The Impact of Emerging Technologies on European Listed Real Estate

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Executive Summary

Today we are witnessing the emergence of new technologies that can radically transform the way we live, do business, and perceive ourselves. These technologies possess an enormous disruptive power due to the speed of their development, and a variety of potential business applications.

A wide array of interrelated forces are increasingly impacting Real Estate: mobility, the sharing economy and the changing societal meaning of 'ownership', increasing spend on experiences over things, shifts in the nature of work and the workplace among others. We are focusing in this paper on five specific technologies that support these broader forces and bring further change in the industry: Artificial Intelligence, Blockchain, the Internet of Things, 3D Printing, Virtual, Mixed, and Augmented Realities. Based on a broad scan of the literature and insights obtained during interviews with experts working at the intersection of real estate and technology, this paper aims to investigate the impact that these disruptive technologies might have on European listed real estate in the next 5-7 years.

We continue to track this rapidly-evolving field, and this paper represents a snapshot of today that we believe is useful in forming a coherent view about tomorrow. We hope it lays the groundwork for further exploration of these trends and technologies.

The analysis begins by looking at the impact that the emerging technologies will have on demand for three key types of commercial real estate assets – Office, Retail, and Industrial (other asset classes, including Residential, are excluded from the scope of this paper). It shows that the emerging technologies have some potential to support a continuation of trends triggered by the previous generation of digital technologies. Consequently, we are likely to see further changes in how buildings are occupied and used. For instance:

- → What tenants expect from an office space will change as the jobs we do and the way we work change. It is quite likely that demand for collaborative and co-working workplaces will rise, higher levels of connectivity and personalisation will be demanded, greater flexibility in lease terms will be expected, while occupancy and space usage will be better forecast and optimised.
- → As bricks-and-mortar retailers build a stronger online presence and e-commerce leaders acquire property portfolios, physical and online retail will no longer be competitors, but rather become integral parts of the same business, each having its own advantages that should be balanced and maximised. New technologies will open new opportunities to enhance the online retail experience and speed up the delivery process, while the function performed by physical retail space will continue to shift towards entertainment and product experience, display and exchange.
- → Emerging technologies will drive demand for high-tech industrial assets (data centres, online distribution hubs, the specialised logistics) required to support digital infrastructure and technology businesses. Such facilities will be subject to increasingly sophisticated requirements.

Overall the availability of more flexible and short-term lease arrangements, changing space usage patterns, and better ways to manage and forecast occupancy are likely to enable a more efficient use of space by occupiers, which in turn will have consequences for landlords. First, landlords can expect less rent from under-utilised (i.e. inefficiently occupied) space. Second, landlords might need to undertake and bear the costs of re-fitting space to handle more flexible and dynamic tenant demands. Finally, the cost of maintaining space should rise – given more intensive wear and tear from higher density occupancy. Landlords may have to work harder to maintain per-unit income levels, and 'working harder' should include seizing opportunities to enhance asset value and operations offered by new technologies.

Emerging technologies are likely to expand the list of parameters affecting asset valuations. A building's digital infrastructure (including embedded IoT technology), transparency of its state and performance, the flexibility of its structure and systems, as well as the building's cybersecurity are all likely to be considered alongside more traditional factors such as base location. Furthermore, as new living and

occupancy patterns erode traditional income streams (e.g. turnover rent, long-term rent, income from parking), new ways of generating direct and indirect income from assets will develop.

On the operational side, emerging technologies open possibilities to gain competitive advantage through improving performance of key real estate business functions. The main areas of opportunity relate to enhancing the efficiency of back-end operations (e.g. lease, acquisition and disposal, facilities management and occupancy management), enabling smarter design and construction, and delivering superior customer experience. Furthermore, the availability of IoT-generated data and AI-enhanced analytics may enable better decision-making and more effective risk/return balancing at both the asset and portfolio levels. To start leveraging the power of these emerging technologies, a five-step approach is outlined. This approach includes the following action points:

- → **Beware of the Hype:** develop a good understanding of emerging technologies (their limitations, the stage of their development, potential applications) to avoid deception
- → **Choose Your Power:** select a combination of technologies that work and add specific value to your business
- → **Gather Your Allies:** build partnerships
- → **Know Your Competitors:** watch out for competition from within and, especially, from outside the industry
- → **Use Your Power Wisely:** understand the responsibilities that come when using these technologies (e.g. cybersecurity, data protection regulations, higher level of transparency)

This approach emphasises the importance of building a degree of technological understanding and the ability to spot and realise opportunities offered by the new technologies.

Introduction

We are living at an exciting time when new information technologies, long considered part of science fiction, are becoming a reality and are changing the way we live, work, do business, and perceive ourselves. Building on previous generations of disruptive digital breakthroughs, these technologies seem to have a wide variety of applications and an enormous power to transform whole industries, with their influence going far beyond the pure notion of commercial success.

This paper aims to investigate the influence that the new generation of digital technology may have on listed real estate industry in the coming years[1] including their impact on:

- → The demand side – how different types of real estate assets are occupied and used (focusing on retail, office, and industrial asset types)
- → Parameters defining an asset's value
- → Operations, e.g. how buildings are delivered, acquired, maintained, and managed

The specific impacts of emerging technologies on capital and the real estate pricing, as well as broader factors affecting the overall real estate industry (e.g. political and economic climate, climate change, regulatory changes etc.) were considered out of scope for this research.

Technology fields that we investigated include:

- → Artificial Intelligence (AI)
- → Blockchain
- → The Internet of Things (the IoT)
- → 3D printing
- → Virtual, Augmented, and Mixed Realities (VR, AR, and MR)

These technologies were selected because of a variety of use cases relevant to real estate and because they are forecast to reach a wider adoption in the next decade [1]. Furthermore, they are effectively building blocks for the next technological wave that will include Autonomous Vehicles, 4D Printing, Smart Robots, Smart Workplace, Cognitive Computing and others, and is expected to unfold in the late 2020s [1]. Therefore, understanding the technologies in focus comes first.

While researching this topic, we interviewed experts possessing knowledge of both technology and the real estate industry. Our aspiration was to bring an external perspective to EPRA members from professionals who continuously research or work to implement these emerging technologies.

The list of interviewees included:

- → Dr Claire Penny (CP) – Global Industry Leader - Cognitive IoT for Buildings, IBM Watson Internet of Things
- → Dr Andrea Chegut (AC) – Research Scientist, MIT Center for Real Estate
- → Francisco Jeronimo (FJ) – Research Director, European Consumer Wireless and Mobile Communications, International Data Corporation (IDC) EMEA
- → Josh Artus (JA) – Co-founder and Director of Built Environment Strategy, The Centric Lab
- → Paul Chen (PC) – Lead Managing Consultant, RealFoundations

[1] For our research, we focused on impacts that would likely materialize between today and 2025.

- → Ragnar Lifthrasir (RL) – Founder of velox.RE and the International Blockchain Real Estate Association (IBREA)
- → Richard Belgrave (RB) – Head of Europe, Leverton
- → Steve Weikal (SW) - Head of Industry Relations, MIT Center for Real Estate, on Real Estate Fracking
- → Ted Kempf (TK) – Service Industries Director, Microsoft
- → Volker Buscher (VB) – Global Digital Service Leader, Arup

This paper combines the insights received during these interviews with an extensive literature review and RealFoundations' internal organisational expertise. It has a broad focus and represents an exploration of the potential technological impact. It is targeted at general real estate professionals—not just IT practitioners--and as such is relevant for the whole EPRA Membership, regardless of portfolio composition.

Throughout this paper we often use declarative rather than qualified language. For example, we write "will…", but we really mean "will *likely*…" This represents a simple stylistic decision. We want to report as clearly as possible on our analysis and the future to which it points; but we remind the reader that the notion of "likely" is always implied when we talk about the change that is yet to come.

Towards the 4th Industrial Revolution

1. Towards the 4th Industrial Revolution

1.1 The Digital Revolution

Several times throughout the history of humankind, new technologies have fundamentally transformed our perception of the world and our way of living, causing profound economic and social changes.

The first major shift happened around 10,000 years ago when the domestication of animals triggered the agrarian revolution. Production, transportation, and communication were enhanced by the ability to combine animal and human efforts, leading to population growth, the development of larger human settlements and, ultimately, urbanisation. The second radical shift took place in the latter half of the 18th century when the advent of steam and water power fostered the first industrial revolution which, in the late 19th century, was followed by the second, instigated by the discovery of electricity and the development of production line manufacturing techniques.

The most recent major transformation - the third industrial revolution, also known as the Digital Revolution - started in the 1960s and was brought about by the advancement of information technology. This included the invention of semiconductors and mainframe computing in the 1960s, personal computing in the 1970s and 1980s, and finally the internet in the 1990s [2].

The Digital Revolution radically extended our knowledge base, reduced the costs of information, and led to the development of information goods, creating new trillion-dollar industries.

The economic benefits included:

- → **Efficiency:** opportunities to automate business functions by streamlining business processes and using Information and Communications Technology to replace more expensive factors of production, such as capital and labour.
- → **Inclusion:** opportunities to reduce information uncertainty and asymmetry during transactions, enabling transactions that could not previously be executed as parties were unable to find each other, or else struggled to build the required level of trust.
- → **Innovation:** opportunities to use new business models (e.g. search engines, e-commerce platforms, social media, sharing economy platforms) with low marginal costs to add one more user or transaction, and thus – in economic terms, increasing "returns to scale" [3].
- → **Customer Focus:** opportunities to use new means of interacting with consumers, understand them through their digital footprint, and deliver superior services through enhanced efficiency, inclusion, and innovation [4].

At the macroeconomic level, these benefits enabled better capital utilisation and boosted trade and competition [3]. These benefits, however, have remained unequally realised across different businesses, economic sectors and geographies, while traditional industries - where the impact of digital has been the most substantial - struggled to fully embrace new technological advances [3]. This was largely the case for real estate and, to an even greater extent, its sibling-industry – construction [5].

1.2 Digital Impact on Real Estate

Digital technologies began to penetrate the commercial Real Estate industry in the 1970s-1980s, when the first products designed to support ownership, delivery, management and occupancy of real estate assets began to appear. This included:

- → The appearance of Microsoft Excel that for years has remained one of the primary tools used by real estate professionals [6]
- → The emergence of property management and accounting systems created to support the management of increasingly globalised corporate property portfolios and newly-established (in the US) Real Estate Investment Trusts (REITs)

- → The release of Computer Aided Design (CAD) platforms – a software that digitalised and facilitated the design process, deepening the understanding of a designed structure and reducing the need for rework [7]
- → The appearance of direct digital control Building Management Systems (BMS), which introduced a new way of monitoring and controlling systems and equipment installed within the building, including heating, ventilation, air conditioning, as well as lighting, fire alarm and building security

In the 21st century these solutions became more sophisticated in terms of the functionalities they offer, enabled some degree of integration with other systems and began to move to "the Cloud", allowing better information exchange, data storage and analytics. New kinds of software, incorporating more recent information technology advances, have emerged. These included Integrated Building Information Modelling (BIM), Data Warehouse and Analytics Platforms.

Overall, these digital tools improved the efficiency of real estate operations by introducing a degree of automation into property management processes and building control, facilitating building design and construction and enabling more informed decision-making through better data visibility.

Being Smart

New possibilities to automate and analyse building performance brought forward a concept of smart, or intelligent, buildings – a vision of what a building should be. There is no single definition of a smart building, as different institutions choose to emphasise different aspects of building "intelligence". But fundamentally, buildings are considered smart when their structure is connected to their function through a thoughtful use of information technology enabling the provision of building services that ensure comfort and safety of occupants at minimal cost and environmental impact over the asset lifecycle [8].

More ambitious interpretations go beyond that and see smart buildings as "living organisms: networked, intelligent, sensitive and adaptable" [9]. Such buildings interact with building operators and occupants, empowering them with new levels of visibility and actionable information. Such buildings are also forward-looking innovation hubs that support an infrastructure that 'makes possible a truly intelligent world" (e.g. smart grids, driverless cars, etc.) [8]. This wider vision provides a glimpse into building requirements of the future.

Real estate transactions have also been impacted by digital technology. Organisations including Property Market Analysis (PMA), Investment Property Databank (IPD) in the UK, and the Prudential and National Council of Real Estate and Investment Fiduciaries (NCREIF) in US were founded to deliver data analysis and research introduced to track performance within the property market. A variety of "FinTech" (Financial Technology) tools supporting trading real estate assets - buildings, shares, funds, debt and equity – has also appeared. These tools included online payment systems, trading platforms, crowdfunding equity and debt platforms and online exchanges, and are fundamental to the listed real estate market as we know it today [6].

Despite these beneficial changes, real estate and construction have not fully realised the potential of digitisation: efficiency gains have been limited and fragmented; most traditional processes improved only minimally; transactional costs have remained at an exceptionally high level [6]. Furthermore, according to Professor Andrew Baum [6], digital technologies have mostly failed to address the multiple inherent limitations of real estate assets and specifics of real estate market, including:

- → Asset deterioration over time and value depreciation
- → Rigid demand: long-term lease agreements distort cash-flows, making returns less responsive to actual market conditions
- → Rigid supply: zoning regulations and lengthy approval and construction processes delay the response to changing demand

- → High dependency of returns on appraisals being made on an assumption basis (e.g. what the future occupancy and rent will be, etc.)
- → Low liquidity
- → Leverage applied in many real estate transactions affecting returns and risks of investments
- → Complexities and high costs of managing real estate assets
- → Heterogeneity and high price of real estate assets leading to difficulties in diversifying property portfolios

As the concern over global warming is rising, this list can be also complemented by property assets being among the largest users of energy and emitters of greenhouse gas [10].

Similarly, although the number of smart buildings has been steadily growing, they still constitute a minor percentage in building stock and are more a novelty than a normality (to give an idea – the value of global real estate market in 2015 as estimated by Savills was USD 217 trillion [11], while the estimated size of the global smart building market in 2014 was USD 7 billion [12]). Furthermore, it is mostly the focus on energy efficiency, carbon footprint, and, more recently, benefits for residents' wellbeing and productivity that is being advertised and praised in modern smart buildings. In the meanwhile, a wider idea of building intelligence comprising responsiveness, visibility, and innovative foresight remains a vision.

This slow pace of technology adoption by real estate and construction can be explained by:

- → The bespoke and complex nature of assets produced and managed, their high value, capital intensity, long production and life cycle, and high costs of risks
- → Regulatory complexities, which substantially vary across geographies
- → High market entry barriers and limited competition and, as a result, a lack of urgency and low market pull to adopt new technologies
- → The "agency problem": professional advisers (e.g. brokers, lawyers, chartered surveyors and other consultants) working in the industry are wary of actively embracing technological innovation that might disrupt their own businesses [6]
- → Organisational mindset and lack of necessary skillset among staff within organisations – a common problem in many companies coming from a non-digital background [4]

As the property industry struggled to transform internally, it was affected by the emergence of new business models, such as the sharing economy and e-commerce, which were themselves enabled by digital technologies. These business models are challenging the way real estate assets are occupied, often leading to a more effective use of space and questioning traditional leasing arrangements. Furthermore, they signal a shift in working and living patterns and a major transformation of people's perceptions and expectations – a by-product of the Digital Revolution that cannot be neglected. Things that felt strange 15 years ago - remote working, shopping and socialising, instant and free access to personalised information, renting instead of buying, valuing experiences more than possessions – are increasingly considered normal, and real estate must react to this new behaviour.

An important point to highlight here is that real estate has been constantly evolving in response to changes in our living, shopping and working patterns. Some of the major commercial asset classes we have today – shopping malls, offices – did not exist in their modern shape and form a century ago. Thus, it is natural to expect further transformation, as improbable as it may seem.

