined with IoT, blockchain and satellite technologies can transform, to deliveries and operational planning to increase resilience.

Autonomous vehicles

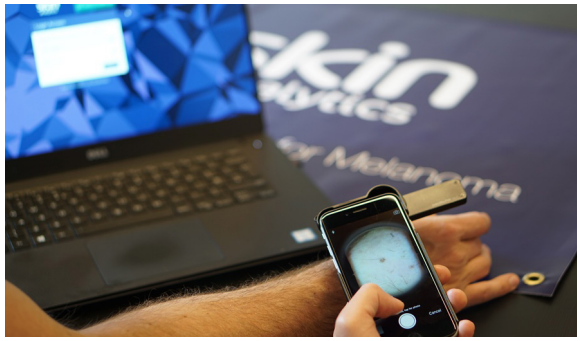
The UK Government has one of the most permissive approaches to trials of automated technology in the world, a notable advantage for the development and testing for connected and autonomous vehicles (CAVs) in the capital.[101]

London has already been the location for CAV trials and in response, TfL has introduced guidance[102] that sets out expectations of how trials of automated vehicle technology should be carried out. It has also published a CAV statement,[103] which outlines TfL's position on this growing industry, and its website features details of all London CAV trials, including those which have already taken place.[104]

Multiple CAV trials have chosen London as their preferred location. As an example, Five AI, a Cambridge-based scaleup, is developing software for shared, self-driving vehicle services in Europe. In 2017, they received government funding for its Streetwise project, which has trialled vehicles in south London. They are also creating large-scale simulations to more quickly identify bugs and testing systems in both the chip and wireless worlds. Its methodology and approach is driven by safety - the company does not put its vehicles on the road unless they are at least as safe as having a human driver. The technology is a complex assembly of cross-dependent and interacting software and hardware components that detect objects, predict actions and undertake other critical tasks.[105] Five AI has already raised over £30 million to continue its development, £12.8 million of which was a record-breaking grant from the UK Government.[106]

Another example is the Smart Mobility Living Lab, based in Greenwich and the Queen Elizabeth Olympic Park, which aims to build the most advanced environment for the testing and development of future transport technologies. With £20 million in funding from Innovate UK and industry, there is now a consortium of partners backing the connectivity infrastructure that will support this testbed.[107] Depending on the evolution of autonomous vehicles, we may also see a rise in context-specific transport and logistics, which would mean that individuals will no longer need to buy and rely upon personal vehicles. The mobility landscape is changing rapidly, and connectivity and automation will contribute significantly to these changes; making roads safer, more efficient and more accessible.

London-based Skin-Analytics developed sophisticated machine learning technology, and uses computer vision to enable patients to track abnormalities on their skin using a smartphone.



Health and life sciences

Between them, London, Oxford and Cambridge form the 'golden triangle' for collaboration and innovation in healthcare and the life sciences. The golden triangle is also the third largest technology cluster in the world after Boston and Chicago, and the strongest life sciences cluster in Europe, behind Boston and the Bay Area in the US. In 2017, life sciences contributed £14 billion to the UK economy, and the sector is predicted to add a further £8.5 billion by 2025, with the addition of around 31,400 jobs.[108] The UK's strength in this area is largely attributed to top quality university research, being home to four of the world's top 15 universities (including Imperial College London and University College London), and six of the world's top 20 institutions for pre-clinical and clinical sciences, according to the Times Higher Education (2019/20). Together ICL, UCL, King's College London and the Mayor of London form MedCity, which was launched in 2014 to increase collaboration and promote the broader golden triangle to investors.

Skin Analytics, a London-based startup, recognised that melanoma is often discovered in later stages, leading to a number of medical complications and reduced survival rates. The company developed sophisticated machine learning technology, and uses computer vision to enable patients to track abnormalities on their skin using a smartphone, and ultimately diagnose skin cancer as early as possible. Abtrace, another London-based startup, uses deep neural networks and natural language processing to transform antibiotic prescription and tackle antimicrobial resistance. Antimicrobial resistance is expected to contribute to more deaths than cancer by 2050,[109] and ML is being used to provide real-time, patient-specific and probabilistic outputs.

The convergence and adoption of advanced technologies for the health and life sciences sector is already happening in London. London hospitals have, for example, set up the London Medical Imaging and Artificial Intelligence Centre for Value-Based Healthcare,[110] to train sophisticated artificial intelligence algorithms from NHS medical images and patient data. The consortium is led by King's College London and includes Imperial College London, Queen Mary's University London, King's Health Partners, Guy's and St Thomas', King's College Hospital and South London and Maudsley, with Bart's Health, multinational industry (Siemens, NVIDIA, IBM, GSK), ten UK-based small to medium sized enterprises and the Health Innovation Network. Indeed, digital health is now the largest medtech segment in the UK, with inward investment to the UK AI sector increasing by 17% over the past year, more than the whole of Europe combined. Furthermore, NHSX is overseeing over £250m in targeted funding to help the best UK innovators to design, develop and deploy new technologies, utilising AI to improve diagnostics, system efficiencies, knowledge generation and public health. The £130m AI award launched this year will support companies using AI techniques to deploy and scale within the NHS and wider care system. These programmes build on the Government's national Test Beds programme, which brings NHS organisations together with healthtech innovators to test new technologies in real-world settings.[111]

Real- time data, combined with AI and possibly even haptics technologies, could be utilised with mobile applications for contact tracing in future pandemics.

In the light of COVID-19, the importance of practical and sustainable use cases of advanced digital technologies for the life sciences sector has become even more critical. Real-time data, combined with AI and possibly even haptics technologies, could be utilised with mobile applications for contact tracing in future pandemics. However, it is important that uses of personal data by the Government and innovators in this area consider the balance between current regulation and what is practical and ethical in a post-pandemic world. To advance research into this space UK Research and Innovation (UKRI) has placed itself at the forefront of supporting domestic R&D in COVID-19 treatment, diagnostics and vaccines, with £25 million through the UKRI/NIHR rapid response call for COVID-19 research, and an additional £42.5 million to support clinical testing of vaccines at Imperial College London and the University of Oxford. Furthermore, London-based AI scaleup Benevolent AI has been using its technology to identify treatment options for COVID-19 - demonstrating the place that emerging technology companies can have in helping to accelerate treatments to market.[112]

Challenges, opportunities and considerations

Despite the incredible potential in advanced digital technologies, there are a number of challenges to their adoption. Some of these challenges are sector-specific, but they can be broadly categorised as follows:

- **Lack of understanding of the benefits**
  Technologies might be misrepresented, overhyped, or management teams across industries may not have enough information, or fail to recognise its potential for their strategies.
- **Unclear ROI**
  Procuring advanced digital technology solutions typically involves significant upfront costs, and there can be uncertainty on how it will impact the bottom line. Given the sophistication of the technologies involved, adequate analysis or research in the profit may not have been conducted. This is especially likely if the sector suffers from lower profit margins (for example, the 1-2% of some areas of manufacturing) or is extremely risk averse (such as public companies that face scrutiny over stock prices).
- **Lack of interoperability**
  Current IT systems and hardware might not be suitable for 5G connectivity. For example, industrial companies typically have connectivity upgrade cycles of around seven to ten years, which can make it challenging to adopt new iterations, particularly when connectivity infrastructure is not typically part of the R&D budget.

Development of products and services that combine advanced digital technologies requires a clear vision of how each can benefit from the others' current and future features.

- **Personnel and lack of hybrid skills**
  Current employees may not have the required skill set to leverage the technology and its combinations, adopt it or integrate it into existing stacks. Many high-skilled technology experts and graduates will be hired by technology companies, resulting in challenges to recruiting digital talent across the economy.
- **Internal bureaucracy or decision-making paralysis**
  Even if the benefits are understood, there may be extensive red tape involved in determining which supplier/hardware/software should be obtained.

There can be technical barriers to the development of products, applications and services using advanced digital technologies, due to their lower levels of commercial maturity - which can also be a barrier to adoption of these technologies at an industrial scale. Many of the barriers to the adoption of individual technologies overlap with those applying to the adoption of the wider advanced digital technology stack, such as access to high quality labelled data for AI, interoperability for IoT and 5G, or investment into immersive content.

Developing multi-technology products and services across the advanced digital technology stack

Due to the cost and skills barriers associated with developing advanced digital technology solutions, startups and scaleups often focus on a specific technology USP for their business. However, the development of products and services that combine technologies through the advanced digital technologies stack requires a clear vision of how each technology can benefit from the others' current and future features and trends.

Until recently it has been rare for startups to actively explore the combination of technologies across the advanced digital technology stack, often due to the associated prohibitive cost barriers, lack of awareness or lack of access to suitable skills. Challenges might include difficulties in hiring the right staff across multiple technology disciplines, or the upfront cost of investing in hardware, network infrastructure and devices.

5G and future networks

For a startup or scaleup, to explore how its AI-powered product, service or application can be enhanced by using 5G, they would need to either have access to a 5G testbed environment with the necessary technical support, or hire a 5G network expert who can inform and advise on the technical development of the solution underpinned by 5G.

It is for this reason that Digital Catapult set up its 5G testbed in Brighton and London and the 5G Testbed Acceleration Programme , in advance of the establishment of the UK Government's Department for Digital, Culture, Media & Sport's (DCMS) 5G Testbeds and Trials Programme. The aim was to help stimulate both the supply and demand for 5G across the value chain before its broader roll out across the country. Subsequently a number of different 5G testbeds have been set up across the country, largely through the strategic drive and funding opportunities that have come through the 5G Testbeds and Trials Programme - establishing their Rural Connected Communities (RCC) and Urban Connected Communities (UCC) projects in the West Midlands; along with the Industrial 5G projects and the Industrial 5G accelerator with Digital Catapult and Ericsson; and the recently announced 5G Create competition.

AR is being combined with computer vision (AI) to help render information over the physical environment, creating the physical internet through the AR cloud.

However, more needs to be done, not only on 5G, but more broadly to help foster collaboration between network technologies and other advanced technology areas, to enable the next generation of startups and scaleups in London and the UK to develop products, applications, services and experiences that will be globally competitive. This involves encouragement, working with Digital Catapult and UK5G to explore how these networks will change business models, create new opportunities, and evolve thinking from "I will use it when it is built" to be focused on "how can I get ahead by exploring new network technology now, and what skills do I need to do that?"

AI and immersive

As an example of an application that uses multiple technologies from within the advanced digital technology stack, London-based Improbable uses AI to enhance VR and AR.[113] Its cloud-based, multiplayer platform is used for building online games, reducing the time to first prototype, and using open source solutions to mitigate most common multiplayer bugs. The technology enables the creation of massive simulations - virtual worlds - at a greater level of scale and computational complexity than previously possible, while able to support more simultaneously connected users. Improbable's debut platform, SpatialOS, is a distributed operating system, from network to hosting, that seamlessly integrates with major game engines; its global cloud hosting locations ensure low latency for players around the world. Improbable's development of virtual worlds built on SpatialOS is likely to be especially valuable for AI research: multi-agent, simulated environments have a high level of complexity, co-operation and reactions.[114] Improbable has raised over £409 million in investment, and in 2017 was one of the select few British tech startups valued at over $1 billion. Its team hopes to create complex real-world systems for transport infrastructure, telecommunications networks or the behaviour of fleets of autonomous vehicles.[115] As a similar example, DeepMind currently uses StarCraft for AI training purposes.

AI researchers have commented that while compute power is heavily attributed to advancements in the development of AI, simulated environments are the 'second puzzle piece' in its acceleration.[116] For example, augmented reality is being combined with the computer vision[117] discipline of artificial intelligence to help with rendering information over the physical environment, creating huge potential for the physical internet through the AR cloud.

AI and IoT

The convergence of AI with IoT sensor data is also becoming a predominant trend. The IoT market is maturing, reducing costs and knowledge barriers for startups, while IoT companies that already incorporate data analytics can more easily extend their offering to include AI.

London-based startups are capitalising on the combination of AI and the IoT. For example, NodeNs Medical is an early-stage London-based startup that has developed plug-and-play sensors that can improve operational efficiency, patient safety and user experience. Its 'smart' centimetre-precise millimetre-wave real-time locating sensor, incorporates machine learning capabilities for active monitoring. Each sensor has edge-AI technologies embedded into its chip, with data transmitted via WiFi to the hospital command centre or IT system. This combined IoT/AI technology is novel in its capability to track users passively without the use of wearables, and is currently being used for patient flow optimisation and fall detection.

The technology and communications sector accounts for a rapidly growing carbon footprint, outpacing other sectors in terms of CO2 emissions.

The environmental impact of data consumption and computation

While the advanced digital technologies stack has huge potential for economic growth, this will result in vast quantities of data being connected through cloud services to data centres and used to increase compute power across numerous devices. While most climate change action is focused on reducing emissions across industrial sectors such as transport, manufacturing and energy, the technology and communications sector also accounts for a rapidly growing carbon footprint that is already outpacing other sectors in terms of CO2 emissions. At a global level, data centres are set to have a bigger carbon footprint than the entire aviation industry: by 2030, data centre energy consumption is predicted to generate 8% of total worldwide carbon emissions.[118]

The Greater London Authority is pushing for action to prevent climate change, with plans for London to be a zero carbon city by 2050 and the publication of the London Environment Strategy in May 2018. This runs alongside the UK Government's range of commitments and pledges to tackle the climate crisis. It is important that the GLA and the UK Government work together to consider and act on the environmental impact of data consumption, and both the UK and London need to take proactive steps to encourage the technology sector to adopt clean energy and offset their rapidly growing impact.

Technology giants such as Google, Amazon, Apple, Microsoft and Facebook have committed to moving to renewable energy use over the next few years, and it is important that the Mayor encourages businesses across the capital to look at ways in which they can reduce the carbon footprint of their activities and factor in longer-term carbon offsetting and reduction strategies. Additionally, if data centres are localised to store citizen data, they should be built sustainably and use clean energy sources as much as possible.

The importance of specialised innovation and acceleration programmes

Specialist acceleration programmes can help startups and scaleups working with advanced digital technologies to explore under-served sectors that offer huge economic potential. Such innovation activities curate and connect cohorts of participants with industry challenge owners, solving real-world problems while helping both sides to work together, attracting further investment and facilitating new business contracts. They can be vital in fostering and scaling the supply of advanced digital technology products, services and applications, supporting startups and scaleups in building solutions to meet growing demand and overcome common capability failures. Digital Catapult's Augmentor programme works with B2B immersive technology companies, helping them to test, refine and pitch their business offering, and connecting them with potential customers and investors. It has led to significant success, with many innovators exploring how their technologies can be applied in other sectors, despite never having worked with or considered them previously.

The Mayor of London's Civic Innovation Challenge is looking at how to accelerate the use of technology for London in a variety of ways, including logistics, planning and online harms. The Challenge's open innovation activities help to

Specialised acceleration programmes can help build connections between the London startup ecosystem and sectors of the UK economy outside the capital.

overcome barriers to developing solutions by helping public and private sector organisations to navigate the capital's fragmented ecosystems of startup and scaleup innovators. As the local industrial strategy for London is developed, the Mayor of London and UK Government should consider further investment into specialised acceleration programmes, exploring how the London Office of Technology and Innovation (LOTI), can work with the Catapult Network, other RTOs and local authorities to help build connections between the London startup ecosystem and sectors of the UK economy outside the capital or, such as logistics, that can have an impact on the supply chain.

