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**Future (Post-COVID) Digital, Smart and Sustainable Cities in the Wake of 6G: Digital Twins, Immersive Realities and New Urban Economies**

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# Future (Post-COVID) Digital, Smart and Sustainable Cities in the Wake of 6G: Digital Twins, Immersive Realities and New Urban Economies

**Abstract:** With the advance of 5G technologies by both academia and industry, 5G adoption is gaining widespread acceptance in numerous cities, prompting further innovations in Smart City technologies riding on the wave of the Internet of Things (IoT). However, even in its infancy stage, the speed of technological advancement is already highlighting the limitations of 5G, and its potentially short lifespan as new technologies are rendered obsolete faster. This fast-moving field is coupled with an ongoing and increasing funding into Research & Development (R&D) efforts by private corporations, to potentially commercialise on the surge in demand for 'smarter' cities'. This paper aims to chart the major directions and scope emerging dimensions inherent to 6G technology, including Digital Twins and Immersive Realities (XR) that, when applied to cities that are currently being equipped with digital infrastructural backbones, may have direct socio-economic impacts upon our lives while responding to the tenets of the Sustainable Development Goal 11. Looking at the future 6G technology this article considers the prospects of 6G, and its associated concepts, and its relations as they pertain to Future, Smart, Digital and Sustainable Cities.

**Keywords:** Smart Cities; Future Cities; 6G; 5G; Digital Twins; Economic Inclusivity; Wireless Technology; Digital Trade; Urban Policy; Urban Economy; SDG 11; COVID-19; Coronavirus

## 1. Introduction

The United Nations (UN) has concluded that 'cities are on the front line of coping with the pandemic and its lasting impacts. Across the globe, COVID-19 is threatening cities and communities, endangering not only public health, but also the economy and the fabric of society' (Nations, 2020).

Humans have long sought to develop cities and urban areas, historically, for social interaction, economic gain and relationship imperatives. This activity continues today enveloped in the current fascination in using technology to pursue the tangible and intangible transformation of cities, rendering them 'smarter' and enhancing their 'wealth'. Being driven by advances in technologies, this pursuit also belies the power of corporate Capitalism that is charting new ways to monitor and manage humans and their activities and values. Both are indelibly associated with the advent of technology, which was prompted by the (Western) Industrial Revolution from 1760s to 1830s, creating today's 'digital revolution'. Since then, cities have experienced subtle but increasing, transformations or sub-revolutions characterized by digital technology innovation changes, especially with the advent of the internet, of which cities have been observed to be amongst the main beneficiaries of these sub-revolutions. The benefits include increased communication capabilities within different platforms and increased transformations in manufacturing industries where the use of data has increased (Allam and Dhunny, 2019; Allam, 2020d). Economic activities in cities across geographies have also been transformed in terms of communication forms, new types of jobs, and new and different frontiers of engagement. As an example, in the financial sector, the introduction of cashless systems, is rapidly gaining ground. Cities have also benefitted from new possibilities like virtual preservation of cultural heritage (Di Giulio et al., 2019), new forms of transportation services including autonomous vehicles, use of sensors and cameras to control traffic, advances in CCTV monitoring and recognition systems, to name a few. Even the current COVID-19 phase is resulting in another sub-revolution forcing so much human activity to be shifted to digital platforms, and necessitating many digital illiterate to experience reformations in their lockdown social cultures and relationships (Allam et al., 2020a; Allam, 2020a; Allam, 2020b; Allam, 2020e).

With this backdrop, this article provides a scoping critique paper as to the future prospects, issues and discussions pertinent to use and application of 6G technology in our cities globally, and to raise some challenges and future research propositions. To achieve this, the paper explores how 6G technology may operate within the smart city ecosystem and offers some perspectives as to perceived potential impacts upon urban economies noting that already, with the 5G technology, some matters are covered.