Sharing Economy

The "sharing economy" began in take shape in the late '00s, when technology enabled a different response to the rise in unemployment and austerity of the global economic crisis. Platforms such as Uber, AirBnB, Lyft, Zipcar and WeWork emerged and quickly gained momentum, achieving multi-billion-dollar valuations and large worldwide user bases [13].

Sharing economy platforms typically display the following defining characteristics:

- → *Create new markets, allowing the exchange of goods and services, thus boosting the economic activity*
- → *Open new ways to use assets, skills, time and money at levels closer to their full capacity*
- → *Function as 'crowd-based' networks, rather than centralised institutions*
- → *Blur the lines between personal and professional lives, independent and dependent employees, fully employed and casual labour, work and leisure*
- → *Shift value away from traditional corporations towards small-scale entrepreneurs working in the digital space and using a shared economy platform to support their businesses* [13]

The principles behind the sharing economy concept are not at all new but were largely abandoned in developed societies during the last two centuries. Before the second industrial revolution and the rise of large corporates, a major percentage of economic exchange was peer-to-peer and took place within communities. Trust and information required for this exchange came from social ties. Similarly, small-scale entrepreneurship has been common throughout history, but gradually lost its popularity as an employment choice in the 20th century (for instance, in the beginning of the 20th century, approximately half of the US workforce was self-employed: this figure dropped to less than 15% by 1960) [13]. *What is novel about the sharing economy is its ability to expand the economic exchange far beyond the trusted social circle. This is achieved through a variety of technological tools that help to build trust and enable otherwise impossible transactions (e.g. internet billing and payment systems, location search, validated online reviews, mobile access to marketplaces etc.)* [6].

Sharing economy platforms affected the use of different types of commercial space. AirBnB allowed private households to rent short-term lodging to those who otherwise could have become hotel guests. Retail platforms including Appear Here and We Pop Up have been helping businesses to find space for short-term pop-up shops and restaurants that are also gaining popularity among consumers. Conceptually similar platforms also allow the leasing of storage and parking space in private driveways, homes, garages etc. In the office market, WeWork, Regus and other co-working space providers are challenging the traditional understanding of commercial office space with long-term lease agreements [6].

It should be noted that WeWork and Regus are not, strictly speaking, sharing economy brands, as they operate in a centralised way, renting space from landlords, refurbishing it into a well-designed space with communal feel and subletting it on a monthly basis to start-ups and freelancers [14] *(players like SharedDesk, which helps people in need of an office space find underutilised space in offices that belong to 3rd parties, are closer to the traditional sharing economy model). However, the idea of co-working that encompasses a more efficient shared use of space through flexibility of leasing arrangements is very much in the spirit of the sharing economy. Consequently, co-working is often considered under the sharing economy umbrella term.*

A recent report by PwC [15] *outlines extensive opportunities for sharing economy models in and outside the real estate space and predicts its overall swift expansion. According to PwC's forecast, just a fraction of the sharing economy, including finance, staffing, travel (e.g. AirBnB), car sharing, music and video sharing, will be generating $335 billion in global revenues by 2025. How sharing economy and co-working concepts will contribute to changes in commercial real estate demand is explored in the next chapter of this paper.*

1.3 The Next Wave of Change and its Technology Drivers

According to the Executive Chairman of the World Economic Forum, Klaus Schwab, a radical new wave of technological advances is already driving the next (i.e. the fourth) Industrial Revolution. This represents a shift of unprecedent scale, speed, and complexity that will be "*unlike anything humankind has experienced*" and will bring *"radical change across the entire structure of the world economy, politics, communities, and in the very essence of what it means to be a human*" [2]. What stands behind these bold statements, and why they should be taken seriously?

The first reason is the notion that the pace of technological progress, as any evolutionary process, is exponential, not linear. Simply speaking, this is because each new generation of technology does not evolve independently, in a vacuum, but "*becomes more advanced through building on the evolution of the previous generation and uses previous generations' feedback to promote improvement at the next stage*" [16]. This principle, that has received the name of the "Law of Accelerating Returns", explains why the rate of change we've been witnessing seems to be constantly accelerating. It predicts that, if things continue the way they currently are, in the 21st century we will experience not the same speed and scale of progress as we experienced during the 20th century, but more like the equivalent of 20,000 years' worth of progress at 20th century speeds [17].

The second reason is our evolution as humans, and the change in our prevailing perception and attitudes. In the coming years not just the new generation of millennials, but also "digital natives" – people who were born and raised using computers and the internet – will be reaching adulthood. This group is at home in a technology-rich environment and feels the need to be connected and have technology integrated into nearly every aspect of their lives. Digital natives process information differently and think differently about privacy. They are likely to more readily embrace change, facilitating the adoption of new technological advances [18].

The third reason is the nature of technologies that are fuelling the 4th Industrial Revolution, among them – the Internet of Things, Artificial Intelligence, Blockchain, Mixed and Virtual Reality, 3D Printing, Nanotechnology, Biotechnology, Gene Sequencing, Quantum Computing [2]. What all these technologies have in common is that they are all digital and are not limited to a single industry, or to a single use case. Instead, they have a wide variety of applications and possess an unprecedent potential to penetrate and drastically alter almost everything we do, posing not only economical and technical, but also political, social and ethical challenges.

Today, many of these technologies appear to be at a nascent stage of development, and a long way from widespread adoption. This is illusive, as the Law of Accelerating Returns also applies to each individual technology. Instead of evolving at a linear rate, these technologies build on previous inventions and, subsequently grow exponentially both in terms of their effectiveness and adoption rate. Furthermore, they are closely intertwined and likely to amplify each other's impact by merging into new innovative products and technologies.

Therefore, Klaus Schwab's warning about the disruptive power of the 4th Industrial Revolution should be taken seriously and the technology drivers behind it should be understood deeply.

This paper focuses on five new technologies that will be contributing to the 4th Industrial Revolution and are the deemed most likely to have an impact on the real estate and construction industries within the next 5-7 years:

- → **Artificial Intelligence** – a branch of computer science that aims to simulate intelligent behaviour within machines, thus opening new possibilities for data analysis and automation.
- → **Blockchain** – a suite of technologies that enables integrity (e.g. data accuracy, reliable behaviour, security) within distributed systems [49] and can provide an alternative, decentralised way to manage information (e.g. digital and physical asset ownership records) and support processes (e.g. purchase transactions).

- → **The Internet of Things** – a suite of technologies that allow the creation of a network of smart physical objects that can communicate, sense and interact with their internal states (e.g. track their condition), each other and, their external environment, and produce data [45]. The data produced can potentially be used to create a digital dimension of a physical environment or object, to better understand and track their condition.
- → **3D Printing** – a form of manufacturing that builds an object "ground-up" by gradually adding raw material, enabling substantial improvements in the production process.
- → **Virtual, Mixed, and Augmented Realities** – a set of technologies that offer new, seamless and immersive ways to interact with information through the creation of a virtual environment or the addition of a virtual information layer to the user's immediate environment.

For more detailed definitions and a comprehensive overview of these technologies please refer to the Appendix of this paper.

Driving Future Real Estate Transformations

2. Driving Future Real Estate Transformations

The disruptive technologies outlined in the previous chapter – Virtual, Augmented, and Mixed Realities, 3D Printing, Artificial Intelligence, the Internet of Things, Blockchain - have a variety of applications and are likely to have both a direct and indirect impact on real estate, by changing the way property assets are delivered, acquired, and maintained, as well as by altering the underlying level and nature of demand for real estate. These technologies may also affect asset value by introducing new variables that influence the desirability of a building and by challenging traditional income streams. This chapter explores these implications in more detail.

2.1 Technology Impact on Real Estate Demand

Commercial real estate demand is dependent on a variety of factors, including the political and economic climates, demographics, government policies and regulations, to name a few, and can substantially vary across different regions.

In the Digital Revolution, the demand for commercial real estate was affected by digital technologies that altered our living and working patterns and led to the emergence of innovative business models (e.g. shared economy and e-commerce) that challenged the way buildings are occupied and used.

Looking forward, we are likely to see:

- → A continuation of these trends as they are strengthened by the new generation of technologies (e.g. IoT, AI, 3D printing, VR, AR, and MR)
- → A higher demand for space personalisation, digitisation, and transparency
- → Opportunities for greater "real-estate fracking". i.e. for unlocking value that was previously hard to access in terms of both physical space and the times at which it is occupied. Real estate owners will have to reconsider their leasing models to reap fracking benefits

"The use of the asset is getting broken up into smaller pieces and is being reconfigured in higher-value ways"

– Steve Weikal, MIT Real Estate Technology Hub, on real estate fracking

2.1.1 Commercial Office Space – Future Trends

In the past decades, we have witnessed the emergence of mobile working, the sharing economy, the offshoring of service industry jobs, and the rise of a start-up economy that has produced businesses with variable space needs. This has created a demand for more fluid and affordable lease arrangements and triggered the growth of demand for new types of spaces, such as co-working [19].

Co-working models have 3 main characteristics:

- → Offices and desk on a shared floor are offered to different businesses
- → Lease terms are flexible, allowing the possibility to move or upgrade at short notice
- → Space providers actively seek to build a community among co-working space tenants [20]

Such models bring multiple benefits. They allow a more effective use of space; they support social interaction within teams and across businesses, creating a fertile ground for innovation [21], and they are favoured by the younger generation of workforce [6]. Consequently, co-working providers, including Regus and WeWork, are doing increasingly well, and the share of co-working as a proportion of total office space is steadily increasing. The question arises of whether there is a plausible scenario within which large corporates will adopt co-working, and whether there will be a need for office space with Artificial Intelligence taking over jobs and Virtual Reality offering an alternative way to interact with each other.

Office space as an asset type will stay relevant despite changes in working patterns triggered by further job automation, improvements in connectivity and long-distance collaboration tools.

Recent research shows that serious shifts in working patterns will continue, as:

- → The millennial generation (which values work-life balance, creative and flexible working environment above all other factors except salary), will reach 75% of the global workforce by 2025 [22]
- → Increasing numbers of organisations are adopting flexible working [22]
- → The global mobile workforce is predicted to grow from 1.32 billion in 2014 to 1.75 billion in 2020, or from 37.4% to 42% of the global workforce [18]
- → Job automation is projected to increase: for example, in the UK, 56% of finance functional roles can potentially be automated [23]

These trends will be supported by emerging technologies, including AR, VR, MR, and AI, and will continue to redefine how we use office space. However, for at least another decade, office will remain a major class of real estate assets.

AR, VR, MR, and Long-Distance Collaboration

Tools and the connectivity available today already provide opportunities to work from wherever one desires. But teams still often prefer to meet at a physical workplace, and office dynamics remains relevant [TK]. Technologies, including VR and AR headsets, will enhance current collaborative tools, such as Skype, and might decrease the need for physical interaction, especially when there is a requirement to reduce costs. However, face-to-face meetings will continue to be important for people to bond [FJ]. Furthermore, nuanced cultural differences will continue to require more impactful interactions that can only be achieved in person [24].

Artificial Intelligence and Job Automation

> "Is it possible that we are now entering a new era of automation in which the rate of previously human-performed work now done by machines may outpace the rate at which these machines create new jobs?"
>
> - Arun Sundararajan, author of "The Sharing Economy"

The impact of job automation can potentially be significant but will take time to unfold. In the next 2-5 years, we are likely to see more and more narrow AI (e.g. machine learning, text, speech, image recognition) being incorporated into solutions that help streamline business processes and automate tasks that computers can perform better than humans (pattern recognition, calculations, rule-based decision-making, etc.) [13].

According to various estimates, 10% to 47% of current jobs in developed countries have the potential to be automated by early 2030s [25]. Most of these jobs are expected to be in transportation and storage, manufacturing, wholesale and retail, administrative and support services. In practice, these numbers will depend not only on technological advances, but will also be subject to various economic, legal, and regulatory limitations [25]. Furthermore, automation has historically led to faster growth and rising employment [26], as new technologies were also creating new jobs. Therefore, the impact of job automation on net employment and on space occupancy remains unclear [25].

An emergence of Artificial General Intelligence (i.e. when intelligent agents will be able to display (at least) human-level intelligence that is not limited to a highly specific set of tasks [27]) would most probably have a more radical impact on employment, but this technology is currently at a conceptual stage.

What occupiers expect from an office space is likely to change, while the demand for new types of office space, including co-working and makerspaces, will continue to rise.

Companies will continue to have different office preferences, depending on the work they do [JA]. Smaller businesses will lean towards flexible options. Thus, one type of office space under threat is the traditional open-plan office under 300 square meters, as companies renting such spaces will increasingly switch to co-working serviced office providers offering smart, flexible spaces as well as access to communities that help small businesses stay innovative and agile [JA].

According to Dr Andrea Chegut, demand for co-working, as well as incubator and fabrication spaces, makerspaces and hackerspaces - different types of collaborative work spaces that offer making, learning, exploring and sharing facilities -- will be enhanced by a further rise in small and medium businesses, and innovation-driven enterprises around the world. Developed countries are attempting to boost their economies through innovation. Consequently, we are likely to see an increase in the number of start-ups – organisations that differ from traditional companies as they do not have a standardised long-term cash flow projection and cannot afford long-term occupancy arrangements. The result is that the demand for co-working and similar spaces supporting a start-up economy will continue to "eat away" at the market share of traditional office space [AC].

Co-working also seems to be gaining the attention of large corporate tenants. In recent years Microsoft, Deloitte, HSBC and IBM have rented desks from WeWork. Although details of lease terms have not been not disclosed, it is speculated that large tenants may favour more flexible leasing arrangements coupled with an all-inclusive managed office, and with possibilities to 'swing' locations (e.g. trade areas in one location for the right to occupy space in another) that WeWork offers [28]. Part of the appeal also lies in the environment and community that WeWork manages to create through design and approach to space management.

Josh Artus believes that most large corporates will still prefer more straightforward and long-term occupancy arrangements, but their requirements for an office space are likely to evolve alongside the composition of their workforce and the nature of the jobs they perform. Talent and workforce models are changing to accommodate the flexibility valued by millennials [22], while the increasing automation of repetitive and mundane tasks leaves more time for creativity and innovation that are vital in times of rapid change. The workspace will have to match this new workstyle – i.e. be flexible, provide a high level of connectivity and offer personalisation to match both business needs and those of individual employees [JA].

The new generation of digital technologies will enable greater personalisation and flexibility of working space, that can enhance both co-working and traditional office experiences.

Technologies like the IoT and AI offer great opportunities to deliver higher degrees of comfort, flexibility, efficiency and personalisation. Real-time sensor-based analytics collected throughout the building and analysed with the help of AI algorithms will allow deeper understanding of occupancy patterns and proactive response to tenants' requirements, improving their experience, productivity and wellbeing [18]. Tenants will also benefit from a higher degree of building responsiveness. Through mobile apps, intelligent, IoT-enabled buildings will be capable of facilitating access, helping with parking, directing an occupant to a workplace that best suits her preferences and schedule, optimising her immediate environment to fit her needs, assisting in locating colleagues etc. [29]. This vision is already being partially realised in the latest generation of smart office buildings, such as Deloitte's The Edge in Amsterdam or the BREEAM Outstanding and LEED 'Platinum' rated White-Collar Factory in London.

It might become harder to lease out traditional areas of office space. Income received from space which is fully leased but under-occupied will gradually disappear.

As smaller businesses turn to more flexible leases enabled through co-working, a combination of AI and the IoT will allow larger tenants to better understand and forecast their occupancy patterns and potentially reduce the amount of under-occupied space – which, today, is estimated to average around 50% in long-term leases [29]. Furthermore, with higher mobility and greater flexibility in working arrangements, desk ratios of 3 (or more) people to 1 desk are already becoming more common. These trends will result in a more efficient use of space, but also in increased wear and tear, as space will be used closer to its full capacity. For landlords, maintaining the same level of rental income from the same amount of office space will become more difficult.