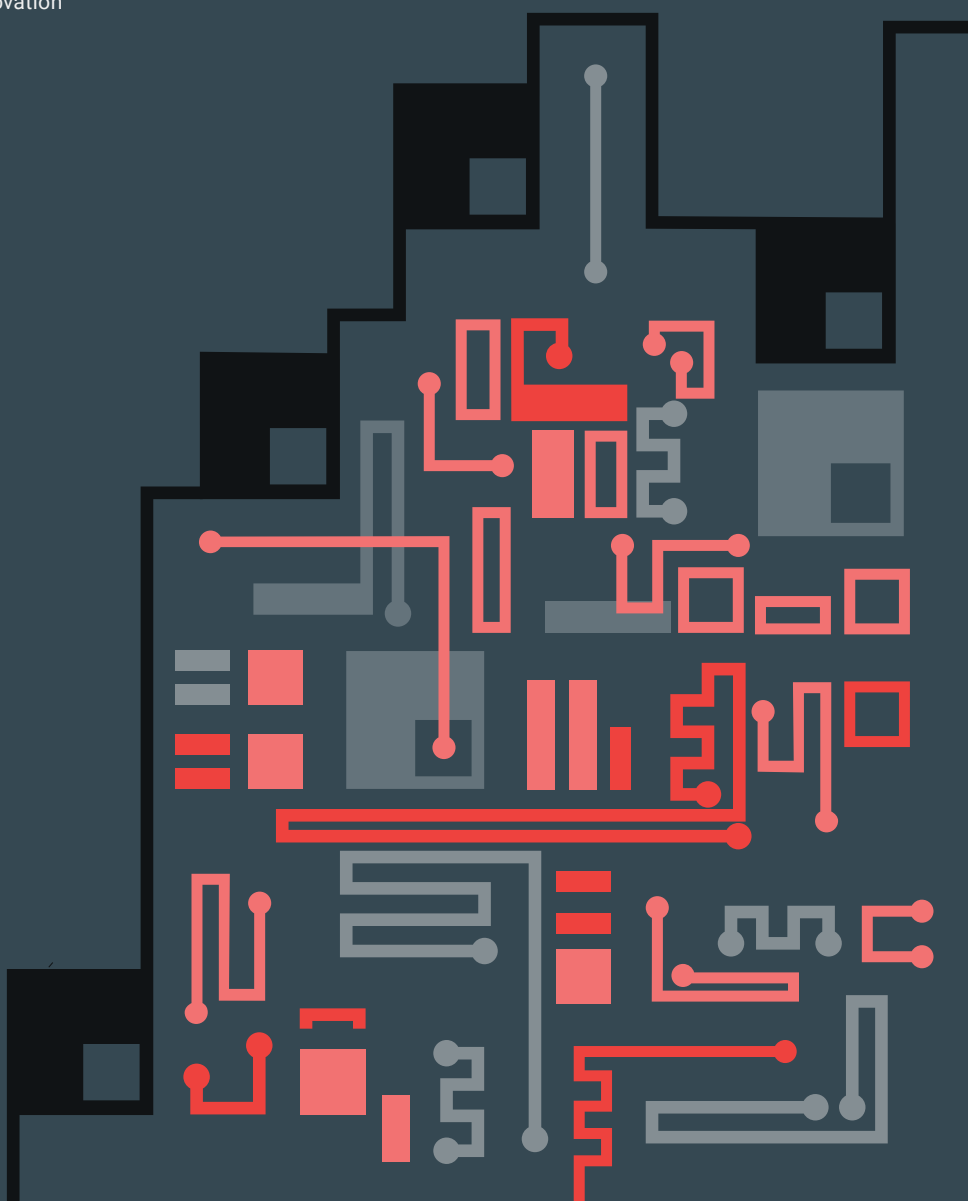
What the advanced digital technologies stack will enable

This document now goes on to explore top-level examples of what this stack could enable across three core themes:

- **Building on the foundations of smart cities in London**
  How the introduction of next-generation mobile connectivity, the internet of things, artificial intelligence and robotics, cobotics and autonomous machines can transform London and enable multi-technology products and services to develop.
- **Augmenting the physical environment**
  How the evolution and adoption of extended reality, underpinned by real-time data, will augment the built environment in London - visualising data in new ways and bringing the physical and digital worlds closer together.
- **Augmenting the physical self**
  How the convergence of technologies across the advanced digital technology stack will augment the physical self by converging London's strengths in design, life sciences and technology.

Building a smarter city

Contents



Building a smarter city

Over the next 15 years... we will see enhancements to maturing smart city platforms, deployment of sensors and devices at scale, the introduction of autonomous vehicles and robotics, and the growth of 5G and future networks connectivity.

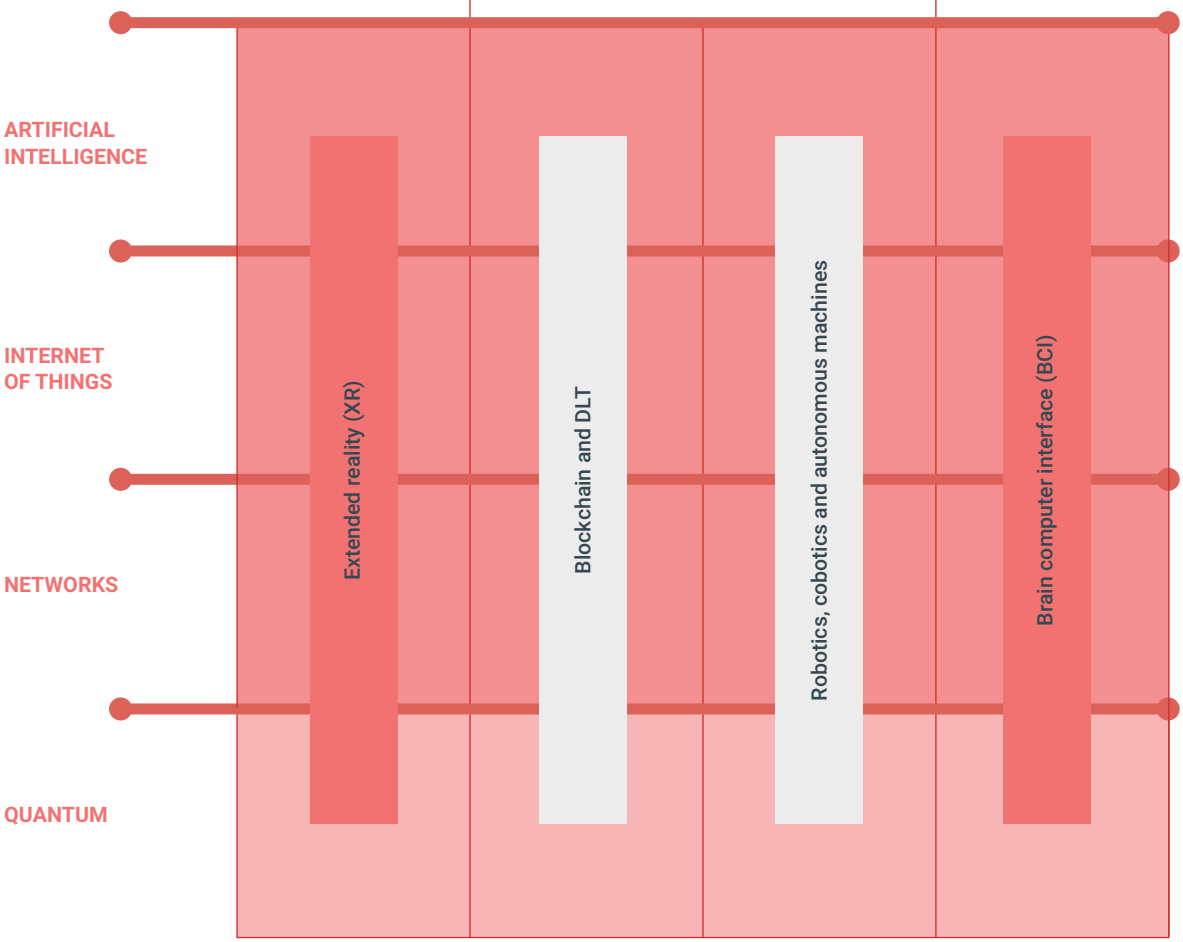
Smart cities have become a common theme for technology applications and use cases for a number of years. Alongside these narratives there has also been an increasing use of the term 'sentient cities,' a city that is digital first, with a focus on offering visitors and residents an intelligent, sustainable, and entrepreneurial environment for them to live and work in. 'Sharing cities' are already part of the Greater London Authority's ambitions, with London and the GLA leading the £25 million Sharing Cities Horizon 2020 European project - across London, Milan and Lisbon - that explores how new technologies can help in improving electric urban mobility, data platforms, smart lighting, smart building retrofit, energy management systems and citizen engagement.[119]

The confluence of 5G, wireless networks, advanced machine learning and IoT, will foster dynamic knowledge transfers and intelligence between humans, machines, and everyday surroundings. Widespread deployment of sensors will gather real insights to improve transportation systems, from safety to enhanced resource allocation for sustainability. For example, IoT sensors powered with computer vision and a high speed network could detect abnormalities in traffic, such as dangerous driving, providing data that can be used to inform city planning and development; or to react to road conditions in real-time, enabling goods to continue moving and ensuring drivers do not remain idle in traffic, thereby reducing the city's carbon footprint. Such innovations are similar to the way that London is currently using real time data insights for transportation systems.

Over the next 15 years, the dynamics of smart cities and implications of the advanced digital technology stack will become even more apparent. We will see enhancements to maturing smart city platforms, deployment of sensors and devices at scale, the introduction of autonomous vehicles and robotics, and the growth of 5G and future networks connectivity. Current volumes of data will increase dramatically, as will the number of opportunities for using it in new and innovative ways. Smart city data capability, immersivity and interactions will be built on the advanced digital technology stack, which will enable new applications, products and services to be developed that meet demands from businesses operating in the capital.

Next generation smart cities

Building on the foundations of advanced digital infrastructure, smart cities will evolve to be more sustainable, carbon neutral and productive through autonomous systems, next generation connectivity, vast deployments of sensors and devices and robotics.



The Mayor must encourage ambitious approaches that are standardised between boroughs, with industry co-investment into advanced digital infrastructure capabilities.

How London will lead the world as a smart city

The Mayor of London's ambition is to make London the smartest city in the world, through the Smarter London Together roadmap.[120]

Goals, such as making London a global testbed city for innovations that can be developed and exported around the world, are crucial to this journey, enabling scaled growth and investment into the capital's most exciting startups, scaleups and ecosystems. It is also crucial for this experimental environment to be fostered across London, which means that the Mayor must encourage ambitious approaches that are standardised between boroughs, and that include industry co-investment into advanced digital infrastructure capabilities.

This infrastructure capability includes the way in which networks interact with artificial intelligence, and how the city can enable the collection and sharing of valuable data to benefit innovators. It is also important for the UK Government to work with the Mayor of London, to ensure that both supply and demand explore the security implications of the advanced digital technology stack, and set out a cyber resilience strategy across all technologies and services.

Advanced digital infrastructure and smart cities

London generates vast amounts of data. It is for this reason that the Mayor set out the Data for London strategy in 2016, and published the Smarter London Together Roadmap in 2018 - to ensure the capital has the most dynamic and productive city data market in the world.[121]

London has gone from strength to strength in data sharing. As an example, the London Datastore (set up in 2010) has evolved from offering a centralised place to store open data, to being a central register where people can discover data, regardless of where it is physically stored. The Datastore is now a place where data can be updated more regularly (daily or weekly) and companies can share data privately with innovators or for research projects. Coupled with the success story of the TfL data sharing initiative that has enabled nearly 700 companies (including Citymapper) to start up, develop innovative data partnerships and scale, it can be seen that London and the GLA have a strong track record in generating valuable data for multiple use cases.

The exponential growth in city data will mean that reducing and eliminating data silos will become critical to the success of innovation for any leading global city. This doesn't necessarily mean creating a vast data warehouse or data lake, but enabling datasets to be queried through technologies such as APIs and connecting data through open standards. Examples of how this is done are already being explored in London, and are also surfacing through the Horizon 2020 Sharing Cities initiative. Through this project, the GLA has enabled the London Datastore to accept live IoT data from the demonstration site in Greenwich. This includes data from energy management systems, sensor arrays on the street, building asset information (including a heat pump), and the various mobility technologies that they have tested. This capability

5G and future networks will become vital in enabling advanced digital infrastructure for smart city devices, products, applications and services.

can be rolled out across London and should form the basis of discussions for the future of the Datastore and the IoT.

Mayor of London is also collaborating with the Alan Turing Institute on an advanced machine learning project using data from hundreds of sensors that monitor air quality, satellite data, traffic light sensor data, Waze data and traffic flow data to help build predictive models about air quality. The plan is to open source this data in 2020 through an API, allowing innovators to build new products and services that can help Londoners to explore the cleanest air quality routes for their journeys, inform air quality policy and interventions, and be combined with medical research.

As next-generation connectivity and vast deployments of sensors become the norm, real-time monitoring of measures such as air quality, footfall, traffic flow and temperature will help to create even greater opportunities for efficiency, and shape a new generation of products and services. Such data collection and sharing needs to be approached in a pragmatic, scalable and ethical way. To support this, the London Datastore should be extended and industry encouraged to include specific challenge data from the private sector, leveraging the platform's new capability for peer-to-peer data sharing between digital and non-digital companies at scale.

Next-generation mobile connectivity

Over the next 15 years, Londoners and businesses within London will demand services and applications that will require greater levels of connectivity and infrastructure. Connectivity, including mobile, will need to offer high availability, reliability, security and bandwidth, along with lower latency, which is why 5G and future networks will become vital in enabling advanced digital infrastructure for smart city devices, products, applications and services. This will not just be for mobile, but also for organisations wanting to manage their own private 5G networks, providing greater control, security and reliability of their connectivity for specific purposes.

It is anticipated that close to 50 billion devices will be connected to mobile networks worldwide by 2020, with Londoners currently using 38 million gigabytes of mobile data a year (a fifth of all the mobile data in the UK).[122] Although we have begun to see the rollout of commercial consumer 5G services by operators this year, the evolution of 5G will continue for the next decade, with several interim releases already planned to offer new features over the next few years. These new features will enable 5G to provide greater control and flexibility for businesses wanting to explore its capability in place of WiFi or other connectivity options. It can also offer a network of networks capability (being able to centrally manage multiple networks) as well as network slicing (being able to allocate parts of a network for specific use cases).

Artificial intelligence is a discipline – like physics – that is incorporated into many products and services. It requires a number of technologies to come together to make it work effectively.

This will be vital to the next generation of smart city capabilities, enabling vast deployments of sensors at scale, some of which will have AI capabilities built in and some of which will connect to AI and machine learning capability in the cloud. Connectivity will be needed for anything from sensors on bins, street furniture and CCTV cameras, through to autonomous vehicles, robotics and possibly even drones. Connected operations, in real-time with high levels of reliability, will offer savings opportunities for London boroughs and businesses across the city, as well as supporting wearable devices for telemedicine functionality with the potential to improve citizen health and reduce pressures on public health services.

The Mayor of London has an important role to play in encouraging industrial and city-scale exploration of 5G and future networks for the economic growth of London and the surrounding region. The Connected London programme aims to enhance mobile and fixed fibre connectivity in London by working with local authorities, using public sector assets, and encouraging investment; and new data analysis has established new ways of working and encouraged adoption of best practice across borough boundaries. It is also important that clear strategic approaches for the rollout of 5G are proactively promoted across the 33 boroughs, with local authorities playing an active role in encouraging local businesses to explore 5G R&D to help demonstrate the business case for co-investment into the infrastructure and surface early use cases. The Mayor should actively work with the UK Government's Department for Digital, Culture, Media & Sport's 5G Testbeds and Trials programme and related initiatives around advanced digital infrastructure, to encourage applications and use cases to be developed by smart city innovators and industry challenge owners across the capital - particularly in areas such as logistics and entertainment.

Artificial intelligence, machine learning and deep learning

Artificial intelligence is a discipline – like physics – that is incorporated into many products and services, rather than being a solution in its own right. In fact, AI requires a number of technologies to come together to make it work effectively.

In order to maximise the benefits of the full advanced digital technology ecosystem that will grow over the next 10-15 years, London should approach AI capabilities as part of an advanced digital infrastructure capability for the broader ecosystem.

This means enabling the city to access AI capabilities at scale, whether at the edge through IoT devices or mobile edge using 5G. The streaming and provision of data from the environment through this infrastructure is critical to AI solution provision. This is also connected to burgeoning AI hardware capabilities that provide computation power and AI chips that provide machine learning efficiency gains through novel processor configurations, such as UK-based Graphcore.[123] By enabling AI capabilities across the city through data science service providers and consultancies connected to AI capabilities in local mobile edge facilities (alongside its own data collecting, sharing and cleaning capabilities), London can establish the backbone of AI powered solutions by enabling its easier integration into a range of startup and scaleup solutions. This will help the capital to become the global leader in AI-powered products and services for the smart city, such as autonomous vehicles, smart traffic lights, self-regulating air quality solutions and/or predictive maintenance.