## **2. Surveying the Digital Landscape Literature and Innovation Allied to 6G**

The numerous transformations in cities are underpinned by improvements in the Information and Communications Technology (ICT) sector, which is now regarded as being among the pillars of economic activities in cities. In addition, improvements in ICT are due to an acceleration from technologies like fibre optics and advances in carbon fibres and composites, leading to higher broadband speeds, and advancements in the wireless sector leading to higher and faster bandwidth capabilities for mobile network operators, who are the main providers of these services.

Where these transformations sit inside the UN's Sustainable Development Goals (SDGs) is relevant. These transformations are enabled inside two Goals. First, Goal 11 that seeks to 'make cities inclusive, safe, resilient and sustainable' that recognizes that 'cities and metropolitan areas are powerhouses of economic growth' contributing about 60% of global GDP whilst accounting for about 70% of global carbon emissions and over 60% of resource use. In their eyes, 'rapid urbanization is resulting in a growing number of slum dwellers, inadequate and overburdened infrastructure and services (such as waste collection and water and sanitation systems, roads and transport), worsening air pollution and unplanned urban sprawl'. Secondly, Goal 9 that aims to 'build resilient infrastructure, promote sustainable industrialization and foster innovation' seeking 'inclusive and sustainable industrialization, together with innovation and infrastructure' arguing that it can aid dynamic and competitive economic forces in generating employment and income. Such forces, in their eyes, can 'play a key role in introducing and promoting new technologies, facilitating international trade and enabling the efficient use of resources'. Additionally, 'in terms of communications infrastructure, more than half of the world's population is now online and almost the entire world population lives in an area covered by a mobile network; whereby in 2019, 96.5% were covered by at least a 2G network.

Through these transformations and policy aspirations, humans have had to rapidly navigate their services from the 2G, to 3G and 4G technologies, as well as deal with abbreviation and digital language changes.

1G evolved in Japan in 1979 being launched by Nippon Telegraph and Telephone (NTT) before being transferred across into North America in 1983 with Motorola's DynaTAC becoming one of the first 'mobile' phones to see widespread use stateside. While eagerly embraced, 1G technology was hampered by poor coverage, low sound quality, the lack of roaming support capacity, no compatibility between different systems, and a non-encrypted call system enabling anyone with a radio scanner to eavesdrop and intercept (**Gandotra and Jha, 2016**).

2G evolved out of Finland through the Global System for Mobile Communications (GSM) in 1991. In contrast to 1G, 2G calls could be encrypted, digital voice calls were significantly clearer with less static and background crackling, and for the first time users could send text messages (SMS), picture messages, and multimedia messages (MMS) on their phones. Although still possessing sluggish transfer speeds, operators passionately invested in new infrastructure such as mobile cell towers having a direct tangible and intangible effect upon our urban lives and fabric revolutionizing the business landscape and the nature of our communications forever (**Akhtar, 2005**).

3G, launched by NTT DoCoMo in Japan in 2001, enabled standardization of network protocol used by providers. Such facilitated data access by users from any location in the world due to the standardization of 'data packets' that scaffolded web connectivity enabling international roaming services (**Scharnhorst et al., 2006**).

4G evolved in Scandinavia, as the Long Term Evolution (LTE) 4G standard, enabling high-quality video streaming. But many users were still plagued by extensive reception blackspots. Another delimitation was that while shifting from 2G to 3G was as simple as switching SIM cards, for 4G mobile devices one needed a new design handset to support 4G necessitating the introduction of new 4G-ready handsets that underpinned Apple's exponential rise into the world's first trillion dollar company (**Pema, 2020**). 4G has proliferated the seductiveness of social media involving, for example, Facebook, TikTok, Twitter, LinkedIn, Weibo, Instagram, Snapchat, Pinterest, and Reddit (**Akhtar, 2005**).