Volker Buscher noted that the property industry is entering an 'experimental stage' and it is currently unclear how technology, flexibility of space use enabled by it, and competition with co-working will affect net rental income, or what will replace the usual 'rent + service charge" model. Lease terms are likely to become shorter, charges for the use of communal space might be introduced, or leases might be linked to occupancy or well-being levels. There is also a question of whether flexibility will lead to a reduction in the use of space as there are plenty of case studies that – counter-intuitively – demonstrate the opposite: when people have the possibility to use and pay for services in a more dynamic way, they ultimately consume more [VB]. Overall it is likely, that corporate occupiers will demand more sophisticated and more flexible services from landlords, as they too will be facing uncertainties brought about by the 4th Industrial Revolution, so real estate players will have to be more agile to keep up.

2.1.2 Commercial Retail Space – Future Trends

Emerging technologies provide opportunities to facilitate the online shopping experience, putting yet more pressure on physical retail, but not eliminating it as a type of asset.

The era of e-commerce notionally began on 12th August 1994, when the New York Times announced the execution of the first secure digital transaction – the purchase of Sting's CD "Ten Summoners' Tales" for $12.48 [13]. Around the same time, future e-commerce giants Amazon and eBay were founded and quickly began to gain prominence, as e-commerce promised a number of advantages over physical retail: faster entry into new international markets, easier searching for products and price comparisons, greater opportunities to track consumers' preferences and to deliver tailored advertising, to name a few.

E-commerce challenged the way physical retail space was used, but its impact was ambiguous and varied across geographies. Even now, it still struggles to overcome its own limitations: access to the purchased physical products is never immediate; an online purchase involves the risk of buying a product that does not meet expectations; areas with limited access to modern banking and poor delivery infrastructure remain excluded. Consequently, the majority of consumers still prefer physical stores. Although the share of online retail in worldwide sales is steadily growing, it remains below 10% [15]. The question now is whether the adoption of emerging technologies can help e-commerce overcome these limitations, capture a greater share of sales, and further erode the demand for physical retail space?

Virtual, Augmented, and Mixed Realities

Online shopping platforms can potentially utilise Virtual, Augmented and Mixed Reality applications to better demonstrate products offered online, thus enticing people to shop online for goods that they currently still prefer to buy at a bricks-and-mortar store. Such products might include furniture and appliances, clothing and footwear [30]. In fact, brands like IKEA and Bang & Olufsen have already introduced augmented reality apps that help customers see how furniture and appliances will fit in their homes.

While AR apps are smartphone-based, more immersive VR and MR experiences will require customers who want to view products from the comfort of their homes to possess headsets. Such headsets are not likely to go mainstream for private use until more lightweight hardware (devices more resembling spectacles) are released – something that is projected to take more than 5 years [FJ]. Therefore, in the short-term, these technologies are unlikely to have a radical impact on online retail.

3D Printing

3D printing "on demand" eliminates the need to hold a large stock of inventory and supports customisation. MGI [31] predicts that by 2025, 5-10% of relevant consumer products—toys, accessories, jewellery, footwear, ceramics, and simple clothing—will be 3D-printed directly by consumers. As a result, consumers will obtain goods that they value more highly (because it can be easily customised based on their size or preferences) at lower prices. According to an MGI estimate, for consumers this could represent a potential economic impact of $100-$300 billion – a figure that reflects both cost savings and additional perceived value that accompanies customisation [31].

Customisation opportunities could eventually drive households to own printers and/or use cloud-based printing services. However, there is a very low probability that in-house 3D printing will become widespread within the next 5-7 years. A more plausible scenario is that consumers will start using scanners and wearables at home to collect information and then send it to a 3D printing shop or order tailored products online for home delivery [JA].

3D printing shops, a concept where a person downloads a file for an object and customises it to their liking before sending it to a "shop" for printing, might emerge at a larger scale and represent a new form of retail. Another variation: on-demand mobile 3D printing, wherein a truck either finishes a product or prints it while it drives toward its delivery destination [SW].

In response to 3D printing technology, traditional retailing spaces are likely to get smaller, functioning more as showrooms, or will be partially converted into warehousing space for 3D printing materials and inventory for online sales. The quantity and volume of goods inventoried at shops will be substantially reduced as stock can be more easily and quickly replenished.

Artificial Intelligence and the Internet of Things

AI, and more specifically Machine Learning, is already an integral part of e-commerce platforms; it helps target advertising, make preference-driven product recommendations, and otherwise track and analyse customers' behaviour. These capabilities will further improve as more customer data becomes available from IoT-enabled products [32].

One particularly interesting area of new possibilities that are emerging with the IoT and AI are drone deliveries – which will likely reduce delivery costs, especially for last-mile shipping, making online shopping more attractive to consumers and profitable for enterprises. According to some estimates, Amazon's use of drones could cost only 88 cents per delivery – a significant reduction in current delivery costs [33]; 80% of that cost savings is expected to come from last-mile shipping efficiency [34]. Drones will likely complement, not fully replace, truck delivery. Thus, UPS is currently testing a new delivery approach: a truck drives to a point near the delivery destination; the truck driver then directs a drone along the "last mile"; and once the drone is dispatched the truck moves onto the next destination; meanwhile, the drone completes its delivery, and then returns to the truck – whereupon the process begins again [35]. (It should be noted, however, that in most countries, the use of both drones and semi-autonomous vehicles will require adjustments to legislative frameworks.)

Interestingly, Artificial Intelligence also presents threats for e-commerce. For example, AI algorithms can effectively falsify customer reviews, thus compromising an important trust-building mechanism used in online sales [36].

Blockchain

Blockchain is likely to impact retail through crypto-currencies, such as Bitcoin, which can bring benefits for e-commerce that include:

- → Allowing people living in developing countries, who do not currently have access to modern banking, PayPal, or other third-party payment systems due to their risk profile, make purchases online (providing that adequate delivery infrastructure is available)
- → Facilitating cross-country e-commerce by eliminating foreign exchange fees
- → Helping merchants avoid chargebacks on transactions (when a customer buys something with Bitcoin, he or she does not have an option to call a bank and ask to cancel the transfer)
- → Enabling savings on card processing fees (currently constituting up to 3% of the transaction amount)
- → Freeing retailers from the burden and costs of processing and handling sensitive credit card data [37]

However, crypto-currencies still have a lot of limitations to overcome prior to their wider adoption, including high volatility and security flaws in trading and storing platforms. Furthermore, although crypto-currencies are not subject to bank fees, most of them currently require a distributed network of miners who run transaction validation algorithms. Since miners have to be remunerated and compensated for their substantial equipment and energy costs, transactions involve additional fees that currently remain at a prohibitive level for small-scale purchases and can fluctuate in a similar way to Uber's 'surge' pricing [38]. Meanwhile, the speed of executing a

transaction and the capability to deal with large transaction volumes remain uncompetitive in comparison to other available payment mechanisms. However, new blockchain solutions are currently being developed to resolve these limitations.

Will Retail Go Mobile?

Start-up Wheelys is on a mission to reinvent small-scale physical retail and facilitate local retail entrepreneurship.

Their first project - a solar-powered full-service organic cafe "contained upon a bicycle" that could be purchased for only $3,000 - was designed to offer a drastically cheaper, greener, and quicker-to-start alternative to a physical coffee place [39]. However, Wheelys made money not only through the sale of hardware (their cafés on a bike), but also through the provision of inventory management software that tracks sold items and determines when a resupply is required [40].

In their next venture, they used this software to launch their first unmanned stores in China and Sweden. The shops are serviced through a mobile app that allows a customer to enter the shop, scan and purchase items. The shops are fitted with security cameras to prevent theft. They are always open and sell basic goods, including chocolates, cigarettes and potato crisps

While a similar unmanned store concept is being tested by Amazon [40], Wheelys are moving to the next step - the AI-enabled Moby Mart that is already undergoing beta testing in Shanghai. With Moby Mart, the staff-less store goes mobile - it can be parked at a parking place, deliver goods to customers and drive itself to a warehouse for restocking. It runs on electricity generated by solar panels and, instead of polluting the air, it cleans it up with an in-built purifier. Wheelys envision that Moby Mart will sell products for immediate consumption including food and medicine, while other goods (e.g. computers, light bulbs etc.) can be ordered for advance pick-up [41].And though our interviewees were generally sceptical, Wheelys' founders believe that their concepts represent the future of retail and will be widely adopted in 10 years' time. To realise their vision, Wheelys are setting up production of Moby Marts in China, planning to sell each store for less than $100,000 – a price far below the costs of building a traditional store [41].

Large retail assets will have to be reinvented into experience and entertainment centres, with show rooms to entice customers to visit. They will need to support high connectivity and use both the IoT and AI to deliver a superior visitor experience.

The impact of e-commerce on the demand for physical retail space is not straightforward and seems to vary regionally. In the US, the demise of traditional shopping malls is apparent (it is predicted that 15% to 50% of malls will be closed or repurposed in the next decades) [42], while in most European countries this does not seem to be the case. Moreover, some recent evidence suggests that physical retailers use their online presence and click-and-collect services to drive customers into stores and increase in-store sales [43].

The reason behind this regional contrast is that in the US a large number of shopping malls with few amenities or attractions beyond the stores themselves were built a half century ago in isolated suburban locations that are hardly accessible without a car. Since then, the demographics of surrounding areas has changed, the assets have become outdated from both structural and building systems perspectives, while the malls have struggled to offer a better alternative to online shopping. In Europe, shopping malls are generally better placed, better integrated into the city network, more modern, and contain more diverse amenities [42].

According to our interviewees, these more modern types of large physical retail assets is here to stay, but will be undergoing further transformation towards "digital, convenient, and experiential" [AC]. Malls will have to offer a variety of things to do, creating ecosystems for local communities and focusing on all aspects of leisure and offering diversity in their environments [JA]. While commodity products will continue to be purchased online, shopping centres can host anchor stores that showcase the more "flashy" products and draw people in for a technologically-enhanced experience. The IoT and AI will be more widely used to track and analyse consumers' behaviour in stores and make the shopping trip more enticing for them, VR and AR will showcase products, and 3D printing will offer on-demand customised

goods. As a result, bricks-and-mortar spaces will become more technology-heavy and acquire a stronger digital dimension, demanding an appropriate infrastructure.

Dr. Claire Penny predicts that, within the next decade, retail will become a more mature IoT user, applying technology to understand the demographics of people coming into the store, their conversion ratios, the speed of serving a customer, the attraction of a new showcase etc. Understanding these parameters will support the optimisation of store inventory and operations, and a better overall customer engagement. Consequently, the use of IoT will be vital for store competitiveness, and landlords are advised to be proactive in embracing the IoT within their assets [CP].

På Gränsen – Unlocking IoT Benefits for Retail Type of Asset

På Gränsen in Finland is one of the first European shopping malls to use a combination of facial recognition and people counting technology through IoT cameras to enhance its performance. The number of visitors, the time of day at which they visit, their customer profile, even their facial expressions and emotions are being analysed, and real-time adjustments are made to boost operational effectiveness and deliver tailored marketing and advertising. The result – an estimated 30% increase in store profitability [44].

Why E-commerce Giants are Branching into Brick-and-Mortar

In 2017, e-commerce giants Amazon and Alibaba, in somewhat surprising moves, acquired physical retail portfolios. Amazon famously paid $13.7 billion to purchase natural and organic grocery business Whole Foods and its c. 460+ stores in the US, Canada and the UK [45]. *Alibaba bought Intime – a company that owns 29 department stores and 17 shopping malls located in Chinese urban areas. In addition, Alibaba owns 20% of Sunning – China's major electronics retailer with 1,600 stores across 289 cities* [46].

Both Alibaba and Amazon are fast-growing, highly strategic and forward-looking companies dominating their markets (as a reference, 80% of e-commerce in China passes through Alibaba services, and a substantial share of physical retailers also sell online through their platform [46]*). They are leading retailers, but first and foremost they are data and technology companies that have developed deep insights into both the supply and demand sides of the retail industry. So, their actions can be viewed as a meaningful indication of where retail is going in the long-term: a seamless merger of online and "bricks-and-mortar" shopping experiences, where both digital and physical spaces are used for what they do best. And this balance between what we do online and what we do offline is likely to evolve as new technologies enable enhancements in both environments.*

For now, their newly acquired retail portfolios provide Amazon and Alibaba with a network of distribution outlets as well as food outlets in prime locations, opening a new way of getting their products to the consumer [JA] and eliminating a major advantage of primarily physical retail chains who are in turn branching into e-commerce. They seem to be covering all the bases and are putting pressure on traditional retailers to catch up.

Technological Competencies vs. Industry Experience

As Amazon and Alibaba are building their physical presence, Walmart is partnering with Google in an attempt to beat Amazon "at their home ground" [47]. Amazon meanwhile has been struggling to create an engaging shopping experience in their recently-launched physical book store [48].

Will Amazon win in retail business using their exceptional technological competencies and data insights, or will Walmart (or other industry players) keep their dominant position, swiftly adding technology expertise to their 55 years industry knowledge? The jury is out, and it will be interesting to see how this competition will develop. For now, Walmart's net sales are far ahead, while Amazon's net sales growth rate is far superior.

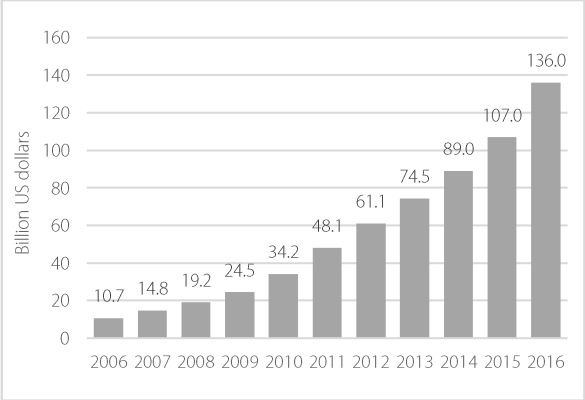

Figure 1 - Amazon net sales revenue from 2006 to 2016

Source: https://www.statista.com/statistics/266282/annual-net-revenue-of-amazoncom/

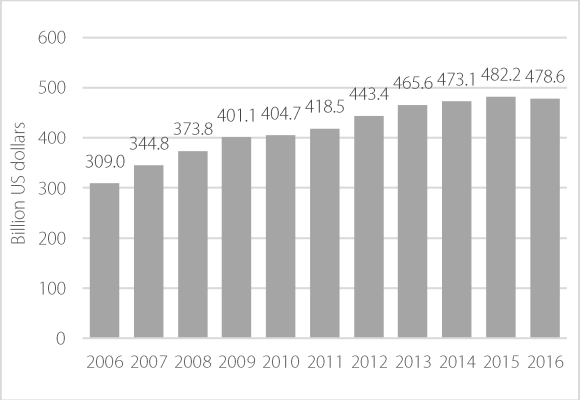

Figure 2 - Walmart's net sales worldwide from 2006 to 2016

Source: https://www.statista.com/statistics/183399/walmarts-net-sales-worldwide-since--2006/

The traditional approach to leasing retail space will have to be reconsidered.

When visiting a shopping centre becomes a leisure pastime, shops are transformed into showrooms and most products are bought or ordered online, how will turnover rent be calculated?

Paul Chen believes that the traditional approach to retail leases – base and turnover rent, will go away. In essence, real estate companies do not want to collect turnover-based rent. Getting a high turnover rent simply means that the base rent is too low. What real estate companies want is to establish the correct level of base rent, and this might be achieved through better data and analytics. Rents are also likely to become dependent on new parameters that can be measured and analysed using new technologies and can in turn more directly reflect the value delivered by the retail space [PC].

2.1.3 Industrial Space – Future Trends

Emerging information technologies will further enhance the demand for high-tech industrial real estate.

Digital does not merely reside on the Cloud but requires physical real estate to exist. While retail and office spaces are being optimised, industrial real estate will continue to benefit from strong demand fuelled by the development of digital technologies and digitisation.