London already has smart city strengths and should grow further with the right set of interventions and support to drive adoption of AI more broadly. As mentioned above, the project being run by the Alan Turing Institute and the Mayor of London is already looking at AI predictive modelling for monitoring air quality, to demonstrate the best travel routes for London pedestrians. The Mayor of London and organisations such as LOTI can play, and have already played, a crucial a crucial role in setting out data standards and schemas, but more can always be done in this space. By making more city-based datasets and data streams available in clean and standardised formats, there will be greater acceleration of innovation in AI, while also promoting collaboration regionally and internationally (such as the multi-city Synchronicity project[124]).

Encouraging edge facilities and IoT deployments for London

Most AI development is currently focused on centralised computation through public cloud providers (such as AWS, Google Cloud and Azure). While this is likely to continue for the foreseeable future, edge-based computation (processing and acting upon data closer to where the data is generated, such as on a sensor device or in a local data centre) offers significant opportunities, such as lower latency (or in other words higher data speeds), improved bandwidth, security, privacy and greater levels of control over how data is used and processed. Applications spanning autonomous vehicles, CCTV, immersive mobile gaming, and smart cities will all make use of advanced AI/ML algorithms that require large amounts of data for training, with continuous feedback and instantaneous intelligent processing (inference) when in operation. Sending every bit of information back to a centralised cloud data centre is costly and inefficient. The opportunities for edge computing will be widespread in the future, and London should be ready to support and benefit from them.

Using mobile edge facilities in London will demonstrate and accelerate the scalability of AI-based solutions in combination with next-generation 5G connectivity. To be able to do this, the Mayor of London should take active steps to plan building mobile edge facilities, by encouraging real estate availability, and enabling access to existing and future computing infrastructure beyond its original intended use (such as that being used for CCTV or for autonomous vehicles in the future). It is envisaged that a wide range of edge infrastructure providers will emerge, from existing cloud providers (such as the AWS with the Wavelength service in partnership with Vodafone[125]) to smaller players, including the public sector. The GLA should investigate both the opportunity to build edge infrastructure for London and its operations, and the regulatory framework for trustworthy usage and sharing of data at the edge.

World-leading quantum companies should be encouraged to set up in the capital, to foster strong working relationships with the ecosystem and factor quantum into longer term R&D infrastructure planning.

Quantum computing in the smart city environment

In the future, quantum computing is likely to have a large number of applicable use cases in smart cities. Due to the intrinsically statistical nature of quantum mechanics, the first usable quantum computers process large amounts of data without providing 100% accuracy. This makes it most suitable for large-scale operations where an average answer will be sufficient, such as optimising city-wide traffic flow at a macro scale. As Professor Andrew Shipilov from INSEAD points out in his blog in January 2019:

"The system could give different suggestions to different cars to shorten their travel time. Even if a given forecast – e.g. the next five cars should detour via Street A to unclog Street B – is only 98 percent accurate, it would still be good enough on average. Everyone would have a better chance to arrive in time for dinner."

There are other areas that require high levels of accuracy - but not perfection - at city scale. Quantum computing could be used to optimise electrical grids, "another problem that requires massive computational power, but can tolerate small errors."[126]

The Mayor of London should promote further collaborative R&D into quantum for smart city use cases, bringing world class research centres focused on quantum into partnerships with other notable companies and organisations working in this space. Through London & Partners, world-leading quantum companies should be encouraged to set up in the capital, to foster strong working relationships with the ecosystem and factor quantum into longer term R&D infrastructure planning.

The city as a platform for innovation

For companies to take the first steps in adopting new technologies, they need to be able to justify a business case and understand the return on investment being offered through use of the advanced digital technology stack. So while testbeds and demonstrators should be created to explore advanced digital infrastructure and the opportunities it offers for London businesses, it is also important for the Mayor to encourage the exploration of smart city trials and use cases across the UK Government's grand challenges of clean growth, AI and data, healthy ageing and the future of mobility and any further themes that emerge over the next year in response to COVID-19. Innovation that begins in London can have a significant effect on the broader UK economy. By establishing and engaging startups and scaleups on the journey around these use cases, London can act as an incubator for new studies to generate customer pipelines for its innovators.

Smarter safety

The Mayor of London should support and encourage London Gateway to be a global leader in the use of 5G, in particular for the application of next-generation connectivity for robotic cranes. Belfast Harbour, for example, has already conducted real-time demonstrations of the benefits of 5G technologies, including operations teams wearing augmented reality headsets connected to a 5G device to understand potential use cases, and using an AR device for crane operators to receive "step-by-step maintenance guidance and remote support through video collaboration with a remote expert, via an application server in the cloud."[127] These demonstrations were the result of a private public partnership between EE/BT, Belfast Harbour and a number of mixed reality startups and scaleups, including Ubimax and VRtuoso.[128]

This type of use case could be extended to include ground-based remote crane operation in a variety of situations in London, such as large construction projects. By removing crane operators from hazardous environments into safer locations on the ground, utilising real-time connectivity for high responsiveness, London could become a global leader in health and safety approaches to construction and industrial equipment. London-based ExtendRobotics already creates industrial robotic tools that perform complex tasks at human level dexterity, in hard-to-climb, confined high spaces, ensuring the operator encounters zero risk.[129]

Smarter logistics

The flow of goods around the capital underpins the London economy and has a significant economic impact across the UK.

Logistics covers the transportation of goods between two points across different modes (land, water and air), the processing and storage of those goods, and their delivery to the customer. This involves three areas of activity: logistics hubs, inter-site logistics and last mile logistics.

The advanced digital technology stack offers significant benefits for logistics. Future networks and AI will interact with IoT technologies, such as sensors and wearables, to drive better real-time tracking and more intelligent predictive route planning for delivery. New applications and services will help to improve sustainability, and reduce carbon footprints and waste. For example, by monitoring and regulating the temperature of fresh produce being transported to a supermarket, and using ultra high definition (UHD) cameras to monitor goods deterioration, logistics companies and retailers can reduce food waste. When this capability is then linked with automated warehouse management - ordering goods only when they are needed and in quantities that are more sustainable - the efficiency gains could be significant, and go a long way to helping London achieve its own carbon neutral targets.

The combination of 5G, IoT, AI and cobotic systems will make London's logistics hubs more efficient.

Getting goods out of ports and airports more quickly will also improve efficiency and productivity gains. The combination of 5G, IoT, AI and cobotic systems will make London's logistics hubs more efficient, moving containers and cargo on more swiftly, improving supply chains and connections with other parts of the UK and helping to handle shocks to the food system and value chain that can come from increased demand, changes in consumer behaviours or crises (for example pandemics, climate change).

The Mayor of London should raise awareness of these efficiency gains through a focus on the adoption of advanced digital technologies by logistics and the supply chain companies and organisations across the value chain, inspiring and encouraging London-based startups and scaleups to explore such use cases for their products and services. This will generate demand and case studies that can be extended across the UK, and exported (via organisations such as London & Partners) to other countries seeking to optimise national and international supply chains.

The Mayor should also engage with R&D projects and related proposals, such as those within the Made Smarter ISCF portfolio and innovation ideas being developed by the UK Food and Drink Sector Council, which is exploring how advanced digital technologies can improve the transparency of UK food supply chains and shipments to cope with shocks and build resilience. The Made Smarter Review estimated that the "UK food and drink industry could realise £56 billion in productivity growth and efficiency savings over a ten year period through the wide-spread adoption and integration of novel industrial digital technologies across the supply chain."[130] The Mayor should work with the Food and Drink Sector Council, UKRI, BEIS, the Catapult Network and the AgriTech Centres to feed into the design and development of a food and drink supply chain resilience programme to enable better data sharing across the capital and more widely across the country using advanced digital technologies.

For example, recent, well publicised, health and safety issues relating to food contamination and allergens (for example, the NHS listeria outbreak and Pret/allergy lab reaction) have also created challenges around production methodology, traceability and accountability in the supply chain. The Mayor of London should connect London-based businesses and NHS Trusts with R&D projects that are exploring these challenges through the ISCF, and ensure that the learnings and use cases being developed are fed into planning and future innovation strategies for the capital.

Greater connectivity, data, trust and visibility will be enabled by advanced digital technologies, fostering more localised, personalised, peer-to-peer micro-manufacturing and collaborative production.

Smarter manufacturing

As both Digital Catapult and the High Value Manufacturing Catapult highlighted in 2017, over the next five to ten years distributed autonomous manufacturing led by demands from the consumer sector will be one of the mechanisms that drives disruption in traditional manufacturing business models.[131] A consumer-centric model for personalised and localised manufacturing will use technology to make the process accessible, enabling customers to input their own requirements (such as the colour, style and comfort of a new pair of trainers) and receive an automatically generated design, complete with its bill of materials and associated operations, that can be made available to the manufacturing ecosystem.

Manufacturers can then bid to perform an operation, supply parts or assemble the finished product. Decentralised by its nature, distributed autonomous manufacturing will enable consumers to interact directly with manufacturers. Greater connectivity, data, trust and visibility will be enabled by next-generation advanced digital technologies, and will foster more local, peer-to-peer production, micro-manufacturing and collaborative production.

Distributed autonomous manufacturing in London has become a possibility because of transformative technologies such as 3D printing, blockchain, artificial intelligence and machine learning, and the IoT. These technologies enable manufacturing processes to be distributed to local facilities, and even to the customer. London has a significant opportunity to create localised manufacturing facilities and capabilities that connect with the new creative production corridor in the Thames Estuary. Distributed autonomous manufacturing would capitalise on the potential of the advanced digital technologies stack, and create huge opportunities for the capital to trial new approaches that reduce the burden on the supply chain and waste, while increasing customisation and personalisation of goods to meet the demands and needs of consumers.

A new manufacturing ecosystem could emerge in the capital as a result of new trends and demands in production, characterised by:

- Highly personalised/specialised finished goods
- Personalised combination services
- Evolution of a maker-consumer relationship
- Autonomous stock allocation
- Commoditised production of high value components across the supply chain
- Automated product design

Distributed autonomous manufacturing would capitalise on the potential of the advanced digital technologies stack, creating huge opportunities for the capital [and] reducing the burden on the supply chain.

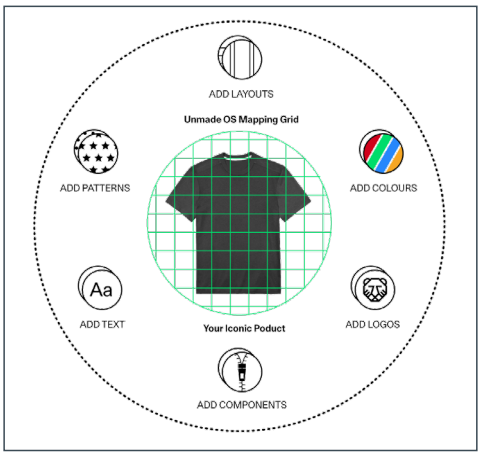
As an example, Carbon3D in California has partnered with Adidas and Ford to take its rapid prototyping and 3D printing business global, attracting funding of $260 million. London has started to sew the seeds of this new and emerging scene through high growth startups such as Unmade, which has worked closely with global leading fashion brands to improve ecommerce and on-demand personalised/localised manufacturing.

In 2019, the UK Government Department for Digital, Culture, Media & Sport invested £4.3 million from its Cultural Development Fund into the Thames Estuary production corridor, creating opportunities to test and trial localised and personalised manufacturing capabilities, building on London's various strengths in this space. Bringing together industry, logistics companies, fashion houses, manufacturers, SMEs and technology startups to build collaborative R&D 3D printing textile facilities to test these new business models would be a strong signal of intent for London to build capacity and capability in localised manufacturing.

It is part of the Mayor's ambition to build a large 3D printing facility in Silvertown,[132] and in the meantime, smaller and more distributed facilities could be encouraged in partnership with the manufacturing sector to explore how such localisation can be integrated into the ecommerce offering of London's creators.

CASE STUDY

UNMADE Ltd.



Unmade is a global fashion software company working with pioneers from the fashion and sportswear industry. It offers digital solutions that power fashion's new 'driven by demand', industry, which depends on customer engagement, customisation and collaboration. This new industry will be data driven, focusing on the consumer to transform the fashion sector and make it more sustainable.

The business was started by Hal Watt, Kirsty Emery and Ben Alun-Jones in 2014. Their cutting-edge technology was nominated for LVMH Innovation Awards at VivaTech Paris in 2017, and was included in 2019's Most Innovative Tech Brands survey

conducted by Brands Key inc. In July 2019, Unmade secured a £4.8 million seed round, on top of its £4 million venture round in August 2018.

One of Unmade's clients is fashion retailer, Opening Ceremony, which approached Unmade with the vision of involving its customers by handing them creative power. Unmade worked with the Opening Ceremony team to develop a customisable knitwear collection that would be made to order. Rapha Custom, a cycling clothing company, enlisted the help of Unmade to give customers autonomy over the design of their team's kit, including team logos and colour palette. Uniquely positioned against other tools of this kind, the platform captures users' imaginations by showing previews of their designs on a model and on location.

Most recently, Unmade has come together with New Balance to turn its unique designs into production-ready data. This is the first time this has been possible, due to the level of accuracy necessary for footwear production. This partnership showcases New Balance's commitment to being more efficient and sustainable throughout its value chain.

London should lead the way in creating more testbeds for advanced digital infrastructure.

Barriers and considerations

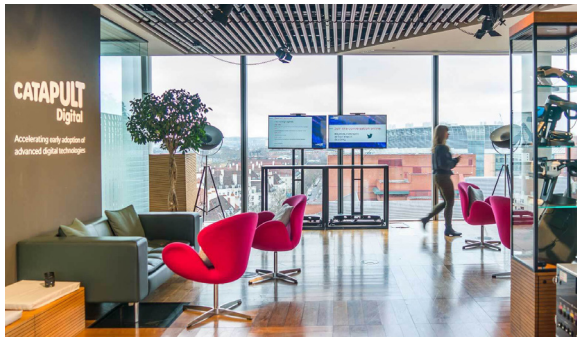
With an increasing population, rapid transformation, ever-changing sectors and the convergence of technologies, London is facing a range of disruptive forces that will change the face of the capital. These changes are taking place in tandem with growing global environmental concerns, the impact of COVID-19, increasing ethical and social considerations relating to technology use cases, and technical and business barriers to adoption. It is therefore important that the Mayor of London, building on the Smarter London Together[133] roadmap, takes into consideration the principle barriers to the development of products and services using the advanced digital technologies stack. This should align with their ambitions for London to become a 'Sharing City' through the EU's Horizon 2020 project of the same name.[134] The Mayor of London's Civic Innovation Challenge, in partnership with the Social Tech Trust and Microsoft has started to help connect startups and scaleups to specific civic use cases, products and services, with high potential for expansion along with bringing in more industry challenge owners.[135]

Funding for testbeds and demonstrators

London should lead the way in creating more testbeds for advanced digital infrastructure, to facilitate the development and testing of new smart city products and services that solve specific challenges and realise new opportunities.

As well as bringing together the infrastructure layers of the advanced digital technologies stack, testbeds can also include urban data sharing platforms to make IoT and private stakeholder data available for new service innovations. Together, these testbeds could link closely with the innovation ecosystem in London, through specialised acceleration programmes, giving cohorts of companies access to R&D infrastructure. London's testbeds could also support the Civic Innovation Challenge programme.

More testbeds would provide access to state-of-the-art equipment, hardware and infrastructure for London-based startups and scaleups to help prepare them for the future, attract broader co-investment, and position their innovations as solutions for real-world industry challenges and focus areas. Establishing such clear projects and capabilities in the capital would enable global promotion to attract inward investment through organisations such as London & Partners.



Connecting London to the levelling up agenda

Regional economic prosperity across the UK is linked to the productivity and growth of businesses that employ large numbers of the local population. These are often multinationals, but can also be small to medium sized enterprises and regional hubs of activity for industry. In these areas, innovation is often linked directly to research and development institutions and organisations - national facilities and research technology organisations (RTOs) such as the Catapults - or associated with a university. To ensure the London startup ecosystem can be more deeply connected with regional organisations and businesses, the Mayor of London should help to co-design interventions that help startups and scaleups connect with regional organisations (such as the UK Tech Cluster Group), specialist businesses, Catapults and RTO's, research institutions / universities and local authorities, helping to overcome geographical and cultural barriers to collaboration. This is particularly important in the light of COVID-19 recovery for the economy and the regions - to ensure that regional digital companies are able to connect into industry challenge owners based in the capital - while providing opportunities for London-based digital innovation to meet demand for digitalisation for local, regional organisations looking to implement new digital tools and technologies.