5G is associated with the 'Internet of Things' (IoT), as coined by Kevin Ashton, a British technology pioneer who cofounded the Auto-ID Center at the Massachusetts Institute of Technology (MIT) in the 1990s. 5G's introduction in the mid-2000s was foreshadowed with Ashton's vision that would see billions of connected devices seamlessly sharing data across the globe all through an IoT in pocket devices (**Edler, 2019**). Such a tool envisaged multiple network-connected sensors that could assist anyone to accomplish everything from GPS navigation to photography to communication as well as use in 'edge devices' such as Wi-Fi-enabled appliances (e.g. fridges, washing machines, and cars) with providers selling its 'superior connectivity' as aiding human transformations in everything from banking to healthcare (e.g. remote surgeries, telemedicine and even remote vital sign monitoring). Its limitation is, unlike previous generations like 3G and 4G, is that one could scaffold off existing hard infrastructure. 5G is far more expensive and complicated to implement because it requires many more base stations than 4G and these must be positioned closer together, potentially leading to possible, as-yet unstudied, health complications and a sea of digital infrastructure installations being required (Di Ciaula, 2018; Kostoff et al., 2020), like the Australian NBN roll-out (Fisher et al., 2020). Such has prompted serious questions about its cost effectiveness and that the communication benefits may not be worth the monetary investment.

Today, driven by corporate market pressures, service providers are avidly still embracing 5G technology, where the supportive infrastructure are currently deployed in different cities across the world (**Oughton et al., 2019**). On this, already, countries like South Korea, China, the USA and the United Kingdom are leading with the greatest number of cities covered by 5G technologies, with many other countries eagerly catching. Globally, **Whitney (2020)** reports that by February 2020, there were more than 378 cities covered by 5G, with more expected in the near future.

As noted by Ashton, with 5G he envisaged it would be possible to connect to a larger number of digitally connected IoT devices (Kamel Boulos and Al-Shorbaji, 2014). Such a vision foreshadowed their extensive use by most cities under the transformative epithet of 'Smart Cities'. To most proponents a 'Smart City' assumes an urban settlement that actively engages in the use of different types of electronic IoT sensors to collect, use, manage and scenario model data. Such collecting, using, managing and scenario modelling activities are and can be used to innovatively and more (economically and human resource) efficiently manage assets, resources and services and thus can aid in fulfilling a city's sustainability operations and credentials. The scope of data harvesting includes information collected from citizens, devices, buildings and assets that can be numerically processed and digitally analyzed to monitor and manage infrastructure including traffic and transportation systems, power plants, utilities, water supply networks, waste, crime detection information systems, schools, libraries, hospitals, and other community services. While efficiencies are a core city governance aspiration, the technology can allow city management to engage directly, in real-time, with both their community and their city infrastructure whilst monitoring what is happening in their city and how the city is evolving (**Allam, 2019**). Like the evolutionary nature of its scope, the 'Smart Cities' term itself is still in its formative infancy lacking consistency in a definition across many relevant disciplines, and is therefore, open to many interpretations (**Allam and Newman, 2018; Allam, 2018**).

Notwithstanding the haziness of its definition, the demand of 'Smart City' related devices, and the inherent need to enable their increasing communication connectivity, is expected to increase. **Rong et al. (2020)** notes that as the number of devices continues to increase, the demand for ubiquitous communication is inevitable and this warrants the increasing popularity of 5G

technology. This popularity, and the lucrative IoT device market in turn, increases competitiveness between different ICT corporations, and governments, as they try to yield as much economic return from it as possible without conceding the parallel exponential growth in human digital monitoring activities and possibilities, and questionable Capital ensnarement of governance and social values.

Such competition is healthy for the Smart Cities concept as superior and quality devices are expected to be manufactured. However, the competition may not be conducive on all social and political spheres, as is evident in the case of China and the USA who are in dispute about Huawei's 5G technology launch, resulting in an additional variable negatively affecting trade relationships between the two countries (**Peters and Besley, 2019**). Despite these challenges, that are surmountable, the full implementation of 5G technologies in cities is expected to transform how urban areas operate, leading to an increased reliance upon digitalization and opening up avenues for the automation of cities.

With more cities adhering to the 'smart' concept and others expected to soon move towards automation of urban dimensions in the pursuit of efficiency and economic performance, it is foreseen that the number of IoT devices will continue to increase, exceeding 75 billion by 2025 (**Statista Research Department, 2016**). This increase will demand even more connectivity capabilities to ensure that communication between devices is seamless and ubiquitous.