IDC Research predicts [49] that by 2020 the amount of worldwide data will grow to 44 zettabytes (or more than 40 trillion gigabytes - a 10-fold growth from 2014) with 10% of this figure accounting for the data produced by the IoT. At the same time, the amount of data that "spends some of its lifetime in the cloud" and, thus requires hosting, will grow from 20% in 2013 to 40% in 2020, driving demand for additional storage [49].

In the meanwhile, E-commerce businesses will be requiring more warehousing. According to some estimates, online retailers use three times as much warehousing space as their physical counterparts, mainly because online orders are packaged individually instead of being stored on pallets [50]. For example, in the UK, an additional 86,000 square meters of warehouse space is required for every £1 billion that consumers spend online. With online sales expected to grow by £18 billion between 2016 and 2019 in the UK, the implication is that an additional 1.5 million square meters of warehouse space will be needed [51].

3D printing will alter the use of storage and warehousing and industrial space. Instead of storing final products, some companies will prefer to keep raw materials and host 3D printers. Furthermore, as the cost of 3D manufacturing comes down, off-shore manufacturers may start moving back on-shore. This trend will be supported by automation enabled through the use of AI.

Professor Andrew Baum [6] outlines a new type of real estate asset – high-tech smart buildings needed to support technology businesses. This category comprises data centres, online distribution hubs, specialised logistics, and will soon include drone hubs and autonomous car charging stations. It also includes office space designed for companies that need extremely fast connectivity, or Amazon locker sites, and click-and-collect stores, thus blurring the boundaries between traditional asset types [6]. High-tech industrial real estate is on the rise globally but is expected to encounter increasingly sophisticated and enterprise-specific requirements.

In the future, increasing demand for data centres is likely to come from the developing countries, including Brazil, China, India, Mexico, and Russia, that will be producing the majority of the world's data. By contrast, today around 60% of data is generated in mature markets [49]. Although data centres usually serve businesses remotely, location is quickly becoming a factor that matters. Not only does location affect latency (the time between a request for data and the response) that is crucial for users' satisfaction, but it also influences legislation and policies applied to the stored data (including national intelligence agencies' access) [52]. In the current political landscape, and as more responsibility to protect data is placed on businesses, this consideration will become more important.

Optimising Energy Use and Creating New Income Stream for Data Centres

Data centres are the engine rooms of the digital era, but they also consume a large amount of energy and generate a large amount of heat, presenting a serious challenge from an environmental sustainability perspective. To tackle this, the city of Stockholm decided to use excess heat from data centres to heat residential buildings situated in a nearby city district. The local energy company – Fortum Värme, with 25 years' experience of capturing and reusing excess heat from manufacturing facilities – has already integrated more than 30 data centres in its cooling and heat recovery network. As a reference, one 10MW capacity data centre can provide heating for approximately 20,000 apartments, thus reducing its net environmental impact while securing an additional income stream.

It is important to note, however, that not all industrial real estate is benefiting from the recent technology advances. Thus, the future of petrol stations is raising concern as Tesla is paving the way for electric vehicles. Whether petrol stations will be redesigned to support car charging and remote autonomous vehicles parking, repurposed into a different type of asset, or fully demolished is currently uncertain.

2.2 Technology Impact on Asset Value

"....one of the main drivers of demand, which currently is location, will not be so strong. The other driver of demand will be smart infrastructure."

Josh Artus. The Centric Lab

Emerging technologies will soon prompt us to reconsider parameters that determine the value of a real estate asset. The focus on traditional income streams (monthly rents, turnover rent etc.) and location will shift to new variables that will be considered alongside, and directly or indirectly (through income and expense streams) affect, asset evaluations.

Such variables may include:

- → Digital Infrastructure (including the IoT)
- → Transparency of building's state and performance
- → Flexibility of building structure and systems
- → Cybersecurity
- → New income streams

2.2.1 Digital Infrastructure

"With IoT we will add another layer of computational and digital complexity to the building so that the building is sensing and talking to you about not only the building's experience but also the people inside of it. The building becomes a 'living breathing entity' and the people inside of it and their experiences become a living breathing thing that you must monitor and engage. That is a differentiator."

Dr. Andrea Chegut, MIT

Digital infrastructure concerns smart buildings in the purest sense of the term. Such buildings are interactive, and empowering tenants and landlords through a deeper understanding of space impact and usage. They are also forward-looking, enabling the adoption of new technologies and innovations [8].

As discussed above, the IoT is adding a digital layer to building assets, releasing opportunities to use data analytics and digital tools to enhance the occupancy experience and optimise building operations. The availability of real-time data that can be aggregated, analysed and acted upon will make buildings more responsive, more manageable and more capable of delivering added value.

Real-time building performance data will also support the development and adoption of the next generation of technological concepts. One example is the Digital Twin technology that would allow the creation of a virtual model of a process or product, which is capable of evolving together with the real object on the basis of "massive, cumulative, real-time, real-world data measurements across an array of dimension" [53]. Such a model can be used to test various scenarios of maintenance, operations, upgrades, etc. In 2017 Gartner included Digital Twin in its list of Top Strategic Technology trends, while Thomas Kaiser, SAP Senior Vice President of IoT, stated that "Digital twins are becoming a business imperative, covering the entire lifecycle of an asset or process and forming the foundation for connected

products and services. Companies that fail to respond will be left behind" [54]. With BIM modelling already being used to improve building design, construction, and operations, it can be easily imagined how Digital Twins can be adopted to manage real estate assets and how it can become an integral part of the next levels of BIM maturity, i.e. Level 3 (online integrated project modelling with cost, schedule, and project lifecycle information) and Level 4 (modelling with incorporated wellbeing and social outcomes).

Digital Infrastructure is also about allowing building occupiers to use new information technologies within the building, and this is often dependent on fast and powerful broadband. Josh Artus has pointed out that, in the modern world, connectivity is becoming almost as important as location. Having fibre connectivity in the building is becoming a must [JA]. As a recognition of this requirement, in 2013 WiredScore certification was developed by US real estate, technology and telecommunication professionals and was soon endorsed in the US, UK, France, and Ireland. WiredScore rates buildings based on several metrics, primarily focusing on connectivity (e.g. how quickly internet connection can be setup, how resilient the internet is, what internet speed can be expected, the degree of flexibility in choosing an internet provider). Information on certified buildings is made available to tenants, agents and the general public, helping to identify commercial spaces that meet particular connectivity needs [55]. Today, more than 150 buildings in Europe are WiredScore certified [56].

Paid to Be Smart?

Real Estate, as a broad industry, is often regarded as a slow technology adopter, and a future in which smart and responsive buildings, supported by the IoT and AI, are the norm appears distant. A question also arises as to whether such buildings will enjoy rent premiums.

According to Steve Weikal and Dr. Andrea Chegut, smart responsive buildings are likely to follow the same pattern as green buildings did several years ago. At first, BREEAM- and LEED-certified buildings were rare and were traded and rented with a significant premium (sale premiums achieved from 8% to 15%). These premiums, however, have been gradually decreasing as more and more certified "green" assets have become available. A similar scenario is likely for smart buildings.

However, if the "green" label appealed to tenants' and investors' environmental responsibility, "smart" will enjoy a much wider business case. Volker Buscher noted that drivers behind smart building infrastructure are not purely efficiency and cost savings, but are much broader and linked to tenants' experience, and, often, the success of the tenant's own business [VB; JA; AC].

> "By having a tech system that understands each employee's needs and feeds into the building system, the building becomes a member of the team rather than just some place where a team goes."
>
> Josh Artus, The Centric Lab

Just as ethernet and structured cabling were initially reserved for high-end users but soon became a baseline requirement for virtually all occupiers, so too, according to Volker Buscher, will the use of the IoT and AI in buildings become more an essential expectation than a luxury in the next 5-7 years.

2.2.2 Transparency

"If you can show factually what a building costs to operate, who uses it, if people are happy… It's a good proposition. It could be powerful information from an investment perspective."

Dr. Claire Penny, IBM

"Environments that can prove they increase productivity will be higher valued."

Josh Artus, the Centric Lab

While valuations are currently based on a set of generic assumptions that define what future asset income and expenses will be, real-time data and analytics will help to root these assumptions in the specificity of the asset. How much a building is occupied; how occupancy patterns vary over time; how much energy a building consumes; how satisfied tenants are with the building; how obsolete building equipment is, and when it needs replacement – knowing more definitive and real-time answers to these questions will constitute more solid ground on which to build valuations, allowing investors to gain deeper knowledge of an asset in the past, present, and future. In other words, assets and portfolios offering greater transparency will reduce investment risks and, all other things being equal, are likely to be preferred over other options.

Overall, a greater demand for transparency is likely to come not only from investors, but also from tenants and government bodies [JA]. The latter might be interested in a building's safety, environmental performance, degree of integration in the community and in the city infrastructure, etc. The former will be eager to get a better grasp of how a building suits their needs and how it can "work" for them through improving workers' productivity (for offices), enhancing customers' experience (for retail or industrial), or enabling operational savings or higher turnover. Landlords who can demonstrate through transparency (likely, through an indexed standard) how their assets can help to boost occupiers' businesses will enjoy a competitive advantage [JA]. Furthermore, a move towards higher transparency is happening across all industries, and there is no reason why real estate should be an exception [AC].

2.2.3 Flexibility of Building Structure and Systems

"Flexibility rules because it enables an asset with little to no retrofitting to come back and live again and serve the economy one more time. Increasing attention is being paid to any structures that offer a high degree of flexibility."

Andrea Chegut, MIT

The 4th Industrial Revolution brings a change of scale, speed, and complexity we have never encountered before [2]. We can speculate on the possible implications of one technology or another, but there are so many factors coming into play, and so many possible scenarios and influences, that the only thing that can be predicted with certainty is that everyone – individuals, businesses, governments – will have to develop an exceptionally high level of agility and adaptability to rapidly-shifting environments. For real estate assets, this kind of agility will have to be designed into both physical structure and building systems.

Flexible building design can imply the facilitated scalability of space in response to varying tenant requirements, the capability to support rapidly evolving technologies, or the ease of conversion to a different asset type. Overall, a building should no longer be serving just a few purposes [JA], but be capable of evolving along with shifting living, working, and leisure patterns.

Designing a flexible building without a major construction budget increase is a challenge that has been explored by architects and engineers for at least a century. Today, this idea is attracting renewed interest from designers and developers [SW], while new materials and technologies may present new solutions.

The tricky part is that the future value of this flexibility can be hard to quantify upfront. But it will certainly play a role in increasing asset longevity, reducing risks that it becomes no longer fit for purpose, and can be considered as part of the overall strategy for a building. According to Dr. Andrea Chegut, flexibility is a great investment as it effectively slows down physical, functional, and economic asset obsolescence and reduces the need for investment in asset maintenance throughout its lifecycle, as less effort is spent on adapting a building to changing occupancy requirements. Josh Artus is also positive: flexibility will be a driver to invest.

The Future of Parking

Looking beyond 2025 – 15 years into the future - we will see the cityscape transformed by one of our latest inventions in the making: autonomous vehicles. Today it is envisioned that driverless cars will be managed by robots to optimise their usage, shared by multiple people, and spend more time on the road (currently private cars spend 95% of the time parked). When needing to be parked, autonomous vehicles will drive themselves to a parking facility outside of prime locations. Such facilities will have little provision for human access (no customer stairs, elevators, wide alleys etc.), but will accommodate maintenance and refuelling (or more likely – charging) facilities [57].

It is not yet clear when (and whether?) this vision will be realised. Furthermore, the speed of driverless car adoption is likely to vary across geographies as to enable autonomous driving local policies and regulation will have to be reconsidered. MGI predicts that only 10 to 20 percent of the 1.2 billion private cars projected to be on the road in 2025 will have the ability to self-drive in at least half of all traffic situations [31]. *Some forecasts are more optimistic, but it is overall safe to say that in 5-7 years' time we will still need parking spaces. However, it is not too early to start thinking about flexible parking design.*

Norman Foster, chairman and founder of the architecture firm Foster & Partners, stated that if he could redo his design of Apple's new Cupertino headquarters, he would pay more attention to the changing patterns of transportation. The building has enough parking space for 11,000 cars—an amenity that may not be needed tomorrow. If given the chance, Foster would increase the floor-to-floor height of the car park, allowing the structure to be more easily retrofitted for habitable space [58].

2.2.4 Cybersecurity

Cyberattacks may develop a whole new meaning and scale when buildings become more digital, IoT-enabled and automated. Ensuring the safety of building occupants and the security of data collected from the building will become paramount. Minding the importance of this issue, it is likely that building cybersecurity standards will be developed (or adapted from existing general cybersecurity standards) and become mandatory; compliance with these standards will need to be demonstrated to both investors and occupants. We can also imagine that breaches of building cybersecurity will negatively affect asset value and raise concern among tenants.

2.2.5 Changing Income Streams

As discussed earlier, building occupancy patterns are changing and traditional income streams (e.g. turnover rent, long-term rent, income from parking) are losing relevance. This is likely to make real estate companies search for new ways of generating direct or indirect returns from their assets, which may include:

- → Income from different, more flexible, and shorter-term lease arrangements
- → Charging increased rent for common areas to reflect flexible working patterns
- → Making rent dependant on parameters measured through the IoT (e.g. productivity, wellness, customer engagement indices and indicators)
- → Offering new services, including data analytics, faster broadband, electric car charging, drone landing hubs etc.
- → Generating and selling renewable energy (for example, by incorporating solar panels on the roof) or excessive heat from industrial assets

2.2.6 What About Location?

Steve Weikal predicts that, for office and retail real estate, current trends – high desirability of city centres and innovation clustering - will continue. Innovation clustering occurs when companies choose to locate where thinking and knowledge sharing happens (not necessarily in the heart of cities), creating critical masses of unusual competitive success and forming a geographic concentration of interconnected companies and institutions in a certain field. This phenomenon is not new - famous examples include Hollywood, Wall Street, Silicon Valley, and more recently London's Shoreditch. However, it is likely to gain increasing attention as cities are looking to boost innovation through the start-up economy and regenerate their less-developed areas [AC, SW].

As already mentioned, location will also play an important role for industrial real estate, but the ideal choice for most tenants will also be dependent on more technical requirements, which will often be specific to a particular occupier.

So, location will not become irrelevant, it will stay very important. But it will be considered together with factors discussed above. And, according to Josh Artus, Europe is likely to follow the footsteps of countries like Australia where the focus has already shifted towards smart infrastructure and the importance of wellbeing.

2.3 Technology Impact on Real Estate Operations

As discussed in the previous section, the emerging generation of digital technologies will expand the list of factors that define the value of an asset, releasing new means for differentiation. Similarly, technologies including 3D Printing, the IoT, Artificial Intelligence, Blockchain, VR and AR will provide new opportunities to gain competitive advantage through enhancing key real estate business functions.

The major opportunities will lie around:

- → Improving the efficiency of back-end operations through automation, transparency, and optimisation
- → Improving the way assets are delivered, e.g. enabling smarter design and construction
- → Enhancing front-end operation by offering superior services to current and prospective tenants and buyers
- → Developing a better understanding of business and portfolio performance through better quality, real-time data, and more powerful analytics

Leveraging these opportunities will be crucial for the survival of any large real estate business while, according to our interviewees, we should expect all explored emerging technologies to be used by the industry in the next 5-7 years.

In this section of the paper, some of the most imminent and interesting use cases are explored.

2.3.1 Blockchain to Facilitate Property Ownership Transfer

In June 2017, start-up velox.RE completed an eight-month pilot programme with Chicago's Cook County Recorder of Deeds that successfully demonstrated how a distributed blockchain solution can be used to transfer ownership of real estate assets.