This will lead to a greater number of products and services that are underpinned by advanced digital technologies coming to market, making London a thriving hub of activity across multiple sectors and smart city deployments that will help to meet growing demand for, and adoption of, advanced digital technologies at scale. The Mayor should encourage direct engagement between areas with different specialisms and drivers, acting as the catalyst for creating collaborative and commercial connections between them. This national effort, driven from London outwards and engaging with the regions inwards, will ensure that the UK is positioned as a global leader in the supply and demand of advanced digital technologies for the fourth industrial revolution, while developing the business case for broader adoption and long term recovery of the economy.

Standards and collaborative approaches to interoperability and security

Given the complexity of smart city deployments, local boroughs across the GLA need to ensure that their planning incorporates open approaches to procurement, networks, platforms and solutions. This will help smart city components to converge more seamlessly, enhancing their collective capabilities. Initiatives such as City Tools by LOTI are building more collaborative environments for boroughs to be able to do this: encouraging collaborations between local authorities, identifying opportunities for new entrants and innovators in the government technology market, and driving cost savings by coordinating contracts and leveraging collective purchasing power. Having a clearer and more transparent dashboard will also help technology providers to see how they can form partnerships for interoperability with other providers, to enhance their own service offering or allow new entrants to explore.

With such large volumes of data – much of it personal – being collected and processed across the capital, considerations around its ethical and sustainable use are essential.

As this initiative starts to yield results for the city, learnings and approaches could be extended to other local authorities around the country to maximise regional understanding. Building on the Scale Nationally recommendation of the LOTI's City Tools report, the UK Government's Ministry of Housing, Communities & Local Government is evolving this approach into a national resource that will increase collaboration beyond London and further strengthen its position. If this is also linked to challenge-led innovation, local authorities could discover a host of innovative technology providers to solve real-world problems, and the opportunities created could be significant. As 5G is rolled out further, a greater number of sensors and devices for connected and smart cities will flood the market, making the need for planning and transparency even greater, to avoid siloed data and digital walls between boroughs. However, 5G also provides greater scalability of data collection and processing - with more control for cities and boroughs through network slicing (segmenting parts of a network to perform different operations), or networks of networks (managing all devices and networks through a 5G network to break free of network silos).

Tackling smart city ethical and security challenges

With such large volumes of data - much of it personal - being collected and processed across the capital, considerations around its ethical and sustainable use are essential to the functioning of a modern democratic city. The nature of the advanced digital technology stack itself also raises questions about the data being collected on individuals. Is it sensitive? Is it collected in real-time? Who owns it? Who has access to it? How is it used? These considerations come with ethical, sustainable, social, economic and technical considerations that require sensible thought from decision makers across the value chain.

As sensors are deployed at scale and surveillance is increased for security, often in tandem with computer vision and facial recognition, this raises important questions of how citizen and human rights are balanced against the need to use such data-based technologies on an everyday basis. There are a number of papers that should be explored on this topic, such as The Royal Society's "The Ethics of Smart Cities and Urban Science" report,[136] or the Mayor of London's commissioned report "London Policing Ethics Panel - Final Report on Live Facial Recognition"[137]). Practical ethics guidelines and considerations should be explored by policymakers and industry to ensure better forward planning.[138] The Mayor of London and the UK Government should collaborate to take discussions beyond just the ethics of artificial intelligence and machine learning. They should include practical technology R&D ethics testbeds for the advanced digital technology stack as a whole, to help inform policy makers and industry of the best approaches to limit the negative impacts and increase opportunities for adoption.

It is essential that the city's systems, services and supporting technologies are resilient.

Further to the ethical challenges, it is also essential that the city's systems, services and supporting technologies are resilient, as the domino effect of a cyber attack could have profound consequences for London and the economy as a whole. The Mayor of London should again work with the UK Government, and in particular the National Cyber Security Centre (NCSC), to ensure that the Mayor's action plan for cyber security brings the right actors together to inform future strategic interventions. This will help the NCSC to tackle the scale and growth of vulnerabilities across the entire socio-technical system for London. For example, this could include facilitating consultations on what the city should consider critical infrastructure. In turn, the consultations and any subsequent actions from the NCSC should inform how the city plans strategically for robust secure-by-design cyber-resilient approaches across boroughs, services and technologies.

The Mayor and the UK Government should explore working with organisations across the Knowledge Quarter, alongside the innovation and research ecosystem in London, to establish a smart city sandpit or test environment. This resource should be used to explore security, policy, and technology opportunities and challenges at city scale, and then tackle those challenges head on. This proactive approach will help to foster and build the idea of cyber twins for the city, helping London to partner with other cities to share successful approaches to cyber resilience and encourage collaboration on threats and future challenges. Initiatives such as the DCMS programme Cyber 101 delivered by Digital Catapult, and Plexal's London Office for Rapid Cybersecurity Advancement actively work with cyber security startups and should be encouraged to connect directly to Mayor of London initiatives and local authorities to leverage their networks and ecosystems to help make sure that their proactive preparations also yield positive economic opportunities.

Building a smarter city

Recommendations

- Actively encourage industrial explorations of 5G and next-generation mobile connectivity for the economic growth of London and the GLA region. The Mayor should actively work with the DCMS 5G Testbeds and Trials Programme and similar schemes to encourage applications and use cases to be developed by smart city innovators and industry challenge owners across the capital, particularly around areas such as logistics.
- Approach AI capabilities as part of an advanced digital infrastructure capability for the broader ecosystem. This means enabling the city to access AI capabilities at scale, whether at the edge through IoT devices or via mobile edge using 5G. The streaming and provision of data from the environment through this infrastructure is critical to AI solution provision, and should be driven alongside the collection and sharing of useful city data and focused industry challenges through the London Datastore - allowing access to real-time APIs from emerging IoT infrastructures or labelled data sets that can benefit innovators.
- Take active steps in planning mobile edge facilities, encouraging building through real estate availability, and providing access to existing and future computing infrastructure (such as CCTV or connected autonomous vehicles) for users beyond those originally intended. This should include investigating the opportunity to build edge infrastructure for the city and its own operations, as well building a regulatory framework for the trustworthy use and sharing of data.
- Promote further collaborative R&D on quantum for smart city use cases, bringing world class research centres already focused on quantum into partnerships with world-leading companies in this space. Through London & Partners, world-leading quantum companies should be encouraged to set up in the capital to foster strong working relationships with the ecosystem and factor quantum into longer-term R&D infrastructure planning.
- Create a focus on adoption of advanced digital technologies by logistics and the supply chain in the capital, helping to inspire London-based startups and scaleups working with emerging technologies to explore supply chain use cases of their products and services, as well as generating demand and case studies that can be extended across the UK and exported via London & Partners to other countries looking to tackle globalised supply chains. This could be linked to a future revamp of the Mayor's London Tenders portal - CompeteFor - providing more focus on specific industry and regional-based industry challenges, including underpinning industry sectors such as logistics.

Building a smarter city

- Explore the creation of small localised manufacturing facilities and capabilities that connect to the new creative production corridor in the Thames Estuary. Distributed autonomous manufacturing would make use of the huge potential of the advanced digital technologies stack and create opportunities for London to trial new approaches to manufacturing that can reduce the burden on the supply chain, reduce waste and increase customisation and personalisation of goods to meet the demands and needs of Londoners.
- Help to co-design interventions that help London's advanced digital technology startups and scaleups to connect to specialist businesses and local authorities across the country, where there are geographical and cultural barriers to collaboration.
- Consider the ethics of the entire advanced digital technology stack rather than just artificial intelligence and machine learning. Explore the creation of practical technology R&D and ethics testbeds for the advanced digital technology stack in specific smart city contexts. This should be used to help inform policy makers and industry of the best approaches to limit negative impacts and increase opportunities for adoption.
- The Mayor of London should take a harmonised approach across boroughs in establishing advanced digital infrastructure and adopting common standards-based solutions wherever possible, and especially in the areas of AI and IoT where market fragmentation is still very high. This will ensure that the benefits of new innovation can be easily replicated across the capital, while minimising the dependency on specific vendors, so that the infrastructure can evolve freely in the future.

Augmenting the physical environment

Contents

Augmenting the physical environment

Immersive interfaces will change the way we interact with data, how we live and work in London and how the broader UK economy, skills and research expertise can be more closely connected to the capital.

Alongside better connectivity, combined with the volume and ubiquity of data, intelligent systems and robotics, there will be a shift in the way that London embraces extended reality and immersive technologies at scale. Immersive interfaces will change the way we interact with data, how we live and work in London and how the broader UK economy, skills and research expertise can be more closely connected to the capital. This shift will break down geographic barriers, democratising capabilities by allowing virtual collaborative working to emerge.

The advanced digital technology stack will enable the next generation of immersive technologies to interact with data, AI, enhanced mobile connectivity, and - potentially - quantum powered devices, alongside sensors, connected devices and distributed ledger technologies to form a new digital interface with our physical reality.

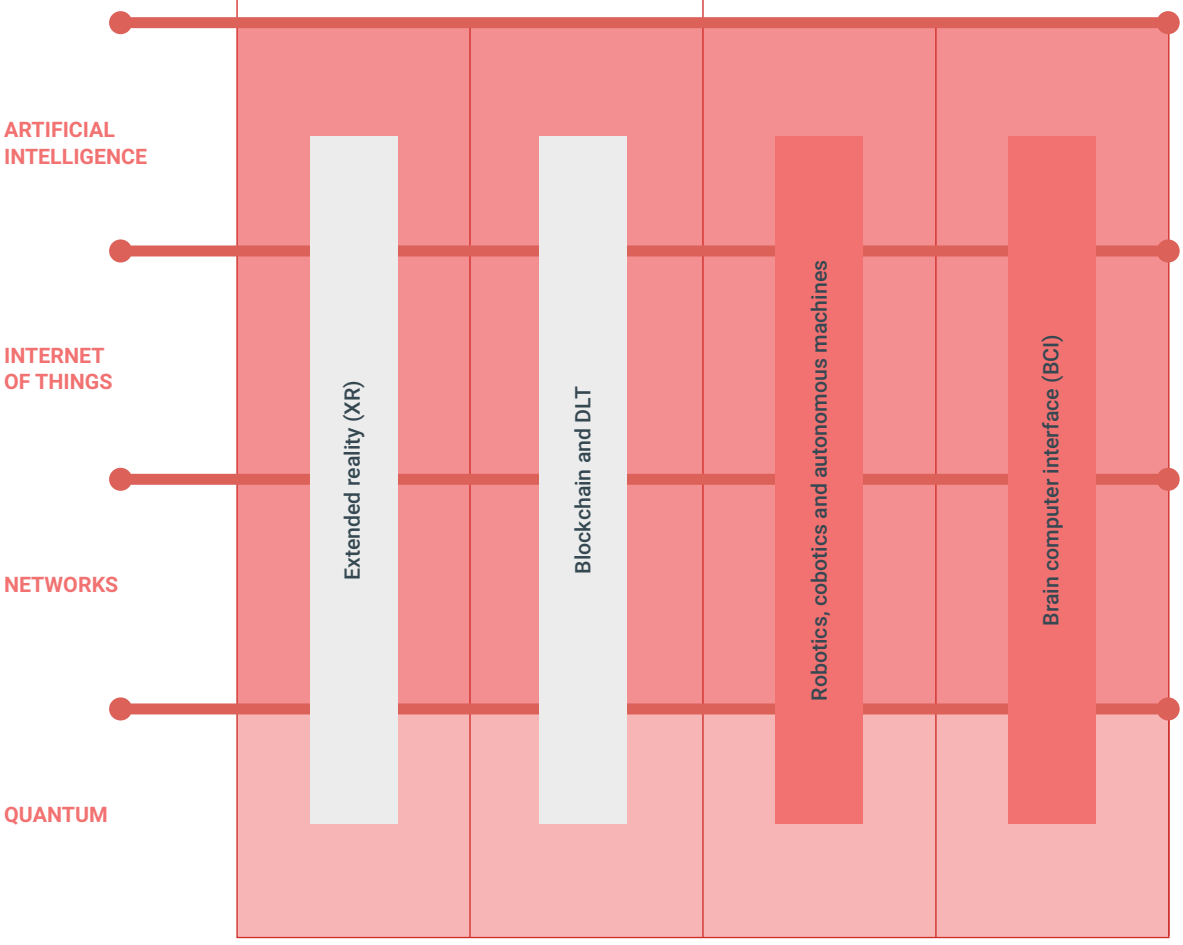
This will be most evident in three significant developments:

01	The augmented reality cloud
02	Immersive workspaces
03	Live streamed immersive entertainment and next-generation content production

Augmenting the physical environment

Augmenting the physical environment

Spanning ultrareliable augmented reality cloud at scale across the physical environment in London, along with next generation immersive content production and collaborative workspaces, London has a real opportunity to bring together the new physical internet.



Augmenting the physical environment

The augmented reality cloud

Augmentation will form a crucial aspect of how humans will interact with data and one another in the future

Within just two years, the transformative convergence of technologies will move from nascent trends to increasingly commercialised products and services. As the World Economic Forum points out in its report 'The Future of Jobs' (2018), there will be four clear technological drivers of change by 2022:

- Ubiquitous, high speed mobile internet
- Artificial intelligence
- Widespread adoption of big data analytics
- Cloud technology

By 2035, there will be a significant blurring of the divide between the digital and the physical, as data is visualised through new and immersive forms and distribution channels. This overlap has already been seen in augmented reality games such as Pokemon Go or Harry Potter Wizards Unite - and in future this augmentation will form a crucial aspect of how humans will interact with data and one another in the future.

One of the most fundamental aspects of this shift will be the capabilities afforded by the augmented reality cloud (AR cloud). For London, this will lead to the creation and growth of a new range of startup and scaleup extended reality companies - offering a host of consumer and B2B solutions that will impact almost every sector of the economy.

What is the augmented reality cloud?

Variously known the AR cloud[139] by many, the Magicverse[140] by Magic Leap, the Mirrorworld[141] by Wired, the Cyberverse[142] by Huawei, Planet-scale AR[143] by Niantic and Spatial Computing[144] by academics. Ori Inbar[145] defines it as "a persistent 3D digital copy of the real world to enable sharing of AR experiences across multiple users and devices". In 2019, PwC estimated that AR will boost UK GDP by £44.4 billion by 2030.[146]

Location-based games are growing in popularity. There have been over a billion downloads of Pokemon Go, and over 20 billion kilometres walked playing the game.[147] Its wizarding successor, Harry Potter Wizards Unite grossed $12 million in its first month.[148] AR is already being applied in training[149] and education,[150] healthcare, [151] heads-up wayfinding and navigation,[152] tourism,[153] retail,[154] field service,[155] real estate sales,[156] design[157] and architecture.[158] As it evolves further in combination with 5G connectivity, large volumes of data, machine vision, and new hardware devices (such as AR glasses), there are a number of potential applications, business models and experiences that could emerge to have a profound effect on how we live and work over the next 15 years.

Augmenting the physical environment

The bridge between the physical and digital

AR cloud experiences will be driven by where you are in the world, not just in terms of GPS co-ordinates but also your immediate surroundings: whether you are indoors or outdoors, what room you are in, and what objects or other people are around you. All of this may also affect the virtual avatars, information or interactive components that are layered in the same environment. Your location may also interact with your own personal data: your own account built in the AR universe that you can control and configure with your own preferences.

The world map in the AR cloud is neither a 2D nor 3D: it is hyper-local, containing the insides of rooms, street furniture, doorways, steps, surfaces and the connections between them. This requires a significant amount of detail, which companies are already starting to map. The incumbents in this space have an advantage with existing mapping such as Google Maps, Earth and Street View, along with Apple Maps and its Indoor Maps Program,[159] and Bing Maps. There are also significant geographic data players such as Foursquare and OpenStreetMap who are likely to become key players in this evolving ecosystem.

Accompanying this world map will be persistent, stateful (tracked or recorded) geographic assets and data, some static, others interactive with behaviours of their own. They could be layers of information, such as instructions, directions, and visitor information, or game characters, artworks or virtual scenes. This information forms the content as media tethered to a physical location, available to be combined and experienced by people in that area.

At present, most people interact with data and information through their smartphones. Over the next 15 years, the expectation is that people will be using AR headsets, glasses or audio-only wearables, with different types of control and eye tracking. Apple, Google, Facebook, Amazon, Magic Leap, Snap, Niantic and other major players are likely to have taken steps to release headsets, glasses, AR browsers (like WebXR[160] already running on Chrome), or AR games engines (such as Unity or Unreal) that will evolve and improve as we move further into the 2020s and early 2030s.

Deep learning and computer vision will be crucial to layering digital assets over the physical world around the user.

AI, deep learning and computer vision

Deep learning and computer vision will be crucial to layering digital assets over the physical world around the user, a fundamental aspect of AR cloud applications, which rely on mapping and localisation, and detecting objects, environments or other people. This key capability builds upon advances in deep learning and computer vision, as well as localisation and mapping techniques developed for mobile robots, initially running on powerful smartphones. There has been an explosion of startups and acquisitions aiming at the two nascent markets with similar sensing needs: the AR cloud and autonomous vehicles.

Innovators around the world are beginning to develop solutions in this space, with London becoming an epicentre for AI's use in augmented reality. For example, companies such as Scape,[161] founded in the capital in 2016, are building highly accurate centimetre-level positioning for location tracking, using machine vision. Competing companies include California-based ContextGrid, which is building an open registry for AR assets. Azure Spatial Anchors and Google Cloud Anchors are also leveraging existing strengths in mapping towards the AR cloud.[162]

In order for London to build on its strengths in this space, it is crucial for the Mayor of London and the broader London ecosystem to provide further opportunities for AI/ML research to join the immersive content sector in exploring the impact of such collaboration and the evolution of AR cloud technologies.

Future networks connectivity for AR, at scale and at the edge

AR cloud systems will only be possible through advanced digital infrastructure, and the use of next-generation mobile networks such as 5G and its future iterations. When the AR cloud is operating at scale it will impose huge requirements - in terms of bandwidth, latency and local processing - on devices and the edge cloud. This is where the capabilities of future networks will come into their own, including the mobile edge computing standards.[163]

Existing edge providers will also play a role in this space - such as Cloudflare, Fastly, Akamai, and the big cloud providers, Amazon, Google and Microsoft - alongside the development of a host of other open source tools for automation, deployment, caching, federated learning and server-less computing solutions. Specialised distributed platforms serving the AR cloud may also emerge, such as youAR for publishing and deploying localised AR content, or London-based Improbable's SpatialOS, which enables multiplayer experiences.

The AR cloud apps, layers and objects that exist within the advanced digital technology stack could also be served globally from a few closed central systems, using distributed advanced digital infrastructure. An example would be massive multiplayer games such as Fortnite, running over AWS. However, it may also be possible that in the future anyone can develop and host AR Cloud content using open standards and protocols, potentially just serving their own local areas. This offers significant potential for 5G private networks and AR to converge in a city environment, supporting local businesses, new business models or retail opportunities.

New consumer tools for [augmented reality cloud] content and app discovery will emerge, the equivalent of app stores or search engines.

The AR cloud and distributed ledger technologies

One of the key aspects of future immersive environments will be the ability to create, own, and transfer or sell unique items and content. A fully interoperable, multi-vendor AR cloud, will need a common layer for keeping track of this information. The only technology that fits this remit is DLT, currently being explored for multiple financial, industrial, and creative applications.

A number of exciting developments are taking place in London, and through distributed teams with a significant presence in London. One such pioneer is Decentraland, which is building an open 3D world akin to Second Life, but fully decentralised and owned by its contributors.[164] Other leading groups exploring the future of digital creativity and art or content ownership include the London-based Decentralised Arts Lab[165] (DECAL) co-founded by Furtherfield and the Serpentine Gallery, one of London's most popular contemporary art venues.

The recent Statement on Crypto Assets and Smart Contracts from the LawTech Delivery Panel[166] confirmed that DLT-based digital assets are compliant with English Common Law, and strengthens the case for using DLT to own, manage, and exchange digital content in the future AR cloud.

Development and distribution using AR cloud

The ecosystem around the AR cloud will include tools for authoring applications, behaviours, creation of assets and environments. While it is expected that platforms such as Unity, Unreal, and Autodesk will continue their dominance and innovate with projects like EditorXR or MARS, more specific offerings will emerge, such as Torch AR, Sketchbox 3D, and Dotty AR for sharing models; Cognitive3D for analytics; Anything World to add voice interaction; or London-based Blippar's[167] Blippbuilder for the creation and development of AR assets (already being used by over 50,000 people).

The big tech players will also look to entice developers with tools like RealityKit (Apple), Maquette (Microsoft), Spark AR Studio (Facebook), Spatial Workstation for immersive audio (Facebook via acquisition of Two Big Ears), Lens Studio (Snap) and Tiltbrush (Google). Facilities such as Digital Catapult and Hammerhead's south London-based volumetric capture studio, Dimension,[168] or new and emerging virtual production studios will enable filming and asset creation. New consumer tools for content and app discovery will also emerge, the equivalent of app stores or search engines.

Digital Catapult, Microsoft and Hammerhead's Dimension Studio in South London provides a world-class volumetric immersive capture facility for use by startups, scaleups and corporates.

AR cloud for logistics and industrial applications

AR cloud has numerous use cases that could develop into scalable products, applications and services for London. In 2018, for example, the Leeds Teaching Hospitals NHS Trust partnered with supply chain solutions London-based company Scandit to use augmented reality and machine learning to capture, track and collate inventory and patient data - resulting in a "95% improvement in cost and time efficiency." This work is now being extended across the NHS, through Scandit working with IT solutions provider Ingenica, to transform inventory management using AR technologies.[169]

Inventory management can also be extended to warehouse management and AR for training and wayfinding across industrial or other large physical environments. In London Heathrow and Gatwick, for example, AR was used for wayfinding in 2017 to explore how passengers could find their way around the airport, by combining 2,000 beacons (internet of things) with new augmented reality wayfinding applications. While this was powered via existing networks, rather than requiring 5G, future iterations could be extended to include more information (such as interacting with retail experiences in the airport), and across wider geographical indoor and outdoor environments.

AR cloud for tourism

AR is already being used in the tourism and travel sector. Smartify, a London-based startup, uses AR to layer information over art to provide context and information for visitors to galleries, enhancing their experiences.[170] They have also explored combining augmented reality with 5G for the 5G Testbeds and Trials Smart Tourism project at the Roman Bath Houses in Bath.[171] Hotels have also started to explore AR too, with customers of the Premier Inn in London being able to use their smartphones or tablets to interact with wall maps to obtain extra information about the city.

As we start to see further development of the AR cloud, tourism will offer a cluster of consumer-centric use cases, various parts of London being transformed to provide historical re-enactments and/or tours that interactively demonstrate the history of the city. Interactive experiences could also be provided via apps to form treasure hunts across the capital. Through such interactions with advanced digital infrastructure, the city itself can become a museum, while some areas may offer experiences that will create new business models and enhance retail experiences.

With bricks and mortar retailers facing increasing pressure from e-commerce, creating immersive experiences in stores is seen as an enabler for the renaissance of the high street.

AR cloud for retail

AR cloud could be transformative for the future of the high street. In July 2019, Warwick Business School published a study on the benefits of mobile augmented reality apps for enabling smart retail, by conducting large-scale surveys and undertaking quantitative analysis of 272 shopping apps. They found that augmented reality apps are already starting to transform shopping on the high street, with nearly half of shoppers being happier with items they have purchased after using AR, and more than 41% being more likely to purchase using AR apps. Expectations are that over the next five years, the use of retail AR apps will become mainstream.[172]

With bricks and mortar retailers facing increasing pressure from e-commerce, creating immersive experiences in stores is seen as an enabler for the renaissance of the high street. Warwick Business School's research also found that AR apps can boost the likelihood of consumers visiting a retail store again, as well as the likelihood of referring it to a friend. These findings demonstrate just how much a visit to the high street is becoming about the experience rather than for savings or necessity, shining a clear light on the opportunity for the AR cloud to have transformative effects across London, on Oxford Street, Regent Street and beyond.

For example, if someone is walking down Oxford Street in the future, their AR glasses will enable them to interact with shop fronts, with personalised adverts and savings being presented to them as they pass, to entice them into the store. At the same time, there may be a sponsored theme on the street that day, with numerous virtual and physical experiences and games to interact with. Going into the store, the consumer may find that the store itself has another theme, maybe highlighting a new range of clothing that had launched that week.

In this new and immersive environment, the boundaries of what is physically impossible are blurred with the digital imagination. This immersivity can be extended to entertainment experiences, and to restaurants - to enhance your dining environment or provide more information about allergens on a menu.

The Mayor of London has an opportunity to work with London's retail/shopping centres, high streets (Oxford Circus, Regent St) and stores (large multinational retailers and local or boutique companies) to encourage the testing and exploration of new retail content experiences using AR. By connecting the retail sector to creative content makers, immersive technologists and games companies, significant opportunities for growth can be created to draw crowds back, by enabling consumers to experience unique immersive environments every time they visit.

AR cloud in healthcare

Life science companies are already exploring ways for AR to enable new treatments and therapies. Examples include interactive experiences that demonstrate how drugs and medical devices will interact with the body, providing more effective ways of demonstrating and explaining new treatments to patients and for pharmaceutical companies to explain to other healthcare professionals. Between 2019 and 2025, AR for healthcare is predicted to grow globally at a compound annual growth rate of 36.35%.[173]

Solutions where XR, AI, and future networks work in concert will increasingly support future work practices for London and beyond.

AR applications have included mapping a patient's body, showing the location of veins and arteries so that medical staff can be more accurate when drawing blood, and reconstructing tumours and organs in 3D so that surgeons can visualise operation sites more clearly, preparing them better for what they will find during surgery.

With critical levels of accuracy required in the healthcare applications of AR cloud, there will be a need to leverage multiple converged technologies, such as computer vision and possibly the IoT with data transfer through advanced connectivity, to provide real-time processing, rendering and layering of information over the body. London has a number of leading companies working on this, such as Proximie,[174] which uses AR for surgical support, enabling doctors from remote locations to provide guidance and advice in real-time during a procedure.

Immersive workspaces

Following on from the AR cloud example of collaborative AR-enhanced surgery, another growing trend in extended reality (XR) applications is the potential for immersive working environments that will enable greater flexibility and geographically distributed collaboration between teams and individuals. Colleagues can log into their AR headset and be able to view data, files, and 3D designs layered over their physical environment. This could also be extended to using VR, bringing people together to interact virtually using hyper-real avatars.

As well as enhancing collaboration and removing geographical barriers, the added value of AR and VR comes from the input methods, such as enabling physical interaction with data. This can give new meaning to visualisation techniques such as employing scale or spatial relations, especially when reinforced with the haptic and audio capabilities of XR technologies. This will transform remote working and collaboration with anyone around the country and the world in socially distanced offices, talent and businesses in London.

In an immersive workspace that brings remote workers together, physically interacting with data representations provides a heightened sense of social presence and so-called embodied cognition, that is, processing information not only through sight and sound but also through the body.[175]

As well as providing avatars of colleagues, solutions where XR, AI, and future networks work in concert will increasingly support future work practices for London and beyond. Natural language processing, emotion recognition and other AI techniques will enable engagement with virtual assistants in human form, and in real-time, once network capabilities reach necessary bandwidth and latency with 5G.

CASE STUDY

Gravity Sketch

London-based Gravity Sketch's multi-platform 3D collaboration and creation platform enables users to create 3D models, designs, and scenes. The immersive design tech startup enables teams to work in an immersive 3D environment in intuitive ways, lowering barriers to 3D literacy. Gravity Sketch is currently used in the automotive, aerospace, defence, and creative sectors; the platform is fast becoming a crucial tool in digital 3D design.

Gravity Sketch plans on moving further into collaborative 3D design activities that combine immersive technologies with 5G and AI to help teams work better together. This includes using ARKit and ARCore, along with other platforms and networks to develop a suite of products that can meet the increasing demand for collaborative immersive 3D design tools. The company is also exploring a 5G proof of concept in Japan with mobile operator NTT Docomo to see how 5G will help them reduce latency, improve image quality and further enhance the user experience.

Before long, most 3D design will take place entirely in XR: artists will physically paint textures on virtual 3D assets in VR, much like they would onto an actual physical object or scenery.

Live streamed immersive entertainment and next-generation production

Content creators will increasingly take advantage of virtual production techniques that help to de-risk various phases of production. For example, directors can visualise complex spaces and interactions in XR before sets need to be built, and 3D artists will soon employ hybrid apps where their desktop software is imported into a XR headset to take advantage of embodied aspects. Before long, most 3D design will take place entirely in XR: for example, artists will physically paint textures on virtual 3D assets in VR, much like they would onto an actual physical object or scenery.

Game engine software and middleware that enables producers to bridge the gaps between various creative workflows and assets are key to these developments. However, both the technology and the content creators will need to meet audience expectations, where the real-time, social nature of entertainment is taken as a given. This is already becoming evident with the global success of games such as Fortnite. Real-time volumetric capture (recording directly into an immersive environment through ultra high definition and infrared cameras) and streaming will enable crossover entertainment, where music and performance artists will interact with virtual characters and audiences across the globe.

Besides volumetric capabilities to capture and produce content for digital products distributed via digital channels, location-based entertainment productions that combine virtual and physical assets are gaining traction. In the future, to scale their business, creative studios in the XR space are looking to extend their location-based productions globally and in real-time, much like sports events. This will require greater levels of XR headset adoption by consumers to elevate content investments beyond its current state, and use of technologies like 5G to enable mobile access that lives up to the ambition of the productions themselves. Location-based venues will maintain viability by premiering advanced XR technologies that are not yet mature for the consumer market, such as experimental full-body interfaces and holograms.

Alongside entertainment and creative hubs in the US and Asia, London is proving to be a testing ground for immersive location-based experiences and their business models. London's strength in tourism enables the highly experimental productions, locations and scale of audiences that are required in the early phases of immersive entertainment. During 2019, immersive productions - ranging from Darkfield's 'sonic theme park' in Canary Wharf[176] to dotdotdot Entertainment's War of the Worlds Immersive Experience, which combines VR with immersive theatre - have proven London's value as a profitable centre for such ground-breaking work.[177]

Augmenting the physical environment

London is therefore in a unique position to showcase local and national UK content with the potential to reach a global audience. While future networks capabilities may make geographical location less meaningful in terms of immersive content production (as people will be able to collaborate and work from anywhere), London will continue to be one of the global hubs where ground-breaking work is premiered, bridging location-based and digitally distributed immersive entertainment.

At a national level, R&D programmes like the Industrial Strategy Audience of the Future initiative are setting important precedents in an effort to maintain the UK's reputation as a world-class content production hub. London's role is central in these efforts, and the Mayor of London should tap into the massive creative potential of such programmes, fostering connections between those working and living in the city and immersive productions, facilities and exhibition spaces. London also has the scale and intellectual capital to educate future creative leaders in immersive entertainment, and therefore should partner with leading UK universities and companies in shaping the future of immersive entertainment on a regional, national and global level. This would guarantee that the immersive entertainment industry sees London as the model for the future.

London is home to many leading entertainment venues and locations, and companies such as the Royal Shakespeare Company are actively researching and developing new ways to engage global audiences with the help of immersive technologies, making London's West End and other music and theatre venues international models for next-generation immersive experiences. London's prominence as a centre of immersive and creative excellence offers opportunities for the Mayor to encourage the creation of new specialist immersive facilities in London that celebrate immersive creativity, talent and entrepreneurship, and will showcase UK content to the world. However, it is important that access to XR tools and platforms is democratised. Creators already establishing themselves in the market are struggling to resource activities that cover the full spectrum of designing and executing the immersive customer journey, from audience research to user evaluation to ticketing and customer loyalty.[178]

A combination of a public forum, a co-working space, an exhibition space, and an entertainment facility supported by the Mayor would help to bring the immersive community together and open it up to more diverse creators from London and across the UK, enabling them to reach an international audience. It would help to grow the ecosystem through business support for small studios, and provide a central place for immersive businesses to showcase their work to consumers, helping them to scale up and making London the go-to place for next-generation immersive production experiences.

XR has potential to transcend the flat user profiles and limited means of communication provided by current social media and online platforms.