This is not the first attempt to use blockchain to facilitate real estate transactions. Previously, the Republic of Georgia tested the use of blockchain to maintain land registry records, while Sweden is working on making property transactions more seamless by using smart blockchain contract solutions. Both initiatives are using private or centralised blockchain technology that, while making property records more secure and immutable, does not eliminate the need for a public body to maintain the title register.

The velox.RE solution represented a serious step forward. It used public or distributed Bitcoin blockchain to transfer ownership from buyer to seller. A blockchain-based deed was used instead of a paper deed, and a transaction executed on blockchain was recorded in the public records. The county was not directly involved in the ownership transfer and did not run any specialised software. Its role was reduced to outlining legal and procedural steps for the transaction [59].

Velox.Re founder Ragnar Lifthrasir believes that public blockchain is the future for real estate industry, as it eliminates the need for centralised control, allows the incorporation of cryptocurrency-based transactions (normal currency can also be used but using cryptocurrency allows more seamless transactions), and, if a platform like Bitcoin is used, is highly secure. Despite numerous reports of Bitcoin theft, the security of Bitcoin blockchain technology itself has never been compromised. It was external applications, designed by 3rd parties to support Bitcoin trade (e.g. cryptocurrency wallets, cryptocurrency exchanges etc.) that have been found to contain security flaws.

In our interview, Ragnar also noted that, although some use cases for internal private blockchain exist, it is the public blockchain that will bring disruption in the years to come [RL]. Public blockchain brings transparency into real estate transactions, thus tackling the problems caused by the fragmentation and centralisation of the property industry. Such problems include illiquid assets, slow price discovery, expensive due diligence, incomplete and unverified property data, high transactional costs, legal inconsistencies, fraud, and haphazard mortgage tracking [59].

Can a similar solution be implemented in Europe, where we use a title register system (i.e. ownership change is reflected in public records) instead of a deed registration system (i.e. ownership is transferred directly from one party to another, and the deed publication in county records is optional)? Ragnar believes that it is absolutely possible, but that more process and regulatory adjustment will be required.

Property Transactions in Bitcoin

Developers are opening up possibilities to use Bitcoin to purchase real estate. British entrepreneurs Michelle Mone and Doug Barrowman have launched a £250 million luxury residential development in Dubai that is priced in Bitcoin. The development is due for completion in 2019.

Developers insist that the use of bitcoin is not a marketing gimmick, but a response to a new demand from cryptocurrency holders who might want to buy real estate with their ever-increasing cryptocurrency savings. A payment can be executed through a cryptocurrency payment platform such as BitPay. According to BitPay CEO Stephen Pair, the transaction "can happen in minutes from anywhere in the world with the speed of sending an email" [60].

Bitcoin is gaining growing worldwide acceptance as an alternative to traditional currency, and its use has some potential to facilitate property transaction. However, property pricing is seen to be a bold move due to Bitcoin's extreme volatility.

2.3.2 Artificial Intelligence Helping with Lease Abstraction

European firm Leverton has developed AI-based software that helps to make lease abstraction cheaper and faster. The Leverton platform uses deep learning to scan through a lease and extract the necessary data, allowing the partial automation of lease abstraction and lease processing with a 50%-70% time saving. The benefits, however, go beyond pure efficiency. The essential idea is to transform unstructured data to structured data that can be fed to property management or lease administration systems, and subsequently analysed to unlock a deeper understanding of the lease exposure [RB].

Richard Belgrave, Leverton's Head of Europe, explained that his company sees its solution as a "digital bridge in between documents and data." As a document is processed, a permanent link is created between extracted information and the raw digitised data source, making abstraction more transparent and giving more confidence to users.

Another advantage of Leverton's platform is that in-built AI enables constant improvement of abstraction results. Every user of the platform is contributing to the algorithm's learning, and in turn every user is benefiting from the resulting improved accuracy. Such an approach allows clients to effectively use the platform regardless of the number of leases they want to process, providing that their documents – and the fields to be abstracted - do not substantially deviate from the norm (for instance, the algorithm must be trained specifically to work with different languages) [RB].

While AI algorithms are being perfected, Leverton believes that the best implementation scenario is a platform adoption with additional quality control: the software is used to extract data and link it with a digital copy of the paper source, then a client or service provider team performs additional spot checks on extracted data. This approach has so far proved to work well, as clients continue to build-up their trust in new technology and new software [RB].

Today Leverton is working and partnering with a number of real estate organisations and envisions its platform developing further, possibly providing in-built analytics and expanding to deal with other types of legal documents. They also do not exclude the possibility that paper leases will soon be digitised, but consider their solution just as relevant for purely digital documents, being confident that the requirement to produce structured information from unstructured source data will remain.

Can Blockchain Transform the Commercial Leasing Progress?

One more possibility that is being widely debated in real estate industry is the use of blockchain and blockchain-based smart contracts to process lease transactions. Some property professionals suggest that such an application of blockchain technology can offer many benefits, including the removal of intermediaries from the lease transaction and the elimination of litigation between parties. Furthermore, leases will be recorded on blockchain and the need for lease management systems will thus disappear.

However, current limitations of blockchain platforms make realising this vision difficult:

- → *It is not clear what type of blockchain could enable a combination of all these benefits. Two major types of blockchain platforms exist: public or distributed (i.e. maintained with no central authority), and private (i.e. handled in a centralised way) [61]: please refer to Appendix for more details. Both types can help prevent the falsification of data. However, while public blockchains are practically immutable, private ones are less so, as they are 'at the mercy' of the organisation that handles them. Public blockchains, however, have an issue with privacy, allowing all users of the blockchain network to see all transactions handled by this blockchain. While full transparency is generally acceptable when we deal with property titles, it appears less so when we it comes to lease agreements. Blockchains can be designed to incorporate permissions to access certain information, but it would take us back to some degree of centralisation. A solution to this is likely to come as the next generation of distributed ledger technologies and platforms are developed.*

- → *Currently available blockchain technology cannot fully substitute for a property or lease management system, which typically include a wealth of additional functionality. Blockchain solutions, like Bitcoin, have a limited capacity to store data and no robust search functionality, so data is not easily accessible.*

- → *A smart contract is a piece of code and the way it works resembles a vending machine mechanism: when a certain condition is met (a payment is received) a predefined action is performed (a product is released). Though smart contracts can facilitate some standard parts of the leasing process (for instance, they are very good in handling multi-signature escrows [RL], or the stamp duty required for a lease in some countries [PC]), it is difficult to imagine how they can fully replace a sophisticated commercial lease that may include bespoke terms and guidelines on how parties must behave in a variety of situations [PC].*

- → *Smart contracts can automatically deal with certain situation when a party is breaching a contract, e.g. penalties can be automatically charged if a payment is not received by a defined date. But they cannot eliminate the possibility of litigation or the need for human involvement in the leasing process. Smart contracts by themselves cannot perform an end-of-tenancy inspection or decide what to do if any unexpected or ambiguous situation has occurred.*

Blockchain technology is still at a nascent stage and will no doubt evolve to overcome some of these limitations. At this later stage, it will be possible to more clearly assess whether commercial leasing represents a viable use case for blockchain in which it can deliver advantages that cannot so readily be achieved by other means.

In Fear of Disintermediation

Can blockchain and blockchain-based smart contracts lead to the elimination of intermediaries currently supporting the real estate industry?

Blockchain is yet to prove whether it can be applied to leasing, but it seems to offer great opportunities to improve the process of property title transfer. It will also have an impact through FinTech (e.g. through transaction processing, lending and crowdfunding platforms.). Ragnar Lifthrasir is confident that we will witness a wider adoption of Blockchain in the real estate industry within the next five years, that will result in more peer-to-peer transaction and thus decrease the need for third party involvement. However, Steve Weikal noted, that a similar claim was popular during the dot.com boom, but this eventually resulted in an increase in the number of property brokers, while internet technology was used to deliver a superior level of services.

> "Blockchain will make things faster, cheaper, smarter, but there will still be a need for humans to guide and be the interface with other humans"
>
> Steve Weikal

Overall it is questionable whether, in the short term, a much greater degree of disintermediation will occur in commercial real estate due to the complexity involved in large real estate transactions [PC, SW]. However, a combination of AI, Blockchain, and the IoT will change the role of agents and intermediaries, decreasing their involvement in certain types of real estate operations [PC] and augmenting their roles on others [CP]. Furthermore, according to Richard Belgrave, new technology solutions have the potential to facilitate some property operations, such that it will be cheaper and easier for real estate companies to perform them in-house than delegate to external agents. This could potentially lead to the reversal of the post-2008 outsourcing trend. Whether this will be realised will most likely depend on who will be quicker and more capable in the adoption of new solutions and thus release the benefits of new technologies – real estate companies on their own or service providers. Either way, overall this should represent a win for property companies.

2.3.3 The IoT and AI Improving Building Operations

As mentioned in the previous section, a combination AI and the IoT provides many opportunities to improve occupancy, facility and energy management, and to optimise performance through analysing real-time data and acting upon the results.

A good example of what IoT and AI can do with real estate assets has been recently demonstrated by Google, which used its Deep Mind AI to track and control more than 120 different variables in their data centres to work out the most efficient cooling method. The result is a 40% reduction in electricity needs for cooling with 15% overall power savings, which for Google translates into approximately a 660 GWh saving per year [62].

To unlock the power of the IoT, it is recommended to equip a building with an IoT platform that:

- → Supports connectivity of IoT devices, allowing them to communicate with each other despite possible differences in data protocols and formats used by each device
- → Helps asset tracking and ensures visibility of devices (and their performance) within the IoT network
- → Stores data collection from IoT devices
- → Runs analysis on collected data to understand building operations
- → Performs management actions on the basis of rule-based triggers [63]

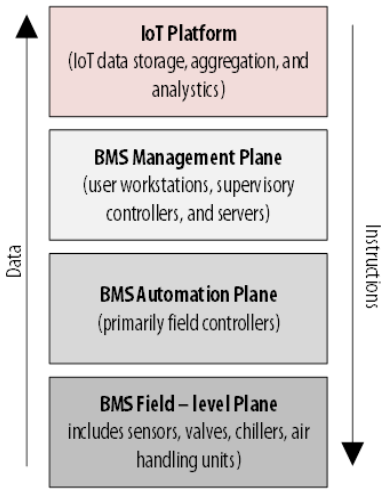

Figure 3: IoT Platform and BMS layers architecture.

Source: developed from [60]

For greater visibility, automation and building control, an IoT platform can be integrated within BMS systems forming an additional layer on top of traditional management, automation and field-level panes (see Figure 3) [64].

IoT platforms are themselves an emerging technology that is still very much at the development stage, and which is predicted to achieve wider adoption in the next 2-5 years [1]. Today many vendors, including IBM (Watson IoT Platform), Microsoft (Azure IoT Suite), KAA, Amazon (Web Services AWS IoT), Cisco (Kinetic), PTC (ThingWorx), are moving beyond their first prototypes and now beginning to offer a second generation of more robust IoT Platforms solutions. Such pre-built solutions have the potential to greatly facilitate adoption of the IoT and allow real estate players to benefit from IoT platform providers' technology expertise.

According to Dr. Claire Penny, modern IoT Platforms such as IBM Watson, use deep learning algorithms to enable a deeper understanding of an asset, the rapid identification of pain points and proactive action. Such algorithms can track:

- → How the building behaves and respond to a certain level of occupancy or particular weather conditions
- → Occupancy patterns and what factors affect them
- → How water, gas and electricity are used within a building and how they can be optimised
- → What building equipment is not performing correctly, has a risk of failure and/or needs to be replaced

AI models incorporated in such IoT platforms are pre-trained to handle a range of scenarios and can be applied across a variety of assets with minimal additional training [CP].

The key advice from Dr. Penny when it comes to implementing IoT in a building is to clearly define your purpose (for example, whether you are planning to find opportunities to save money or increase your income streams) and settle on a single open-source IoT platform

that can handle a variety of data sources. Choosing multiple platforms would add unnecessary integration burdens and complications, notably when handling platform upgrades.

2.3.4 Towards Smarter Design, Construction and Maintenance

Looking at the potential application of emerging technologies to design and construction, it can be argued that the greatest value will be unlocked by improving the way real estate assets are delivered and maintained.

Virtual Reality can open a new way of interacting with "virtual" building (e.g. via BIM models), allowing designers to experience and better test the design before it is built, and then to virtually track the building process in a more interactive way. Mixed Reality can be used on site to create an overlay of information from drawings, change orders and other documents making site inspections and snagging much more seamless [TK]. Enhanced Reality can be used during the in-use phase to facilitate maintenance operations.

WeWork Uses a Combination of the Internet of Things and AI to Better Understand Space Usage and Improve Design.

WeWork is actively using real-time data and AI to build a deeper understanding of how space is occupied by its tenants, and thus improve the design of new properties.

One example is WeWork's development of methods to predict how often meeting rooms are used and hence determine the optimum number and size of meeting rooms in an office space. To answer these questions, WeWork's research team gathered data on 800 meeting rooms of different types and from different locations, and then used machine learning to search for patterns and make predictions.

Data fed to an AI neural network included information about the layouts of various WeWork locations, including the numbers of offices, their size, the number of meeting rooms and facilities they have, as well as the frequency of meeting room use in recent months. Over time, the network established a relationship between the layout and meeting rooms usage and was able to forecast how certain types of meeting rooms will be used in a given layout before starting construction. WeWork estimates that its AI is 40% more accurate than human designers in making such predictions, and the firm continues to train its neural network as more data are becoming available [65] .

Meanwhile, Josh Artus believes that the time is not at all far away when IoT- and AI-enabled drones and human-assisted drones will be covering more aspects of the building process. Drones will be used to provide construction oversight and security monitoring, deliver materials, and make measurements to facilitate the production of as-built drawings and they are already getting endorsed by the most proactive developers.

> "3D printing is coming – it's too good not to be used."
>
> Volker Buscher, Arup

Another big game-changer is 3D printing. While the first 3D-printed buildings have been produced in China and Dubai, experts believe that the greatest potential of 3D printing lies in producing bespoke parts, complex joints and elements required in construction or maintenance on demand and on site, at just a fraction of the costs and using less material than a traditional approach [VB].

Finally, blockchain technology can potentially be applied to better track the supply of construction materials or to maintain a history of suppliers or contractors who performed a specific piece of work, allowing greater transparency and supporting a higher-quality safety

audit [PC]. Furthermore, a number of initiatives, such as IOTA, aimed at applying distributed ledger technology to support the IoT, are currently in the works.

> 'If you have some sort of a public record to see who the supplier of faulty pipes was, and who they supply them to, you can instantly see what other buildings are at risk and act upon it.
>
> Paul Chen, RealFoundations

Volker Buscher agrees that the blockchain potential for construction appears to be high but notes that - unlike other technologies discussed is this paper - blockchain is not yet mature enough to determine how strong this use case will be. But it is worth keeping an eye on.

Overall, it is very likely that a combination of these technologies will allow a shorter construction timeline [VB, JA] and enable very substantial costs savings [JA]. The latter will depend on developers' balance between pursuing a cost-reduction strategy and focusing on delivering buildings that provide a better occupancy experience [JA].

2.3.5 Stronger Front-End Operations

A significant benefit of emerging technologies is the possibility to enhance the customer experience both directly - through the provision of superior front-end services - and indirectly, by enabling a better occupancy experience. The latter opportunities lie in the use of IoT and AI to create more responsive spaces and provide seamless maintenance services and have been already covered in this paper. The former are rooted in the use of VR, AI, and IoT to support a more engaging product presentation, a better understanding of customers, and faster transactions.

Virtual Reality applications can facilitate the sale of properties off-plan and over long distances through interactive video tours. The technology will realistically replicate walking through a property, as opposed to just watching a video. Potential customers will be able to take a tour of assets that are yet to be built, plan redesigns, and acquire a greater understanding of the overall development. [FJ]. This has the potential to eventually become a better and cheaper alternative to traditional, physical marketing suites.