Key considerations and barriers for XR technologies in London

London has a great opportunity to become a leading hub for XR content creation. It has the tradition, creative workforce and technology ecosystem to do so. However, the sector requires support to prevent silos between 'old' and 'new' forms of creation slowing down momentum - brokering support between established forms of production and the ones crucial for XR is needed. For example, established art institutions in the UK have access to national audience insight databases, but such tools are not available for XR startups and aspiring creators, even if their audiences overlap. This is a policy issue which, if solved, would put the XR content creation community in London in a better place to diversify and succeed commercially.

Maintaining London as an attractive base for XR hardware manufacturers will be important for sustaining successful partnerships between content creators and those who enable the content with their hardware. Universities in London that continue investing into XR research and development are key to providing the XR industry with new innovations and a highly educated workforce. London authorities can also support upward mobility and diversity, where creators from diverse backgrounds discover XR and consequently, through their creations, make XR an interesting platform for expression and everyday use within their communities.

The barriers to XR adoption in the near future will be similar to consumer technology adoption in the past. In the early 1990s, most people did not find mobile phones useful and distanced themselves from early adopters. Yet within the decade, mobile phones had become ubiquitous, with the smartphone taking off after the iPhone's UK launch in 2007. We can expect that XR adoption, using consumer AR glasses, will follow a similar acceptance process: the perceived value of a technology increases as more content and services become available, and individuals start seeing their peers using it. When XR is seen as a general purpose offering, adoption will increase - and XR use in the workplace will greatly influence this perception.

If and when XR technologies become the next mass computing platform after smartphones, they also present an opportunity to reshape some of our communication habits. Interacting effortlessly via XR, in real-time and with robust three-dimensional representations of others, will facilitate more nuanced social exchanges and efficient communication. XR has potential to transcend the flat user profiles and limited means of communication provided by current social media and online platforms. Even before mainstream adoption, London authorities can lead the way in exploring how to leverage XR for specific use cases in social contexts, such as education, and providing platforms for public discussion.

Finally, it is important for the Mayor of London to note that widespread adoption of XR will also create privacy concerns that are difficult to fully anticipate. The marriage of XR and computer vision in consumer devices, whether AR glasses or VR headsets or their hybrids, will open up possibilities to gather behavioural data in unprecedented ways. Public authorities and legislators need to take part in creating ethical guidelines with the manufacturers. Educating the public about privacy concerns relating to technologies such as XR will be equally important.

Augmenting the physical environment

Recommendations

- Explore the policy implications of augmented reality at scale in the city, looking at new licensing arrangements and considerations for digital and physical ownership (for example, if you own a physical store do you own the AR storefront and where can immersive advertising be placed?).
- Encourage the creation of new specialist venues in London that celebrate immersive creativity, talent and entrepreneurship and showcase UK content to the world. A combination of a public forum, a co-working space, an exhibition space, and an entertainment venue, supported by the Mayor of London would help to bring the immersive community together and open it up for diverse creators from London and across the UK to reach global audiences. This could also be aligned with the work of London & Partners, allowing the capital to position itself as a global leader in next-generation immersive content production through events, festivals, showcases and demonstrations. This could align with the launch of initiatives such as the 'London Resort' theme park in Swanscombe.
- Work with London's universities and leading art and design research institutions to help build a skills base for next-generation immersive content production that will supercharge the London creative sector and create high skilled jobs of the future.
- Seed fund small pilots for collaborative design and explorations of immersive technologies, and work with initiatives such as CreativeXR to showcase London's creative strengths to the world.
- Consider the ethical aspects of AR with authorities, legislators and experts creating ethical and regulatory guidelines with headset manufacturers. This should also include educating the public about privacy concerns about technologies such as XR. Encourage the establishment of an XR ethics testbed in London, exploring how the volume and ubiquity of personal data can be integrated into use cases. Create open standards for applications to be built using the technology in sustainable ways that are user friendly (such as limitations on the number of adverts) and showcase how AR and extended reality can be used for good.

Augmenting the physical self

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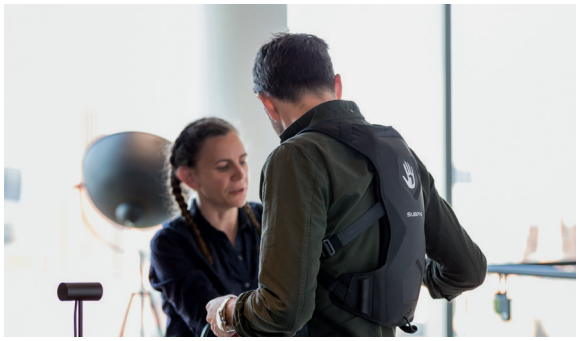
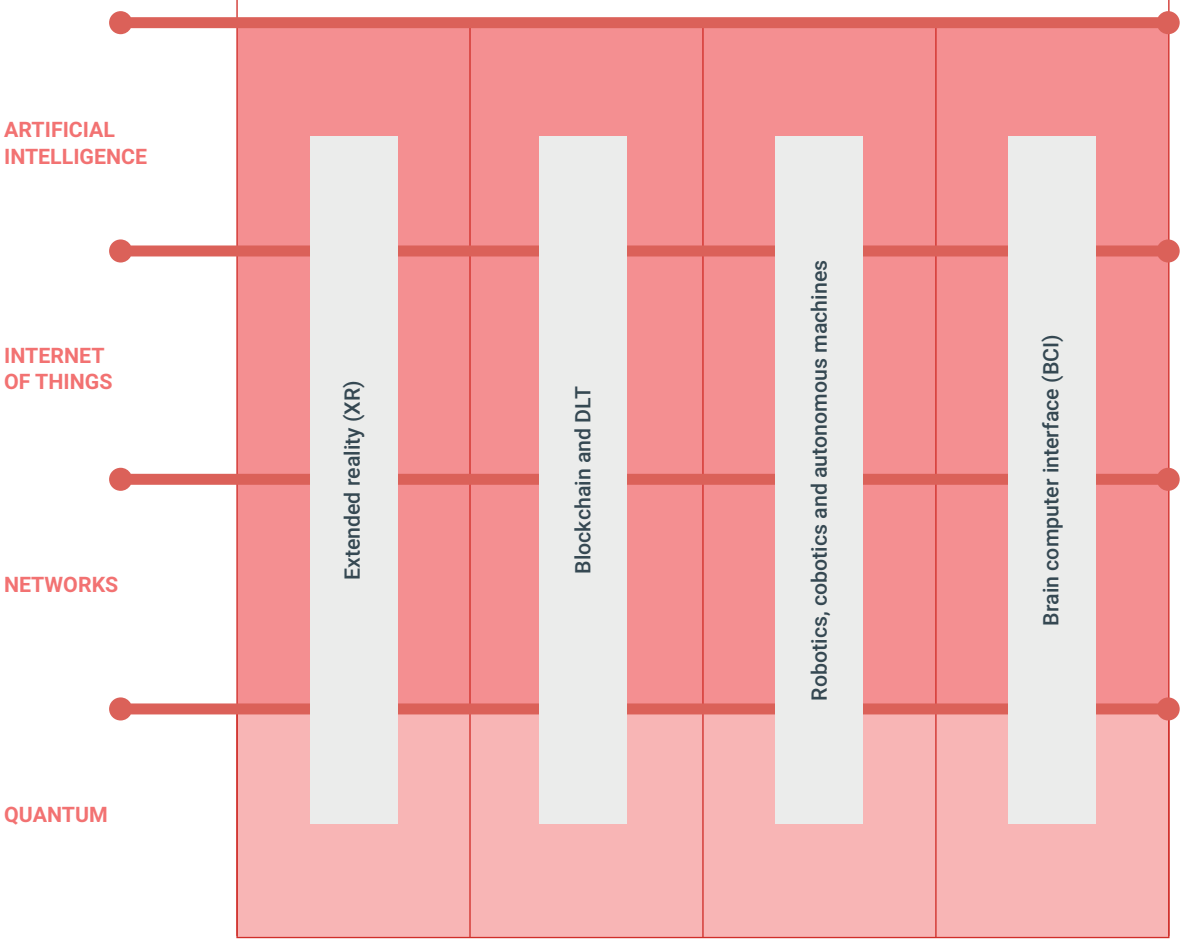
Augmenting the physical self



Augmenting the physical self

With London's strengths in technology, neuroscience, life sciences, artificial intelligence, art and design and the internet of things – over the next 10-15 years we will see a growing number of use cases of enhanced human capability and/or improving the lives of those living with physical and mental health conditions. London has the opportunity to lead the world in ethical, sustainable and transformational use cases for good.



Augmentation of the physical self refers to technologies that enhance human productivity or capability and/or overcome physical barriers, usually by being implanted or worn on the body.

The advanced digital technology stack lays the foundations for businesses to develop intricate products and services that begin to enhance and improve human capabilities, from the convergence of lightweight design and wearable technologies to medical devices and robotics, and ultimately neural interfaces with computers. There are many ways in which technologies will continue to 'augment' people's lives. For example, access to goods, services, and information will contribute to general improvement in quality of life: fifteen years ago, an individual would not have been able to access and listen to all the music they want, wherever they want, yet this is now made easy by internet and mobile technologies.[179]

On a superficial level, systemic effects of technology have therefore already begun to 'augment' experiences through personal handheld devices, which now enhance the standard of living through the ubiquity of information, and knowledge at the touch of a button. This access to information and data through the internet can be extrapolated further to include how people can become physically closer to technology and data - taking further steps towards wearable technologies and feeling, visualising or hearing information in novel ways that interact with themselves and their physical environment.

Enhancing human capabilities

Augmentation of the physical self refers to technologies that enhance human productivity or capability and/or overcome physical barriers, usually by being implanted or worn on the body.[180] Enhancing human biology may sound far-fetched, but in principle, humans have used 'technology' to augment themselves since cave dwellers sharpened rocks and sticks to catch prey from a distance. Technologies that augment physical capabilities are improving exponentially, driven by enhancements in mobile and hardware devices, the internet of things, robotics, computation, cloud-based data storage and connectivity - alongside artificial intelligence.

The convergence of design and technology will create more stylish and lightweight wearable technologies, an area where London can contribute its significant strengths as a global design leader.

Design and technology convergence

In 2017, Scott Galloway, Professor at NYU and Stern Business School famously commented that VR would never take off, due to the headset making people look "stupid."[181] While this does not take into account growing trends of use cases for VR, it does succinctly highlight underlying design barriers to the deployment and use of extended reality and other advanced digital technologies. Current devices and head-mounted displays can sometimes be clunky, expensive, and quickly outdated - the usability and design aspect of the technology often limits accessibility for its use. When this is coupled with the lack of a standardised intuitive user interface, users often have to take a frustrating amount of time to get to grips with navigating a virtual space or trying on a new wearable device, making the experience disjointed rather than seamless.

Over the next 15 years, the way in which these hardware technologies are designed, from aesthetic to interface, will be an important factor in their widespread adoption and everyday use. There is a clear opportunity for the convergence of design and technology to create more stylish and lightweight wearable technologies, an area where London can contribute its significant strengths as a global design leader,[182] especially when enabled by the capital's strong investment and innovation ecosystem.

By following the general trend in advancement of technologies that are immensely powerful yet more discreet, there is huge potential for wearable technologies to become more rapidly adopted by consumers, especially as 5G and future networks can enable devices to become even lighter when computation power no longer needs to be stored on the device, instead connecting to the cloud. This convergence of design and hardware will make wearable and embedded technologies comfortable, stylish additions to an individual's clothing and accessories.

Through these new hardware interfaces, advanced digital technology augmentation of the physical self falls broadly into three main categories:

- Sensory augmentation (hearing, vision)
- Wearables, appendage and biological function augmentation (exoskeletons, prosthetics)
- Neural augmentation (brain computer interfaces)

In these three domains, there is considerable overlap - for example, wearables will eventually incorporate many sensory and neural augmentations to reach their full potential.

Sensory augmentation

Sensory augmentation - that is, improving or enhancing the hearing or vision of a human being - is a growing field of interest being enabled by the convergence of advanced digital technologies. As wearable devices become more mainstream, hardware and software solutions that enhance human sight (such as the ability to zoom in and enhance images that the eye cannot see on its own) or hearing (such as sensory enhancements of immersive sound experiences) are likely to evolve.

Augmenting the physical self

London based immersive sound company Darkfield's FLIGHT experience takes place in a 40ft high-cube container and lasts for 30 minutes - using a multi-sensory approach

Examples of such technology improving eyesight in the visually impaired are already emerging. London-based company Give Vision has developed a clinically validated low vision aid using immersive technologies (an AR headset that uses computer vision) to help UK patients with low vision to improve their sight, read, work and live independently. As hardware and connectivity improves through the advanced digital technology stack, opportunities to enhance the wearability of immersive devices will enable them to become more lightweight and transformative at scale for health applications that can improve the lives of millions.[183] In the future, such AR devices could be reduced to the size of a contact lens, with a number of companies including Verily (a subsidiary of Alphabet)[184] and Samsung (which has filed a patent for a smart contact lens in the US) already exploring the potential. [185]

Often augmentation fails to focus on other senses that contribute to the human experience, such as hearing. A number of immersive audio experiences are now being developed alongside visual immersive technologies, bringing new products and services to the consumer that enhance interactions with sound, music and voice.

Given that the power of sound can alert users to something behind or above them, it is important that they can recognise audio cues and changes when moving around immersive experiences. There are a number of London-based immersive sound companies creating audio tools and solutions. Abbey Road's Spatial Sound studio is the first facility in the UK to offer scoring and film sound post-production, with an increasing focus on immersive sound.[186] There is potential for building greater capacity to ensure that the UK and London can lead the world in the sphere of immersive sound experiences, merging evident strengths in music, creative content and immersive technologies.

As more applications, products and services are built, augmented sound-led content and experiences will begin to open up new streams of possibilities for entertainment and media, generating new revenue models, experiences, products and services for London's creative ecosystem.

In partnership with the British Phonographic Industry (BPI) and its Innovation Hub, Digital Catapult led a 2019 programme called SurroundScapes: The power of immersive sound. This highlighted a number of sound-based immersive companies, most of which are based in London, including Darkfield,[187] 1618: Digital,[188] Magic Beans[189] and PlayLines.[190] Virtual assistants (such as Alexa, Siri, Google Assistant and Cortana) are likely to become more complex and take on additional tasks and functionality. As wearables proliferate, there is likely to be greater interaction with voice-based AI technologies. KPMG predicts that voice assistants will evolve to enterprise-level use, suggesting that they will start to be used for real-time note taking in meetings by 2022, through to having fully-fledged assistants for all members of staff by 2027, prioritising and responding to emails, scheduling travel and managing calendars. Moving into the 2030s and beyond, virtual assistants will be able to provide in-depth insights and analysis to support decision making across the organisation, aggregating data from multiple sources (news, contracts, events and other files) to deliver real-time proactive, predictive and informed planning. Everyday use of virtual assistants is likely to increase, partly thanks to the growth in wearables, for shopping, leisure, entertainment and work. Underpinned by advanced digital infrastructure, information and informed analysis will be available as part of a conversation with technology, rather than through a click of a button or a typed search.[191]

Haptic interfaces will develop that allow users to feel the immersive environment around them, interacting with data as if it is physically there.

Wearables, appendage and biological function augmentation

Over the past two decades, hardware has generally begun to get smaller, consistently developing to become more user-centric in design, weight and user interface. As further evolutions and iterations of wearable devices become market-ready, wearables and appendage enhancements could be using devices as discreet as sunglasses.[192] Exciting developments in wearable technologies are starting to reach the market, incorporating AI data processing in real-time to provide more personalised insights.

Examples include London-based WILD.AI, which tracks female athletes through wearable devices and provides AI-powered recommendations that adapt daily to changes in their physiology and personal progress. Another example would be DNANudge (also London-based), a personalised genomics company and a spinout of Imperial College London, which has built a wearable band that offers tailored health advice according to the user's DNA. It can scan food items when someone is shopping and tell them if it is a good match for their profile. As these wearable technologies become more widely adopted, more functionality and insights will be taken from greater amounts of data processed through mobile edge facilities, making them more personalised, lightweight and stylish as a result.