AI-supported platforms will help find customers but are likely to be more applicable while dealing with private buyers and tenants, rather than large corporations. The way agents market spaces will become more visual as AI image recognition will be used to facilitate property searches. Data from social networks can also be used to analyse and track potential customers and deliver targeted advertising, as well as to build customer profiles [TK]. Furthermore, the IoT is expected to play a role in sales through the data that it gathers. Such data can become a main factor in deciding on the leasing or sale terms and negotiations.

Altogether, through transparency, efficiency, and a better understanding of customer preferences delivered by these emerging technologies, the length of the lease and sale negotiations processes could be streamlined, decreasing the time that buildings remain unoccupied.

2.3.6 Better Informed Strategy and Decision-Making

One of the most important implications of emerging technologies is a change in how property businesses are managed and how their strategic direction is defined. If opportunities delivered by new technologies are leveraged, decision-making can be grounded in more accurate and real-time data, enabling more effective management and helping to stay attuned and responsive to both external and internal change. Furthermore, AI-supported analytics will allow a deeper understanding of cause-and-effect relationships and more accurate forecasting.

The emerging technologies' capabilities to support the enterprise strategy place a heavier emphasis on the importance of having access to high-quality data and analytics within a business. Consequently, attention should be paid to building and maintaining an Information Model tailored to the specific needs of every business.

An Information Model, that forms part of RealFoundations' proprietary methodology, defines a formalised information management structure within an enterprise, outlining rules, operations, and relationships between the sourcing, processing, and delivery of data. It extends beyond and is distinct from the technology used to support it, and includes the following components:

- → **Controls Environment** that includes processes to create and use information and manage data quality risk
- → **Information Governance** that links information to the mission of an organisation, and determines and maintains the meaning of data and data standards
- → **Business Measures** that outline common organisational metrics that must be supported by data
- → **Data Model** that defines data required by the business, where it is created, stored, and altered
- → **Technology Map** that tracks applications used to maintain business operations and their interactions with each other
- → **Data Movement** that encompasses internal and external data flows
- → **Information Suppliers** that include details on information providers and mechanisms to monitor and improve their information supply.

The Information Model forms a core component of the business' Operating Model. By design it should be aligned with the business' Functional Model (describing the work done by or for an enterprise) and Sourcing Model (describing where and by whom the work is performed), to support strategy and enable continuous improvement.

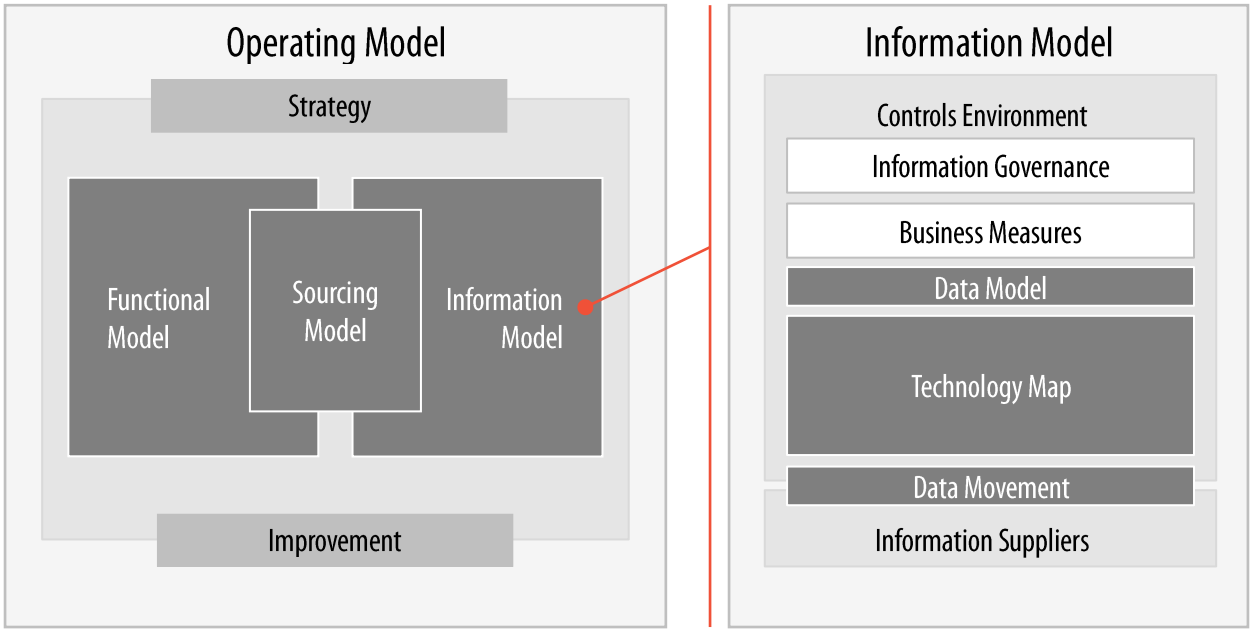

Image 1: RealFoundations' proprietary model supporting the Real Estate Enterprise Strategy. Source: http://www.realfoundations.net/howweengage/#how-we-engage

Suggested Approach

3. Suggested Approach

As emerging technologies bring a new wave of change into the real estate industry, a question arises as to how the enabled opportunities can be leveraged, and threats mitigated. Although specific strategies to embrace these emerging disruptors will vary between different businesses, this chapter introduces a five-step approach to start harnessing their power:

- → **Beware of the Hype:** develop a good understanding of emerging technologies
- → **Choose Your Power:** select a combination of technologies that work and add specific value to your business
- → **Gather Your Allies:** build partnerships
- → **Know Your Competitors:** watch out for the competition from within and outside the industry
- → **Use Your Power Wisely:** understand the responsibilities that come when using these technologies

3.1 Step 1: Beware of the Hype

The first step towards making emerging technologies work is to develop a deeper understanding of what these technologies are, their present limitations, where they are in their development and where they are heading, what their possible applications are, and how they can be relevant to the business. This implies acquiring a degree of technology knowledge personally and ensuring that a deeper knowledge resides or is easily accessible within the business. Minding the paramount role of technology for business competitiveness, appointing a Chief Technology Officer will become mandatory for every large enterprise.

Having technology expertise within the organisation will help spot new opportunities and reduce the chances of being caught off-guard by the exponential growth of emerging technologies or misled by the hype surrounding them. The "Six Ds of Exponentials" and "Hype Cycle" models discussed below are useful in understanding these phenomena.

Six Ds of Exponentials

The deceptive pattern of the evolution of digital technologies is comprehensively described by the 'Six Ds of Exponentials' framework developed by Peter H. Diamandis to illustrate the chain reaction of information technologies' technological progression [66].

The 'Six Ds of Exponentials' include 6 stages:

1. **Digitalisation:** When a technology becomes digital, its growth rate and cost-performance improvement "hops on an exponential curve" as it profits from the advances of previous generations of information technologies and can be much more easily spread and reproduced.

2. **Deception:** At the beginning of the exponential curve, growth is very slow and hard to distinguish from a linear increase. Predictions based on exponential rate of improvement appear improbable and even experts fall into a trap, basing their forecasts on the assumption that the speed of technological advancement will remain constant over time.

   Thus, in 1990 critics predicted that with the then-current speed of genome scanning, it would take thousands of years to complete a scan of a human genome – a task that eventually took only 15 years to accomplish [17]. A much more recent case that caused a stir in 2017 is solar energy. Despite the warning that solar energy growth at 1% a year back in 2016 was only 7 doublings away from 100% growth, voiced by Ray Kurzweil, the International Energy Agency (IEA) continues to linearly adjust its solar power growth predictions, ignoring an evident exponential trend (see Figure 4) [67].

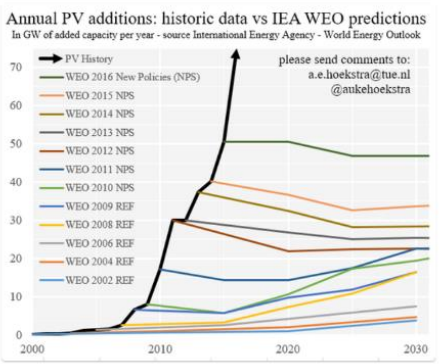

Figure 4: Annual PV additions: historic vs IEA WEO predictions

Source: [67]

3. **Disruption:** Disruption follows deception. Markets and industries are transformed or destroyed, and new ones are created. Traditional market players who miss the exponential trend and base their business strategies on linear growth assumptions struggle to retain their competitive position.

4. **Demonetisation:** As disruption unfolds, traditional income streams are eliminated by new business models.

5. **Dematerialisation:** A generation of radically new products becomes available. Old products swiftly become obsolete as demand for them disappears.

6. **Democratisation:** Technology enables dramatic decreases in the costs of fulfilling the same business and personal needs. What previously was reserved for a select few, is now available to a wide audience.

A classic example of the Six Ds is the Kodak story. When the company failed to recognise the exponentially evolving growth of digital photography, its major income stream vanished as people stopped buying film (demonetisation), the demand for their core product – cameras – drastically decreased as digital cameras became an integral part of smartphones (dematerialisation), and their overall business model built on the idea of people paying to share their memories through taking and printing photos completely lost its relevance as photo-sharing websites and social networks made image sharing easy, fast, and free (democratisation) [66].

Gartner's Hype Cycle Curve

A crucial takeaway from the Six Ds model is the importance of not being deceived by the slow growth of emerging technologies at the nascent stage of their development. The Garner Hype Cycle curve is a useful tool to understand and track new technologies as they remain within the deception stage.

Before a technology achieves widespread adoption, it goes through a so-called hype cycle (see Figure 5).

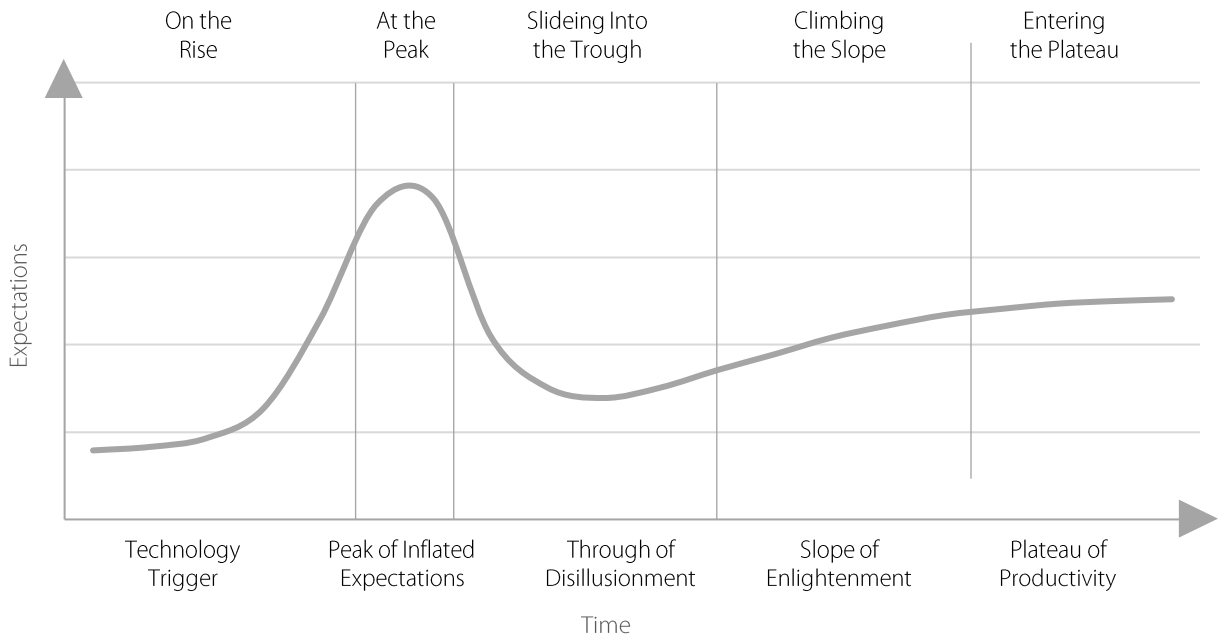

Figure 5: Gartner's Hype Cycle Curve. Source: https://en.wikipedia.org/wiki/Hype_cycle#/media/File:Hype-Cycle-General.png

As the first generation of products emerge out of R&D labs, a media frenzy begins. At first, everyone is excited about the new possibilities that a technology offers, but slowly the mood changes. The technology does not seem to progress fast enough; problems emerge; people and experts begin to think that the technology is a fad. But in fact, these are stages that it undergoes just before its wider adoption.

Every year in July, Gartner publishes its Hype Cycle for Emerging Technologies Report. This report analyses some 2,000 emerging technologies to compile a set of technologies that have the greatest potential to disrupt industries in the next 10 years. The current state of the selected technologies (their maturity, rate of adoption, potential applications) is then explored in more detail. As a result, they are placed on the Hype Cycle curve with a prediction of how many years they are from the plateau of productivity – the high-growth adoption phase when 20%-30% of the potential audience has embraced the innovation. Although Gartner does not always predict technology evolution with 100% accuracy, its report provides a good indication of where a technology is in its development. In Gartner's latest Hype Cycle published in July 2017, AI technologies – Machine and Deep Learning, Blockchain, IoT Platforms, Commercial Drones (UAV) - are all at the top of their hype curve. This is a sign to be careful about what you read in the media as it is flooded by controversial, and often inflated, predictions, and to be vigilant as these technologies move closer to their wider adoption stage.

3.2 Step 2: Choose Your Power

Armed with a deeper understanding of emerging technologies and the possibilities they offer, organisations should choose ones that hold the best value promise.

Volker Buscher suggests looking at improvements that technologies can deliver in a systematic way, exploring not only one technology but their different combinations and evaluating how their implementation can support a business mission and drive strategy. It is important to define how technologies can work to enhance a business: whether they are adopted to improve brand attractiveness to tenants or investors, or to decrease costs by optimising asset performance, or to shorten the time between starting a project and generating revenue [VB]. All these are valid opportunities, but emphasis is placed on different technologies to realise them.

Overall, early adoption of emerging technologies can bring a significant competitive advantage, but also can be expensive and risky. A recommended approach is to look at the smallest amount of technology that can be used, choose a specific product and test it locally, compare the outcome to traditional tools used within the business, and then diffuse it across the portfolio only if the experiment has been successful [JA, FJ, SW].

When thinking about using technology to enhance user experience within an asset, Josh Artus encourages looking at a building like a website. Thus, web platforms providers have a very clear understanding of why people visit their website, what pages they visit, what content sparks more interest and what content is ignored. They then use this data to improve their services and adjust their design [JA]. A building structure is of course more rigid and difficult to adjust than that of a website, but this mindset (supported by AI and IoT capabilities) can help spot business opportunities and deliver the right level of infrastructure.

> "A building is a place where people come to perform a function . . . Think: where are the business opportunities? Then look at what level of infrastructure is needed. What type of services can be added?"

> "But don't go down the unnecessarily smart route, try to look at the least amount of technology that you can use. Having eye recognition to get into a basic office is, probably, not necessary"
>
> Josh Artus, the Centric Lab

Within RealFoundations, we use the concept of an Operating Model to depict and analyse the interaction between technology and business functions. The use of such models supports a systematic approach to designing or reviewing all parts of the business and supporting technical solutions, and thus ensures a strong match between business needs and implemented technologies.

3.3 Step 3: Gather Your Allies

Innovations introduced directly to the business, as part of the everyday processes typically fail [68]. It is often more effective to innovate "at the borders" of an organisation. One way to do this is to form a partnership with a technology firm.