Another growing area of products and services in this space will be appendage enhancements, and robotics/prosthetics. In partnership with the University of Gottingen, Scientists at Imperial College London have been using ML to improve the performance of prosthetic hands. Having built a prototype, they tested it on amputees and found that machine learning-based control of the hand led to significant improvements in fluidity and natural movement over technology solutions currently available.[193] Although based in Cambridge rather than London, companies like BIOS Health (formerly Cambridge Bio-Augmentation Systems) are bringing these technologies to market already, describing themselves as a full-stack neural interface company, and creating the open standard hardware and software interface between the human nervous system and AI.

Haptic interfaces will also develop that allow users to feel the immersive environment around them, interacting with data as if it is physically there. While visual immersion through VR and AR technologies has been the main focus of immersive technologies for good reason, stepping beyond technologies that track hand motion and moving towards wearable tactile stimulations that allow users to feel the digital elements will be a game-changing shift that completes the full circle of immersivity. This is a combination of sensory and wearable augmentation, providing force feedback for the virtual objects. Haptics have already been a mainstay of digital devices for a number of years, with smartphones and touchscreens using vibration to indicate a press or click, even though a button does not physically exist in that location on the device. Video game controllers also provide vibrations to enhance the gaming experience.

Augmenting the physical self

Moving forward over the next 15 years we will begin to see more and more haptic feedback wearables coming into the market. Some already exist with exciting UK companies like Ultraleap[194] (formerly Ultrahaptics) using ultrasound for haptic feedback, or London-based Valkyrie Industries, which has developed a VR haptic feedback glove that gives sensations of weight and texture to human computer interfaces. These technologies are enhanced by precise body tracking, biometrics and machine learning algorithms that adapt to create feedback sensations for end users. As the physical internet through AR cloud becomes more mainstream, different interactions with the virtual environment will become commonplace, with these technologies evolving to be more intuitive, personalised and designed, used at scale and connected through 5G networks and machine learning.[195]

Opportunities for growth and showcasing these new and emerging haptic, wearable and biological function augmentations are paramount to help drive their increased adoption and user familiarisation with the technology. Supporting London's university research into these technologies by helping them to further connect with fashion design and entrepreneurs will help to spark a range of products that can position London as the global capital for tech-focused fashion using advanced digital technologies. Such collaboration can help wearable technology companies move towards producing more comfortable devices that are lightweight, stylish and have the same functionality.

Neural augmentation

Brain computer interfaces (BCI) will link the cognitive power of the human brain to the processing power of machine learning and supercomputing, and enable treatments for life-changing conditions such as paralysis, Parkinson's tremors, and hearing loss. These neural interface devices will interact with the nervous system of an individual, and can be positioned on either the outside or inside of the brain, nerves and other components of the nervous system to record or stimulate activity. BCI technologies aim to leverage the computational power used for artificial intelligence for the cognitive power of the human brain. In the same way, artificial intelligence will benefit from further interactions and collaboration with neuroscientists - exploring data taken directly from human neural circuits and leveraging the findings for improvements.[196]

Current and evolving applications of BCI include:[197]

- Brainstem implants to treat Parkinson's disease and tremors
- Enhancements to the memory and treatment of mental health disorders via transcranial stimulation
- Cochlear implants

Potential future uses include directly controlling devices and computers solely by using the brain, as well as direct brain-to-brain communication, whether simple impulses or complex thoughts.[198] Such futuristic scenarios might not be so far away, with researchers at Imperial College London and UCL collaborating with US universities to empower the next generation of implantable neural interfaces, producing devices that will communicate with, and be functionally similar to, human neural circuits.[199]

Researchers are beginning to explore how brain computer Interfaces can send signals between the brain and external devices such as a robotic arm.

Increasingly, researchers are beginning to explore how BCI technologies can send signals between the brain and external devices such as a robotic arm, and new systems are being developed that allow smoother tracking and responses. At the University of Grenoble in 2019, a disabled man used an exoskeleton powered by brain implants to walk for the first time, moving from single limb movements to full body control, with a 71% success rate using just the mind and robotics. Although these technologies are still very much in the lab, the potential is profound for the future and provides a framework and proof that BCI can potentially help those who are physically disabled to have a better quality of life.[200] London is also taking a lead in this space, with UCL and Imperial conducting research with BCI. UCL, in particular, has been focused on perceptual, motor and rehabilitative activities in unrestricted environments, with the aim of improving safety in human-robot interactions, improving training of complex skills (such as surgery), enhancing neuro-rehabilitation, and developing novel assistive technologies for the ageing population.[201]

Developing use cases of augmentation

Industrial use cases of human augmentation

Industrial use cases of human augmentation typically centre around health and safety. Wearables in particular is a growing sector, with increasing capabilities and accuracy of data enabled through next-generation mobile connectivity and the internet of things.

With health and wellbeing of employees being the number one priority in the UK manufacturing and construction industries,[202] the cost of injury and work-related ill health in the construction industry is £1 billion annually. There is an increasing number of wearable products and services helping to reduce the number of fatalities and injuries in the industrial workplace,[203] with 5G providing ultra-low latency features that will allow robotics and wearables to interact in real-time with millisecond accuracy, to shut down machinery and/or provide time-critical alerts for decision makers to prevent emergencies in hazardous environments.

dorsaVi - a scaleup with offices in London - has built a wearable movement sensor technology called ViSafe that tracks, analyses and reports on how employees move through their daily work lives in order to reduce, understand and prevent workplace injuries. This has already been used at Heathrow Airport, halving manual handling injuries.[204] More examples of these technologies linked to 5G and artificial intelligence will emerge over the next few years, providing even more examples and insights for businesses to prevent accidents, save lives and reduce overhead costs. BCI technologies could be combined with wearables, for example, BCI-enabled helmets could take visual cues from the wearer to remove defective goods from manufacturing production lines, taking action automatically by using neural signals.[205]

Using richer insights from IoT, advanced machine learning and an ultra-reliable low latency network, such as 5G, accuracy could be significantly improved without increasing risk.

As the Manufacturing Technologies Centre (part of the High Value Manufacturing Catapult) identified, if a wearable is being used in the field, the risks will currently be over-reported, to mitigate against missing any potential accidents. This creates a high number of false alarms. In one particular case, a wearable was used to identify drowsy machine operators, and 95% of all alarms raised were false. Through better convergence of the advanced digital technology stack, this challenge can be reduced. Using richer insights from IoT, advanced machine learning and an ultra-reliable low latency network, such as 5G, accuracy could be significantly improved without increasing risk.[206]

The Mayor of London has an opportunity to encourage adoption by considering how these technologies can help to improve the health and safety of Londoners across the construction industry and at scale through 5G. By including explorations of these opportunities in the Mayor's Civic Innovation Challenge - alongside opportunities to connect to advanced digital infrastructure testbeds and R&D facilities - the capital can drive more use cases and examples of ways that augmentation technologies can be used to benefit industry.

Sensory devices for augmented personal immersive experiences

Within the next few years, a large number of immersive haptic devices will flood the market, as sensory augmentation of experiences takes place at theatres, music venues and other entertainment and tourist locations across London. The proposed Madison Square Garden 'MSG Sphere' entertainment venue being built in Stratford has proposed "state of the art music and entertainment that will pioneer the next generation of immersive experiences", to include a haptic system that will convey bass so that the audience can 'feel' the experience. Startups are also getting into this space, with London's CuteCircuit pioneering fashion wearables that include smart fabrics that include haptic feedback.

CASE STUDY

CuteCircuit

CuteCircuit is a London-based pioneer in the field of fashion wearable technology. It merges futuristic fashion design with advanced technologies and smart fabrics, creating clothing with haptic feedback capabilities.

The company was founded by Francesca Rosella and Ryan Genz, whose backgrounds are in luxury fashion brands, and art and anthropology respectively.

CuteCircuit has created an interesting range of technologically complemented fashion for a range of clients. It is currently using £42,000 from the Industrial Strategy Challenge Fund's Audience of the Future to create a new immersive experience that combines sound and touch. Its 'Sound Shirt' is a haptic wearable device, which enables deaf audience members to experience a symphony orchestra by literally 'feeling' the music. It has also designed a futuristic, sensor-enhanced uniform for the cabin crew of easyJet, which was featured in the first runway show on board an aircraft. Other famous clients include Katy Perry and Nicole Scherzinger: the company designed an interactive mini skirt for Perry to wear in concert, as well as memorable red carpet garments for both the singers.

All CuteCircuit items are designed to last as clothes and cultural objects, with many of the pieces on permanent display in internationally-recognised museums, such as the Barbican in London and the Museum of Fine Arts in Boston.[208]

Robotics and neural interfaces will have significant potential for medical and social care.

Sound-based experiences will also become more commonplace. Startup Darkfield has created communal location-based immersive experiences inside shipping containers. These experiences place the audience in complete darkness and then deliver binaural 3D audio and other sensory elements, using the darkness to create a canvas for the imagination. The company has a unique offer grown from over 20 years working in the immersive theatre industry, and over six years creating shows and experiences in complete darkness that use binaural audio, multi-sensory effects and content to place the audience in the centre of evolving narratives. The experiences' greatest asset is the invitation to walk the line between what seems to be happening and what imagination can conjure up.[209]

In the future, experiences are likely to be increasingly personalised, by combining audio immersivity with AI and 5G to create new real-world audio experiences that interact with sensors and wearable devices. This could take place in a retail or entertainment environment. Playlines has recently premiered in the Roundhouse in Camden and in New York, and their experience CONSEQUENCES is an immersive interactive audio-AR grime rap opera, created in collaboration with multi award-winning MC, Harry Shotta. Users can use AR to explore a grime club, follow the rhymes and choose the ending. The experience gives audiences a brand new kind of night out that feels like a combination of secret cinema, silent disco and Punchdrunk's 'Sleep No More'.[210]

Enhanced virtual assistants and neural interfaces for health and social care

Robotics and neural interfaces will have significant potential for medical and social care. The general upward trend in virtual assistants for automated email sending and internet searches will progress significantly, emerging as a highly personalised operating system for individuals, and connected to wearable devices such as AR glasses. Robots and AI-powered virtual assistants might be used as personal medical assistants, for example, helping elderly or vulnerable people to follow their treatment regimen, or detecting diseases or conditions early on.[211] Stanford University has already demonstrated a machine learning system that uses sophisticated facial recognition with sentiment analysis, to successfully identify depression entirely based on facial expressions and vocal tones. This might be also used in a host of other medical use cases.

Use of these AI-enabled assistants is also expected to surface additional social purposes: such as robots programmed to converse and socialise with elderly or isolated individuals. This may be a viable solution for meeting the social care and medical needs of vulnerable, lonely or marginalised subsets of the population - particularly in the light of isolation measures prevalent during the lockdown for coronavirus. As neural interfaces are more widely adopted and people are generating millions of gigabytes of data per day in the not-so-distant future, wearable technologies will provide doctors with in-depth insights in real-time on a person's day-to-day health, enabling them to sift through this data using natural language processing technology or virtual assistants to spot anomalies and indicators of illnesses and hard-to-spot conditions. This information, when analysed using machine learning, has huge potential for the creation of personalised medication. It is well-documented that drugs can work very

differently on different people, with side effects sometimes being severe or treatment simply not as effective. Live streaming of biometrics and copious amounts of retrospective data will enable optimisation of drugs and their uses.[212] Patients may even be able to have their own personalised drugs printed at home. London could have a strong foothold in this market, given its strengths in life sciences, artificial intelligence and the expectation of large scale 3D printing facilities to be built in east London in Silvertown over the next 20-30 years.

Next-generation assistants for the services industry

Virtual assistants, combined with advancements in AI and deep learning, mobile edge computing and lightweight wearable devices, may become more common in the workplace of the future. In 2019, Amazon launched Alexa-enabled Echo Frames: lightweight glasses (31gs) that have a virtual assistant built into them, enabling people to seamlessly connect to voice-enabled AI services. These glasses can also use real prescription lenses.[213]

As technology evolves further, assistants will become more complex and able to action a wider range of tasks. Amazon's Echo Frames and Echo Buds (its earbud version) are just the start to wearables with virtual assistants becoming more mainstream. Enterprise use cases of virtual assistants will also evolve, from chatbots to more common uses of personalised task sharing and planning. In the legal services space, virtual assistants may be used as paralegals, extracting meaning from documents using natural language processing and playing back their analysis for legal professionals. Use cases in sales might include using virtual assistants to arrange and make calls, recording and noting key information into CRM systems and helping to curate top targets for sales pipelines through data analysis. Feeding back IoT sensor data in real-time to virtual assistants working with insurance underwriters could help calculate more accurate and personalised premiums, using AI, 5G and wearables to transform the sector and improve accuracy of quotes.[214]

Barriers and considerations for human augmentation

Trust lies at the heart of human augmentation. Neuro-ethicists are keen to see ethics integrated into brain computer interfaces from inception and throughout the development of the technology. This will help to ensure that people, businesses and public sector organisations are in a position to maximise benefit while preemptively identifying and mitigating against potential harms to individuals, or to the public as a whole.

As with any nascent technology, there are associated risks. BCIs have raised questions about autonomy due to the brain-modulating nature of the technology. There have been a few reported cases where deep brain stimulation to target conditions such as OCD has resulted in striking behavioural changes, such as compulsive gambling. This poses interesting questions around how consent to continue treatment in such cases might be defined, and what parameters and thresholds are to be implemented.

The rich ethical ecosystem, which exists in London should be leveraged to ensure that wearable technologies are being consistently developed within fair and safe parameters.

Neuro-ethicists have also raised questions about self-governance. Inserting decision-making devices and closed looped systems, often powered by AI software, to make independent, and constantly evolving decisions might lead to unforeseen consequences. While medical use of BCI technologies may seem unproblematic for cases such as managing diabetes automatically, well-intentioned brain interventions may not always be welcome due to the psychological effects that automated responses may create. For example, given the extent to which BCI will interact with the brain, the user's ways of living, or even their identity, will rely on using the technology. In a particular case when a patient had to remove their BCI due to the company going bankrupt, the patient felt that they had lost their sense of self.[215] The European Commission is aware of these risks and will be implementing regulations (due 2020) regarding the use of brain computer interfaces. It is essential to get this right first time to minimise harms, and ensure that wariness about the technology does not limit BCI adoption and stunt its social and economic potential.

While the ethical issues relating to brain computer interfaces are intricate, we can learn a lot from the proliferation of AI and its ethics principles in the past few years, as well as their similarity to biomedical ethics.[216] While there will be domain-specific nuances, there is an emerging set of shared ethical concepts - from AI to medicine - that will continue to push BCIs along the correct ethical trajectory. Despite being highly complex, the ethics of autonomy and self-governance have been central ideological pillars for democracy and moral philosophy for centuries.[217] The public and private sectors in the UK should leverage the range of ethical tools already being used across London and the UK to accelerate the advancement of highly practical applied ethics for BCI, with emphasis on unintended consequences and how to mitigate them. The Mayor of London should therefore be encouraging the integration of BCI considerations into applied advanced digital technology ethics conversations and activities, to ensure 'cross-pollination' from key institutions and industries (such as Ada Lovelace, the Centre for Data Ethics and Innovation, Digital Catapult, Turing and so on), and make sure that the right questions are being asked as early as possible.

Ethics of wearable technologies

Ethical commentators have highlighted a few main challenges with wearable technologies, including system vulnerabilities that may compromise user safety, misused data and transparency of use, and software producers prioritising multi-functionality over data safety.[218] It is important to implement practical codes of conduct to mitigate such issues, for example, the Department for Digital, Culture, Media & Sport's 'Secure by Design'[219] report provides key guidance on the risks and development for this technology.

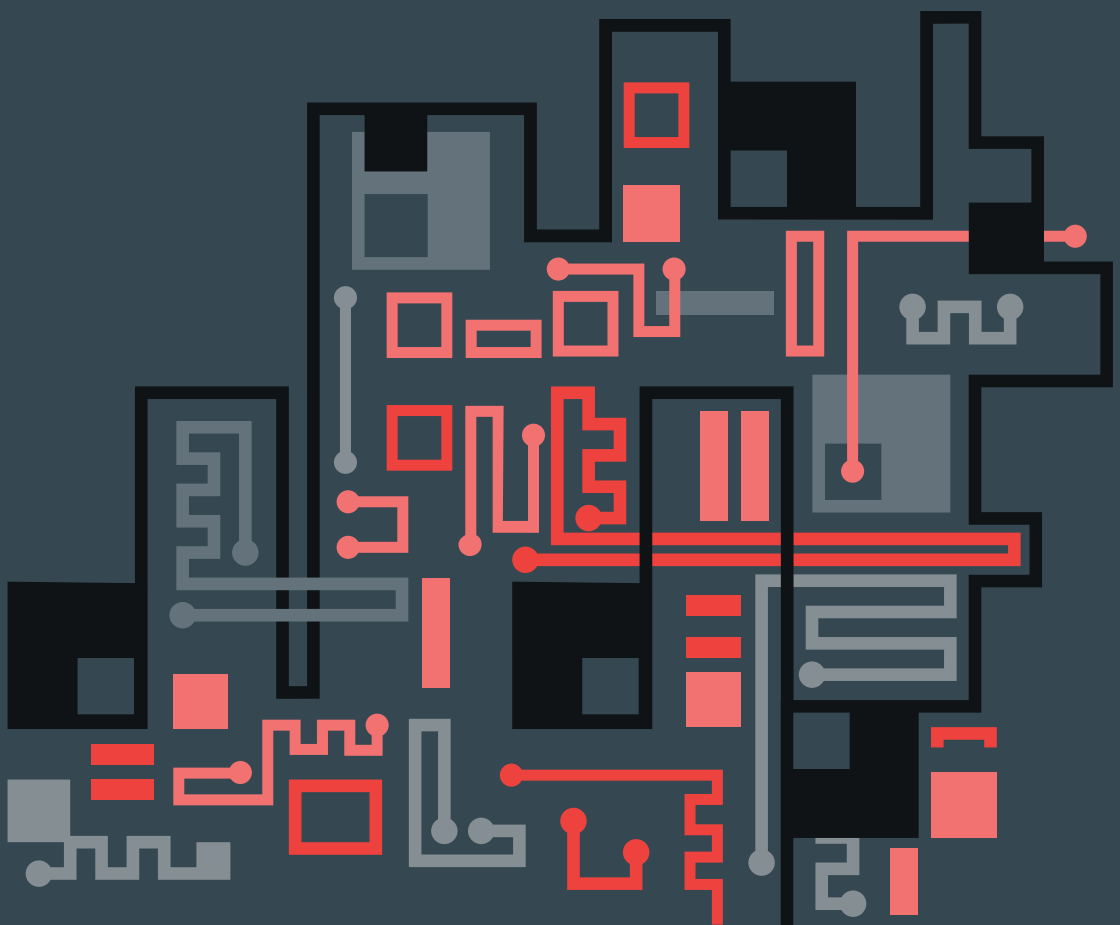
The rich ethical ecosystem, which exists in London, should be leveraged to ensure that wearable technologies are being consistently developed within fair and safe parameters, particularly as they interact across the advanced digital infrastructure stack as data is collected and used at significant scale. Extra care should be taken when wearable technologies are deployed in work environments, as personal data may be especially sensitive, creating the potential for the workforce to feel alienated. It is imperative to continue work in de-identification and anonymisation of data, and as well as having safeguards in place, it would be sensible for companies to introduce opt-out policies where appropriate.

Augmenting the physical self

Recommendations

- Incentivise collaborations in R&D to help bring London's design and technology strengths together, in order to produce more usable and well-designed products and hardware for the future.
- Work with organisations such as the Design Council to support the research in these technologies taking place in the labs of London universities, connecting with fashion/textile designers, universities and entrepreneurs to help spark a range of products that can position London as a global capital for tech-focused fashion.
- Encourage the showcasing of new and emerging haptic, wearable and biological function products and services to help build trust, and increase adoption and familiarisation with the technology. These connections can help wearable technology companies to move towards more comfortable devices that are lightweight, stylish and highly functional.
- Help to shift the narrative around immersive technologies from being purely visual to include audio and touch - highlighting the strengths in London for these areas and building the capital to be the immersive content capital of the world.
- Consider the best use cases for BCI and neural interfaces along with the ethical and sustainable challenges that may be associated with them. Encourage industry-led standards and consider BCI as part of the broader regulatory, ethical and policy considerations of the advanced digital technologies stack of the future.
- Encourage adoption of next-generation wearable technologies connected to edge AI facilities using 5G, to help improve the health and safety of Londoners across the construction industry, in industrial environments and at scale. Include explorations of these opportunities in the Mayor of London's Civic Innovation Challenge, alongside opportunities to connect to advanced digital infrastructure testbeds and R&D facilities.
- Build trust in personal augmentation through robust and proactive planning that balances innovation with regulation. There are numerous opportunities for human augmentation through technology - including social, economic and health/physical benefits not yet considered - while overcoming barriers to physical capabilities and limitations. The Mayor should work with leading universities, innovation centres and organisations to consider these next-generation technologies and what they mean for the individual and society as a whole. By placing trust at the heart of initiatives as they evolve, London and the UK can generate positive news stories about the technology, allowing businesses to undertake responsible development, deployment and use of highly personalised robotics. This includes sensible considerations around wearable devices generating even more mass market penetration and gathering personal data.

Conclusion and broad recommendations



Conclusion and broad recommendations

The Mayor of London has an opportunity to continue to promote market-shaping and co-creation opportunities, ensuring the further expansion of London's technological frontiers. The Mayor should take an active role in promoting London as not just a leader in AI, but a leader across these new and emerging technologies as they converge to form the foundations of the physical internet.

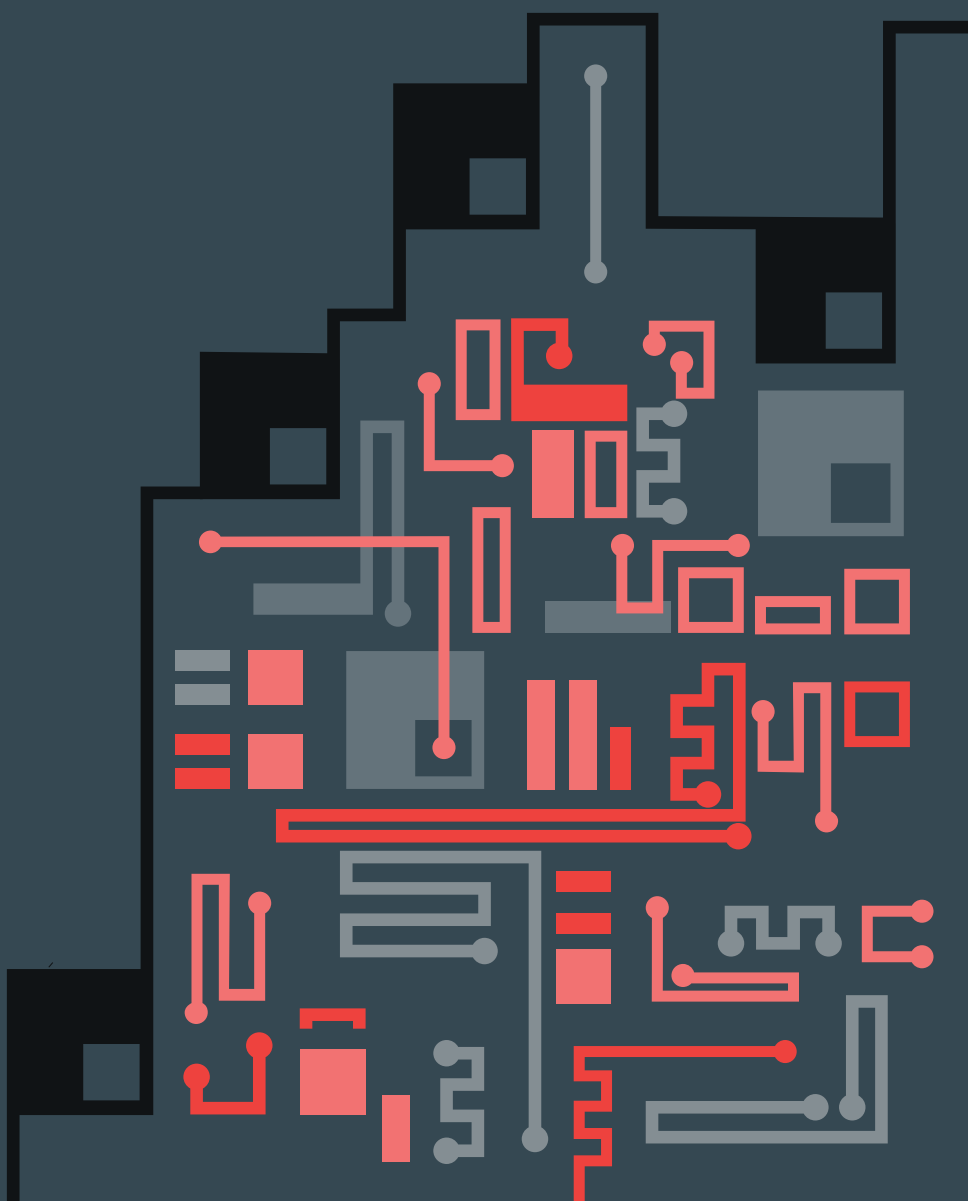
On this basis, these broad recommendations for the Mayor ensure sensible planning and policy to drive the economic and social benefits for London and the UK that can be derived from advanced digital technologies.

- To encourage London-based businesses to engage with Digital Catapult as the Catapult Network lead for 5G, to be part of the 5G Testbeds and Trials Programme, to connect to the UK5G network, and to conduct strategic activities, including workshops and roundtables, to encourage London's startup and scaleup innovator ecosystem to explore what 5G may offer in the development of future products and services. Other collaborations can be sought to help align the ambitions of the Mayor of London and those of businesses in the capital with these innovation and acceleration activities. Such activities should include future iterations or releases of 5G and evolutions of mobile connectivity.
- To work with different parts of the innovation ecosystem in London and across the UK to broker data sharing agreements with corporates and local government bodies, creating significant opportunities for London-based startups and scaleups working with advanced digital technologies to engage with challenge owners across the country.
- To encourage the building of practical advanced digital technology ethics facilities and toolkits in London, to help to ensure that developers are well versed in the ethical considerations required for sustainable solutions that can be used at scale by the public and private sectors.
  - All technologies will have ethical implications - not just AI. The Mayor of London should gather a range of views on the ethical implications of other technologies, such as XR, IoT and 5G, as well as those relating to the broader impact of the convergence of these technologies, paying particular attention to short and medium term applications.
  - The Mayor should encourage collaborations between London's industry, academia, technology giants, startups and scaleups to better prepare policy makers, industry and innovators for the impact that advanced digital technologies will have through widespread deployment over the next 15 years.
- Expand and build on the Mayor of London's Civic Innovation Challenge, looking at ways to promote and support broader applications of advanced digital technology for social good, providing startups and scaleups with access to advocacy groups and social purpose challenge owners, while exploring the development of solutions that utilise ethical frameworks and approaches.
- To consider adoption of AI solutions as part of the broader advanced digital technologies stack and part of advanced digital infrastructure. Providing access to AI-enabling infrastructure and services through edge facilities will enable startups and scaleups to integrate intelligent and predictive artificial intelligence capabilities into their solutions more easily. This is crucial to facilitate the scalability and impact of their services.

Conclusion and broad recommendations

- Working with the UK Government, and with the Office for AI and the DCMS 5G Testbeds and Trials Programme in particular, to encourage collaboration between the digital innovation ecosystem in London (including startups and scaleups), universities and research institutions), telecoms providers, network operators, industry players and system integrators, promoting an interdisciplinary approach to exploring the advanced digital technology stack.
- To consider further investment into specialised acceleration programmes that explore ways in which LOTI, can work with the Catapult Network, other RTOs and local authorities to build connections between the London startup ecosystem and sectors of the UK economy that are outside the capital or that affect the supply chain (such as logistics).
- To continue to extend and raise awareness of the London Datastore initiative by running specific industry challenges around key themes.
- To establish an open standards marketplace to encourage further innovation, building on the standards set out through the Horizon 2020 project, Synchronicity and the Urban Data Exchange.
- To seek ways to map and model the environmental impact that London makes through its current and future consumption of data, to inform future interventions to tackle the challenge of sharing responsibility for environmental sustainability with multinational data centres and technology infrastructure providers.
- To continue and expand programmes such as TechInvest, to encourage and educate more London-based investors and VCs about the convergence of advanced digital technologies, and how this will transform the economy.
- To strengthen understanding of advanced digital technologies throughout the Greater London Authority, and London boroughs to better prepare for the impact and evolution of technology over the next 15 years.

Glossary



Glossary

5G: is the fifth generation of wireless mobile network technology that began wide deployment in 2019.

Additive manufacturing: is the industrial production name for 3D printing, when three dimensional objectives are created through the depositing of materials, often in layers, controlled by a computer.

Advanced digital technologies: the innovative deep technologies that are beginning to converge to form a new technology stack. These technologies can be defined by their ability to enable new human machine interactions that blur the lines between the physical and digital world.

Artificial intelligence (AI): is an umbrella term that sits under the banner of data science. It describes a set of approaches, technologies, machines or systems (often made up of computers running algorithms, and drawing upon data), to perform tasks that would typically require human or other biological cognition to achieve the intended results.

Augmented reality (AR): enables users to experience digital elements layered over a live view of the physical world, often through the camera on a smartphone (for example, Pokemon Go) but also through wearable devices (such as AR glasses).

Blockchain: is a type of distributed ledger technology (DLT).

Brain computer interfaces (BCI): technologies that facilitate collaboration between the brain and a device, enabling an external activity to be performed, such as the control of a prosthetic limb or a cursor.

Civic Innovation Challenge: The Mayor of London's Civic Innovation Challenge offers an opportunity for start-ups to work together with leading corporates and public organisations to tackle some of London's most pressing problems. Its first iteration focused on challenge-led innovation for start-ups to develop innovative solutions to democratising planning, tackle congestion and counter violent extremism online.

Cobotics: a subset of robotics, referring to robots designed to be used in close collaboration with humans.

Compute power: (or computational) power is the speed that instructions are carried out by a computer.

Computer and machine vision: computer vision spans a range of interdisciplinary scientific fields focused specifically on how computers can gain high-level understanding from digital images or videos. Its goal is to understand and autonomously undertake actions that would typically be performed by the human visual system. It may also link with machine vision, the capability to undertake visual automatic inspection and analysis for robotic guidance and process / quality control, this would typically be from cameras.

Data science: is the study of data. It involves mathematics, statistics, mathematical modelling and computer science methods and tools that underpin many of the approaches to artificial intelligence. The goal of a data scientist is to extract insights and knowledge from different types of data.

Deep learning: part of a broader family of machine learning methods. It uses algorithms and computer systems inspired by the structure and function of the brain, called artificial neural networks.

Glossary

Distributed ledger technologies (DLT): Distributed ledgers use independent computers (referred to as nodes) to record, share and synchronise transactions in their respective ledgers, instead of keeping data centralised as a traditional ledger would. Blockchain is a type of distributed ledger technology (DLT).

Extended reality (XR): an umbrella term referring to all real-and-virtual combined environments and human-machine interactions (e.g. VR, AR, MR and haptics) generated by computer technology and wearables.

Haptics: or haptic technology, also known as kinaesthetic communication or 3D touch, is the use of electronically or mechanically generated movement (such as a vibration) that a user experiences through the sense of touch as part of an interface.

Internet of things (IoT): is made up of connected devices, such as sensors and wearables, which generate data.

London & Partners (L&P): the international trade, investment and promotion agency for London, promoting the capital internationally as a leading world city in which to visit, study, invest, grow and meet. It is a not-for-profit public-private partnership.

Machine learning: is a subset of artificial intelligence that allows systems to learn from data autonomously and improve actions through experience.

Mixed reality (MR): allows the user to experience a combination of real and virtual worlds at the same time through a transparent head-mounted display. It enables physical interactions with digital environments and visualisations in real-time.

Quantum computing: the use of quantum-mechanical phenomena such as superposition and quantum entanglement to perform computation. A quantum computer will perform these computations.

Robotics: the interdisciplinary sector of science and engineering dedicated to designing, constructing and using mechanical robots.

Technology stack: the combination of programming languages, tools and frameworks that developers use to create technology-based products, applications and services.

Virtual reality (VR): is where a user is immersed in a 3D environment through a head-mounted display. It means the user is completely closed off from the physical world, with visual and audio feedback that simulates real or imagined experiences.

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