Partnerships bring many benefits:

- → They can be fluid, allowing flexibility of arrangements and quick to dissolve if unsuccessful
- → They provide instant access to new capabilities, creating a knowledge and skills exchange that fuel innovation
- → They allow the sharing of expenses and investment risks

To build a successful partnership it is crucial to allocate an adequate budget and ensure that the partners understand each other's business models and potential risks. This is especially relevant when working with start-ups that have limited resources, unstable cashflow, and

function differently from large corporations. Therefore, it is important to be reasonable with demands and ensure that they are not suffocated by paperwork and micromanagement. A good rule of thumb is that a project team should have balanced representation from both partners. Finally, it is important to be clear of what the contribution of each party is to the partnership and how it is of benefit to the other partner – for instance, operational data can be a valuable resource for a technology firm.

Another approach, which in the past year has proved popular with service providers and other large real estate players, is nurturing innovations from the earlier stages by launching, or partnering with, PropTech-focused start-up incubators and accelerators. Firms that seem to be interested in this route include Hines, British Land, CBRE, Cushman [6], Starwood and Skanska.

3.4 Step 4: Know Your Competitors

> "Disruption flows from agile, innovative competitors who, by assessing global digital platforms for research, development, marketing, sales, and distribution, can overtake well-established incumbents faster than ever by improving the quality, speed or price at which they delivery value. This is the reason why many business leaders consider their biggest threat to be competitors that are not yet regarded as such."
>
> Klaus Schwab, Founder and Executive Chairman, World Economic Forum

While arranging partnerships, it is important to watch out for competitors, who are likely to come not only from within but also from outside the real estate industry. For example, Google is getting ever more serious about building a smart city in Toronto, while Bill Gates recently announced a similar initiative near Phoenix, Arizona [69]. In the meanwhile, Silicon Valley is starting to invest heavily in disrupting construction, [70] also exploring their own radical urban concepts like start-up cities floating outside national borders that are being tested by the Seasteading Institute [71]. This adds to the Amazon and Alibaba acquisition of physical retail portfolios and the rapid global growth of relatively new incumbents WeWork and AirBnB. The latter two have recently joined forces to acquire a larger slice of the business trip market through adding an option to rent a desk in addition to accommodation [72].

A question to ask here is: can leading technology companies use their technology expertise in AI, IoT, Robotics etc. to manage property more efficiently and delivery better services than traditional real estate players? An answer we received from the majority of the interviewed experts is that yes, they can!

But it is not enough only to think about new industry players. It also important to think in terms of new products and new business models. How can technology make an asset obsolete or eliminate the usual income streams? How can it impact the relevance of a space? How can a virtual shopping experience compete with that of a traditional mall?

It is important to note that it is competition from outside the industry - from both new incumbents possessing superior technological skills and capital, and from new products and business models - that is likely to drive change and the adoption of emerging technologies in the real estate industry [JA]. This is why traditional real estate players, who have generally been slow to adopt and use digital technologies to their advantage, can no longer afford to ignore them.

3.5 Step 5: Understand New Responsibilities

Finally, using new technologies brings new responsibilities that cannot be ignored. One of them is cybersecurity.

In 2017 alone we witnessed a number of large scale cyberattacks that had a disastrous impact on their victims. For example, WannaCry ransomware affected hundreds of thousands of targets worldwide, including public utilities and large corporations, the UK National Health

Service among them. Meanwhile, smaller-scale cyber-attacks are a daily occurrence. As the real estate industry and its assets are becoming increasingly digitised and building control is delegated to digital systems, the importance of cybersecurity is hard to overstate.

Different types of cyberattacks exist:

- → Attacks on system confidentiality – aimed at stealing and releasing information
- → Attacks on system availability – aimed at bringing the network down
- → Attacks on system integrity – aimed at affecting operations of hardware and real-world systems

For real estate, these translate into multiple levels of cybersecurity that must be considered:

- → Cybersecurity of data – as data is no longer fragmented but aggregated at a much larger scale, stealing data may provide hackers with much more valuable insights than hitherto on a real estate business, portfolio, and asset operations
- → Cybersecurity of building control and building equipment that has any kind of power (battery, electricity, renewable) attached to it [VB]. The purpose of such a cyberattack may not necessarily be related to taking control over the building, but also to hijacking computer power that can be used to support malicious activities or, even, mine crypto currencies
- → Cybersecurity of networks that support connectivity within the building

Dr. Penny outlined that ensuring the cybersecurity of assets is a massive challenge and should not be an afterthought, but be taken very seriously from the outset. It is also an issue that needs to be at the top of the agenda for all members of the supply chain (e.g. building owners, IoT platforms, BMS, and equipment providers). Overall, cybersecurity is predicted to grow into a major industry on its own right: the global cybersecurity market is predicted to be worth more than $230 billion by 2022 [73] and it is anticipated that a cybersecurity officer will be an important figure in any large corporation [74].

In addition to keeping building infrastructure and data safe from cyberattack, it will be crucial to maintain a clear understanding of what data is being collected and how it is being used across a business. The EU's new General Data Protection Regulation ("GDPR") is coming into force in May 2018 and will introduce much stricter data policies, placing much more responsibility on virtually all real estate businesses.

Finally, emerging technologies are likely to bring a substantially higher level of transparency. Consequently, assets' integration within the community, their environmental impact, and their impact on the city infrastructure will gain greater visibility. For example, vu.city is a platform that creates very accurate (to within 15cm) digital 3D – soon to be VR - models of cities. Such models are connected to live data and street cameras and include multiple layers of information, such as noise, nitrogen dioxide, public transport access data, protective viewing corridors, etc. Although vu.city is targeted at developers and urban planners, it is easy to imagine how a similar platform can demonstrate how a building is performing within the wider city network. For "good" assets, this can become an additional selling point, for others it may become a vulnerability.

Conclusions

Conclusions

Historically, technology has played an important role in transforming how our society operates and has altered our living and working patterns. This inevitably affects the way we use and occupy space and shapes real estate demand.

In addition to this external, indirect influence, in the last few decades digital technologies have had an impact on the real estate industry from within, by enhancing the way assets are managed and delivered. This impact has, however, been restricted due to the complexity of the industry and the inherent limitations of property assets.

As a new generation of disruptive digital technologies emerges, the question arises as to whether real estate industry players should prepare for a more profound change. To answer this question, within the scope of this research we focused on several emerging technologies – including Artificial Intelligence, Blockchain, the Internet of Things, 3D Printing, Virtual, Mixed and Augmented Realities – and explored the ways they are likely to affect the European Listed real estate industry in the next 5 to 7 years (up to 2025).

Our analysis concluded that these new technologies have potential to support trends that are already shaping real estate demand and that have been triggered by the Digital Revolution, such as:

- → The move towards flexible, connected, collaborative and at the same time easily-personalised workspace, remote working, and better occupancy forecasting
- → The rise of e-commerce, its establishment as a core function of most major retail businesses and the consequent shift of physical retail functions towards experience, display, and delivery
- → Increasing demand for industrial retail space, coupled with an increasing sophistication of industrial assets
- → Overall real estate fracking, i.e. the reconfiguration of space to allow extraction of greater value, and the use of space at levels closer to its high capacity

As a result of these trends, it is likely to become more difficult to maintain historical levels of income from traditional space on long-term leases.

Furthermore, the list of parameters determining the value of real estate is likely to be extended to incorporate factors such as digital infrastructure, building design flexibility, transparency and cybersecurity, as well as new sources of revenue.

On the operational side, technology presents opportunities to increase the efficiency of key property management functions and asset delivery, offer superior customer focus, and decide the strategic direction of a business on the basis of better quality and real-time data.

As competition within the industry gains new dimensions and real estate players prepare to compete with products, players, and business models with which they have never had to cope before, leveraging these opportunities to enhance operations and differentiate assets will be paramount to maintaining the competitiveness of any property business.

To begin harnessing the power of emerging technologies, we outlined a five-step approach:

- → **Beware of the Hype:** develop a good understanding of emerging technologies
- → **Choose Your Power:** select a combination of technologies that work and add specific value to your business
- → **Gather Your Allies:** build partnerships
- → **Know Your Competitors:** track the competition from both within and outside the industry
- → **Use Your Power Wisely:** understand the responsibilities that arise when using these technologies

This approach is not limited to a particular type of real estate business: neither is it limited to the five technologies within the scope of this paper. In essence, it underscores the importance of building an internal organisational understanding of new technologies, recognising the threats and opportunities they offer, and acting upon them proactively.

As an organisation, RealFoundations is constantly tracking this rapidly-evolving field, and is committed to the exploration of change and the possibilities that emerging technologies will bring to the real estate space. We hope that this paper provides the reader with an interesting, valuable and holistic overview of the changes coming to our industry. We are convinced that this topic cannot be ignored, and we look forward to being part of the continuing dialogue.

Appendix

Appendix

This appendix provides a comprehensive overview of technologies discussed in the paper.

Artificial Intelligence

Artificial Intelligence (AI) is a branch of computer science that aims to simulate an intelligent behaviour in machines. It is predicted that the evolution of AI will undergo the following stages:

- → **Stage 1**: Artificial Intelligence – when "intelligent agents" will be able to perform a specific function better than humans (also called "Narrow" or "Weak" AI)
- → **Stage 2**: General Intelligence – when intelligent agents will be able to display (at least) human-level intelligence that is not limited to a highly specific set of tasks and replace humans at many jobs. (also called "Deep" or "Broad" AI)
- → **Stage 3**: Super Intelligence or "Singularity" – when intelligent agents will be more intelligent than humans in all regards and, according to different technology thinkers and experts, may either pose a threat to humanity or else bring humanity to a drastically new level of prosperity [75]

At present, Artificial Intelligence is at the first stage of this evolution. Multiple forms of Weak AI - including Machine and Deep Learning, Natural Language Processing, Image and Speech Recognition - are already widely used and are quickly becoming more and more advanced. AI is behind our search engines and behind the spam filters in our inbox; it defines which content you see in your Facebook news feed; and it responds to you when you talk to a voice-controlled intelligent assistant, be it Apple's Siri, Google Now, Microsoft Cortana, or Amazon's Alexa.

To be classified as a form of Weak AI, the behaviour of a machine should meet the following criteria [75]:

- → Be goal-oriented, e.g. have a defined objective that it needs to achieve
- → Be able to self-adapt, e.g. capable of improving its performance over time without human intervention

The second of these properties sets AI technologies apart from traditional computer programming. This difference can be illustrated by the following simplified drawing:

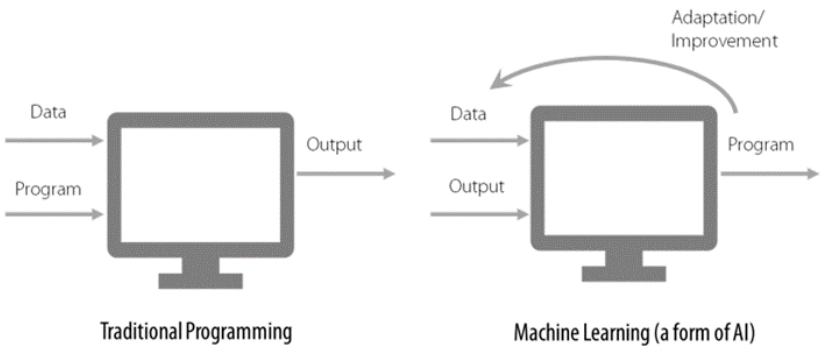

Image 2: Simplified Machine Learning concept. Source [76]

With traditional programming, one would need to write or install a program on a personal computer and then input data. This data would be processed according to the logic defined in the program code and, if the obtained result was incorrect or not satisfactory, the program code would have to be modified manually to correct the output.

With Machine Learning – one of the most common forms of AI that is used as an example – one would use a data set containing input and, often, output data to produce an algorithm. This algorithm would likely be more sophisticated than any manually-written program and would become more and more complex and accurate as it is fed with more and more data [76]. In AI, this process is commonly referred as 'training' and the resulting algorithm can be used for forecasting (e.g. when output and input data are used) or for describing hidden patterns in the provided data set (when an unlabelled set of data is provided).

While other subfields of weak AI - Speech and Image Recognition, and Natural Language Processing – are pretty much self-explanatory, some more attention should be given to Deep Learning – the most recent AI technology that has enhanced previous AI techniques and is fuelling the AI boom of today [77].

Deep Learning is a subset of Machine Learning, and is inspired by the inner working of our brains, which process information by forming connections between neurons. Very large data sets and a new generation of hardware are used to train Deep Neural Networks (DNN). During this process a machine gradually creates multiple hidden layers of connected nodes to eventually connect input and output data (see Image 3 below). For example, analysing a large selection of Instagram images (input data) with tags assigned by Instagram users (output data), a neural network can learn to identify what is depicted in the image, although a certain degree of cleansing would be required to remove incorrect tags. This method can address previously-unsolvable data problems with very high levels of accuracy and granularity [77].

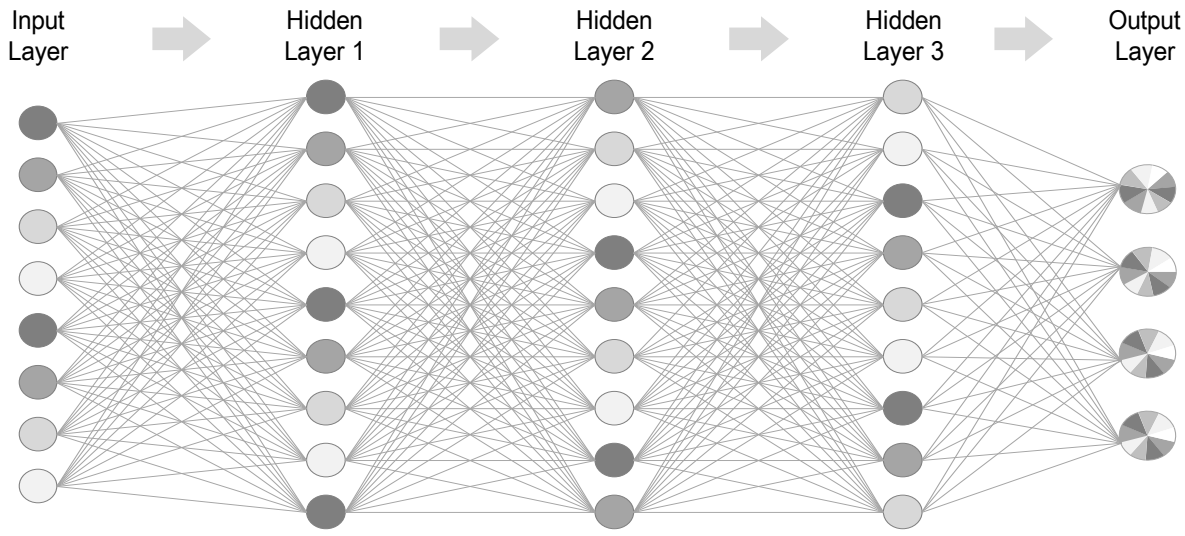

Image 3: Deep Learning Network. Developed from: http://neuralnetworksanddeeplearning.com/

Applications of deep learning are widespread. It is responsible for the latest major improvements in speech, audio, and image recognition and is particularly good in searching for anomalies, diagnostics and dealing with problems where time sequences matter. It is already used, for example, to diagnose illnesses [78], to track populations of wild animals [79] and to help understand and interact with customers and win political campaigns [80]. Leading AI adoption are those industries that were first to embrace digital technologies, such as high-tech and telecommunication, automotive and assembly, and financial services [81].

What is coming next? According to Gartner we should expect Weak AI technologies – Deep and Machine Learning - to reach wide adoption in 2 to 5 years [1]. At this point they are likely to penetrate new industries and drive the next generations of technologies, such as Cognitive Computing, Autonomous Vehicles, Commercial UAV (Commercial Drones), Virtual Assistants, Smart Robots, and Smart

Workspace. As for moving to the next stage of Artificial Intelligence evolution, this is unlikely to happen within the next 10 years [1], since little progress has yet been made in the delivery of General Intelligence, and the idea remains purely conceptual.

Blockchain

There are two major approaches to how a system can be designed: centralised and distributed. In centralised systems, all components are directly connected to one core component that executes control and coordination. In distributed systems, there is no core element. Instead, all components are directly or indirectly connected to all other components, forming a network that is not administered in a centralised way. One example of distributed systems is peer-to-peer networks, which encompass individual computers (also called 'nodes') that make their resources, including data storage, processing power, internet bandwidth) available for all members of the system. All nodes in such networks have equal rights and roles (though might contribute a different amount of resource), and all nodes are both suppliers and consumers of joint resources [61]. File and content sharing networks, often used for free music and movie streaming (e.g. BitTorrent, µTorrent, eMule etc.) operate this way.

A distributed architecture can bring significant benefits to software systems, including:

- → Higher computing power – the computing power of all connected computers, rather than one controlling node, is used to maintain the system.
- → Cost spread - there is no need to maintain a centralised computer and servers to manage the network.
- → Higher reliability - distributed networks do not have a failure point - there is no single computer, switch-off bottom, database, or user that can bring a system down.
- → The ability to grow naturally by adding new nodes [61].

However, these benefits are hard to realise. Members of distributed systems must coordinate their work and manage their communication: this requires some effort and computing power, which leads to a higher network complexity. There is also a bigger issue of security as untrustworthy nodes may attempt to misuse the system. That is why, despite possible advantages, distributed systems are rarely used by businesses and public institutions.

Blockchain represents a tool that enables integrity (e.g. data accuracy, reliable behaviour, security) in distributed systems that do not have any restriction on their participants [61]. The terms "blockchain" and "distributed ledger technology" are often used synonymously; however, new types of distributed ledger technologies, such as Hashgraph, have recently emerged.

Blockchain comprises a suite of technologies that include:

- → Blockchain data structure consisting of 'blocks' of records chained together; this can be visualised as a book where each page (block of records) is numbered and itself contains lines of numbered information, so it is easy to detect if some data has been removed.
- → Blockchain algorithm that contains instructions that determine which data is being recorded in the blockchain data structure.
- → Cryptographic and security technologies that support blockchain operations.

Although blockchain has various potential applications, today its most commonly explored use case relates to managing ownership. This can be the ownership of digital goods, including cryptocurrencies (such as Bitcoin, for which it was originally created), or the ownership of physical objects, such as real estate.

Today, ownership is managed by multi-billion-dollar industries that include banks, insurers, lawyers, courts, and through government-regulated ledgers that handle information on our most valued goods. Blockchain offers an alternative, stepping back from the traditional centralised way of ownership tracking towards a distributed approach:

- → Ownership of an object is tracked by keeping an ordered digital ledger (equivalent to a single blockchain data structure) that records the complete history of transactions related to this object (i.e. not only information relating to its present owner).
- → Instead of having one centrally-maintained ledger that might be damaged, lost or forged, multiple copies of such digital ledgers are stored on different computers across a distributed peer-to-peer network. Blockchain ledgers are immutable and transparent, so they cannot be tampered with by untrustworthy nodes.
- → When a new transaction related to the object has taken place, it is added to the ledger. A distributed network of so-called "miners" – independent individuals who support blockchain operations for a fee – run a blockchain algorithm to ensure that a new record is recorded correctly, and no "double spend" has occurred.

The mechanisms supporting the integrity of blockchain (i.e. blockchain algorithms, in-built security and cryptography) are complex and vary for different blockchain platforms. It is important to note, however, that the integrity of the original and still best-known platform – the Bitcoin blockchain platform, used to support Bitcoin crypto-currency since 2009 – has never been compromised. However, it does have limitations that can limit its usability and wider adoption [61], as follows:

- → Lack of privacy – distributed blockchains such as Bitcoin are fully transparent, anyone can join the network and see the whole history of any transaction.
- → The security model - blockchain identifies property owners through a cryptographic key associated with their account. Although the methods used to support blockchains are some of the best available, users who are responsible for handling their private keys often fail to ensure their own security. This is why we often hear news about lost or stolen Bitcoins.
- → Limited Scalability – cryptographic mechanisms used to ensure the integrity of blockchain were deliberately made complex to ensure the immutability of ledgers. This does, however, slow the processing speed and limits scalability.
- → High costs – running blockchain algorithms demands time, energy, computing power and is thus expensive. As a reference, according to recent research estimates [82], executing a Bitcoin transaction currently demands 5,000 times more energy than processing it with a Visa card.
- → Hidden centrality – as the number of users and the scale of transactions grow, Bitcoin blockchain algorithms are becoming increasingly complex, and ever more powerful hardware is required to support it. The costs of the hardware are becoming a barrier to entry to the network of miners: what was intended to be a large and diverse distributed group may become a small circle operating as an oligopoly.
- → Lack of flexibility and critical size – the immutability and distributed nature of blockchain makes system upgrades and bug-fixing complicated matters.
- → Data storage and accessibility – the amount of information that can be recorded on a blockchain is limited and search capabilities are not fully developed.

In an attempt to overcome these limitations and add new functionalities, new blockchain platforms and new types of blockchain are being developed. Ethereum, a distributed blockchain platform to rival Bitcoin, provides more flexibility, faster speeds, and an easier environment within which to build applications (such as smart contracts) on top of blockchains: however, it struggles to match Bitcoin's levels of security. Private (or "permissioned") blockchain platforms keep the blockchain data structure but move away from its distributed nature and transparency. Instead of being open to everyone, private blockchains are operated by a group of trusted participants who set up rules guiding their operations (e.g. who has access to the blockchain, what data is stored in the ledgers, what security protocols are

used, and how to decide if a transaction record put forward for inclusion in the database is accurate or not). There is also a new, emerging generation of blockchain and non-blockchain distributed ledger technologies, for example Hashgraph, EOS, TON, that are claimed to be technologically superior [83], but today are still not fully proven.

Despite these efforts, cryptocurrency remains the major current use case for blockchain. Another related blockchain application that is currently gaining more and more popularity is Initial Coin Offering – a mean of crowdfunding a new venture by issuing tokens that can be bought by project supporters. Furthermore, blockchain's ability to remove the need for centralised authority and associated intermediaries, and to build trust through transparency and immutable ledgers of historical records, generates a lot of hype and interest. As blockchains are agnostic to the types of data they can store, experts are now exploring blockchain applications across a variety of industries – for maintaining digital identities, payments, records management, voting, crowdfunding, lending, tax, IoT support, etc.

Overall, blockchain technology is at a very early stage in its development - according to Gartner [1], at least five years away from its wider adoption [1]– where it is hard to predict its further development both within and outside the cryptocurrency space. However, if it evolves to combine its major benefits with greater flexibility and scalability, it will become a powerful disruptor.

The Internet of Things

The Internet of Things ("IoT") can be defined as a network of smart physical objects with embedded technology that enables them to communicate, sense and interact with their internal states, each other and their external environment to produce data [84]. This data might include information on their condition, position, the state of their surrounding physical environment, and other attributes [85].

The number of such connected devices has been increasing exponentially since the appearance of the Internet in 1990, and is projected to reach 40-50 billion by 2020 [85], and 500 billion by 2030 because of the following three main drivers [84]:

- → The growing private use of IoT-enabled equipment, such as wearables (e.g. wrist bands and watches, clothing, glasses), smart control home appliances (e.g. smart TVs, smart fridges, security cameras), and sensors in our homes
- → The increasing use of IoT in transportation (e.g. internet-connected cars, and cars possessing a self-drive capability), and cities' infrastructure
- → The adoption of IoT by business, including the manufacturing, retail, healthcare, real estate and construction industries

There are multiple reasons why a window of opportunity for IoT is opening now. These include:

- → Cheaper costs of hardware (the cost of actuators and sensors has halved within the last decade)
- → A dramatic decrease in hardware size (to millimetre and nanometre levels) accompanied by an increase in their processing power
- → More affordable and pervasive connectivity
- → Availability of data storage and analysis tools, including Cloud, Big Data and AI technologies
- → Growing mass market awareness [63].

Being a connector between the physical and digital environments, the IoT has a wide variety of applications that include predictive maintenance of assets, tracking and improvement of supply chain efficiencies, various types of autonomous production, city infrastructure management, building security and many more. In fact, in 2015 MGI [86] analysed 150 IoT applications that may be widespread by 2025, concluding that by this date the total economic impact of the IoT will rise to some $4 to $11 trillion per year. More than a third of this value is likely to be generated in business-to-business settings, while overall business customers and consumers are likely to capture 90% of created value. This would make it one of the most disruptive technologies of our time.

The IoT is also likely to transform existing business models in many industries, including real estate, making businesses primarily data companies, rather than pure product suppliers. This will shift the power balance towards industry players who can better harness the value of data. On top of that, entirely new industries with business models built solely on IoT are likely to emerge [63].

There are, however, hurdles to overcome. To realise the IoT benefits, companies must build an appropriate infrastructure of connected and interoperable systems that allow data aggregation and analytics [86]. Various providers of IoT platforms are currently working to deliver this capability. Furthermore, various technical, legislative, and ethical aspects related to IoT privacy and security need to be addressed, while organisations need to acquire new internal competencies [86].

3D Printing

There are four major ways to make things -- i.e. four types of manufacturing. In *subtractive* manufacturing, a piece of raw material is shaped by removing/cutting excess material; in *forming* manufacturing, force is applied to raw material; in *casting*, raw material is turned into a liquid state and poured into a mould. The fourth type - additive manufacturing - starts with a figurative clean slate and gradually adds raw material in the required place and sequence, building an object "ground-up" [87].

3D printing is a form of additive manufacturing that is currently gaining increasing in popularity.

3D printing consists of the following steps [88]:

1. Creating a 3D virtual model of an object (usually done in CAD software)
2. Converting this model into a standard additive manufacturing file format i.e. in which it is getting "digitally sliced" into layers
3. Transferring the file into a computer connected to the 3D printing machine, and setting up the 3D printing machine
4. Building of the object, layer by layer, by the 3D printing machine
5. Finishing or additional processing (e.g. cleaning, polishing, painting etc.) if that is required [88]

In comparison to other manufacturing processes, 3D printing possesses numerous advantages:

- → It does not require extensive space and allows production to be moved closer to consumers, thus reducing or eliminating the need for shipment, storage and physical retailing. This enables multiple efficiencies, especially for complex production processes, such as construction where required components and fitting can be directly manufactured on site. Manufacturing an object on site is also very helpful when delivery is extremely complicated or disrupted, for example in disaster zones and in space [87].
- → The process of printing an object requires fewer resources, less tooling and less skilled labour. It is often quicker and cheaper, and produces less waste than traditional techniques.
- → A variety of raw materials, including plastics, metal, concrete, and soon biological tissues, can be used.
- → It can produce very complex objects that are difficult or impossible to produce with other manufacturing methods.
- → It allows easier and cheaper prototyping and customisation, as well as facilitating the production of goods on demand [88].

3D printing also encompasses many subfield technologies that promise a wide variety of possible applications and are at different stages of emergence. Such technologies encompass 3D Printed Wearables, 3D Printed Drugs, 3D Printing in Retail, 3D Printing of Dental Devices, Nanoscale 3D Printing, 3D Bioprinting for Life Science R&D, Macro 3D Printing and many others [89].

3D printing is already widely accessible to the general public. Providers such as 3D Hubs offer local 3D printing services to more than 1 billion people around the world [90] while some exciting examples of 3D printing include:

- → Creation of customised surgical implants, while 3D printed organs using a patient's own cells is a next step [91]

- → In construction, 3D printing has been used for a variety of tasks, from applying unconventional building materials such as soil and vegetable fibre [92] to 3D printing a whole building. While multiple Chinese developers have 3D-printed residential housing [93], the first 3D-printed office building was created in Dubai [94]
- → Space X is actively using 3D printing to create parts for its rockets [95]
- → Clothes and shoes producers use 3D Printing to create items from recycled materials [96]

According to recent EY predictions, in the next 3-4 years we will see multiple industries, including Manufacturing, Retail, Energy, Pharmaceutical, Logistics and Transport, increasingly using 3D printing to improve efficiency of production by up to 10%-20%. (The Construction industry was not included in this EY study.) [97].

Besides its wider adoption, 3D printing is heading toward producing more sophisticated objects with increasingly more complex materials and is projected to eventually move into 4D. This implies that an additional dimension will be added to the produced objects – time. In other words, products printed from smart materials will be capable of changing shape or properties over time in a pre-programmed manner in response to outside stimuli, such as temperature, light, humidity etc. This can endow objects with robot-like behaviour that would open new horizons of possibilities such as, for example, adjustable clothing, and medical implants, or water pipes that could adapt to ground changes [98]. However, these advances are likely at least a decade away.

Virtual, Mixed and Augmented Realities

Virtual, Mixed, and Augmented Realties represent a new type of interface, or a new way to interact with information. It is a good practice to distinguish in between Augmented, Virtual and Mixed Reality, though Augmented and Mixed Realities are often united under the "Augmented Reality" name.

Virtual Reality (VR) refers to a three-dimensional environment resembling real life, generated by computers, in which a user can experience total immersion and can manipulate virtual objects [99]. While wearing a VR headset, a user's visual environment is completely changed and he or she cannot see the immediate (real) environment; by contrast, Augmented and Mixed Realities add a new layer of virtual information to the real environment. Augmented Reality (AR) works through a smart device – a smartphone or tablet. A good example is the hit game Pokémon Go. Mixed Reality (MR) takes AR to the next level and seeks to achieve a more seamless fusion of physical and digital worlds, creating a new environment where real and virtual objects "co-exist and interact in real time" [100]. Just like Virtual Reality, Mixed Reality is currently designed to be experienced through a headset, of which Microsoft's HoloLens is perhaps the most widely-known example.

According to Gartner forecasts [1] , Virtual and Mixed Realities are set to reach wide adoption (20% of target users) in, respectively, 2-5 and 5-10 years' time. During the intervening period, according to our interviewee, IDC Research Director Francisco Jeronimo, we should expect these technologies to overcome their current constraints and become more seamless. That will mean better picture quality and field of view, better connectivity, longer battery life, less bulky headset devices, more diverse software and cheaper hardware. However, it is unlikely that in the next decade we will see VR and MR operating through contact lenses or through a brain-computer interface – predictions that are being made by some of the famous futurists [FJ]. These improvements will allow the application of VR and MR to a wide range of use cases that span far beyond gaming and entertainment industries, and include:

For Virtual Reality:

- → Training, especially training that is difficult to conduct in a physical environment: including medical training (e.g. virtual surgeries), military training, equipment operator training etc.
- → Design and architecture walk through and revision: including virtual property tours of both existing and as-yet unbuilt buildings

- → Engaging learning and cultural experiences: including virtual field trips to existing or digitally recreated historical and fictional locations
- → Immersion therapy and counselling for a variety of mental health conditions: including anxiety disorder, panic disorder, phobias, post-traumatic stress and obsessive-compulsive disorders [101]
- → Virtual showrooms: for retailers and their customers.

For Mixed Reality:

- → Streamlining multiple processes by removing the need to print information or review it on a separate device, since the necessary data or drawing can be projected through an MR interface. This can be especially useful in manufacturing, facilities management, construction, medicine, scientific research, as well as in daily life.
- → Product trial and fitting in retail: offering the possibility to see an image of a product (e.g. clothes, accessories, furniture) virtually overplayed on a real physical object or on a human.

These potential use cases are likely to drive growth of the VR and MR markets. Estimating the size of VR and MR market opportunities, IDC forecasts that between 2017 and 2021 the total cumulative spending on these technologies in Europe will reach $18 billion USD (on VR) and $64 billion (on MR). According to estimates, for VR, 5% of this spend will be in construction, and 9% in retail; for MR, 3% will be in construction and 13% in retail [102]. Goldman Sachs' report [103] predicts that by 2025 VR and MR will be used by 32 million users in retail, and 300,000 users in real estate. This number refers primarily to the use of VR for property walk-throughs by real estate agencies, and does not include VR and AR use in construction.

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