Such demand opens even further opportunities for large ICT corporations to consider possibilities of pursuing Research and Development (R&D) of wireless connectivity further into its generation: 6G. A case in point is Samsung, which scopes this possibility in its recently released whitepaper entitled *6G: The Next Hyper – Connected Experience for All* (**Samsung, 2020**). Samsung's vision of moving to 6G is to provide 'consumers' the opportunity to experience ultimate hyper-connectivity that will involve both humans and the world around them. Samsung's paper provides an insight into the different dimensions that this ICT giant is engaging in positioning itself to ensure that many of the loopholes and weaknesses of 5G will be addressed. In addition, relating to cities, Samsung perceives that the intended 6G technology will not only focus upon addressing technological aspects in urban areas, but will be crafted to influence and inform Sustainability and Socio-Economic Dimensions.

### **3. Surveying Smart Cities Allied to 6G**

The Smart Cities Concept can be traced back to 1994, where the city of Amsterdam was the first to engage in efforts to create and integrate a virtual digital urban concept (**Jameson et al., 2019**). Since then, especially after the emergence of the internet in the 2000s, the concept started to elicit the interest of companies like IBM (2008) (**Paroutis et al., 2013**) and Cisco (2005) (**Swabey, 2012**), with both showcasing interest in investing in this new concept. However, as is highlighted by the **Global Data Thematic Research (2020)**, the journey to embracing the Smart City concept has faced numerous hurdles and challenges, with only the 2 companies seen to be supportive of the idea. The failure to gain traction is credited to multiple issues, including the resistance to change especially exhibited by urban governance and their management structures and mostly tied to their concerns about issues related to the economy, society, environment and legality and ethics (**Tompson, 2017; Sánchez-Corcuera et al., 2019**).

In addition to these concerns, the most pressing challenge, as noted by **Rana et al. (2019)**, has been the notable lack of technological infrastructure that could allow the actualization of this concept. For instance, in regard to internet connectivity, a report by the OECD (**OECD, 2017**) demonstrates that it was only after 2010 that internet penetration started to increase in most developed economies, with most developing and least developed economies hosting nowhere near reliable connectivity levels. By 2018, the connectivity levels in developed economies were at approximately 80.9%, while developing economies had only achieved 45.3% during the same period (**ITU, 2020**). This demonstrates that the lack of a primary quality infrastructure supporting internet connectivity is essential in enabling one of the key pillars of the Smart City concept being able to support the seamless communication of different devices.

Like the historical evolution of G technology outlined above, a similar if not parallel evolution has been occurring in the smart city realm.

First generation smart cities were pioneered and spurred on by large private corporations seeking to advance their digital footprint. While their stated attention and aims were upon the notion of big city systems including energy, water, transportation, the concept of smart cities was indirectly being defined and marketed by private corporations enveloped within their marketing catchment activities **(Allam and Newman, 2018; Allam, 2018)**.

Second generation smart cities witnessed the involvement of city policy makers, governance leaders, urban planners, academics and others taking an interest in the changes occurring in a city's fabric and investment arising from this first generation rhetoric and capitalization, as they watched new trends, fashions and even the 'language' of smart cities becoming commonplace. This engagement swept across urban governance, tertiary education, transportation systems, and started to entrance citizens and the wider community who were fascinated with new technologies and advances in smart phones. As a consequence, governance sought to engage the community in new liveability and lifestyle communities and engaging them in policy-making and drafting city aspirations.

Third generation smart cities witnessed smart city corporations, particularly those in 'Silicon Valley' technological enclaves and hubs, seeking to use the city as a platform to create their own new markets. In some ways, aided by government incentives to host new technological venues and clusters, existing and new digital corporations as well as 'start-ups' played a much bigger role in charting and talking about new visions for the urban context.

The fourth generation appears to be now upon us whereby corporations are surrogate governance entities, raising questions about privacy and monitoring, political and media 'false-news' re-narrating. In this shadow, it is clear that the more the innovation, the less the human engagement, and the more that the digital illiterate or 'luddites' are struggling with in comprehending and navigating this new realm. It has also meant that while both corporations and governance are increasingly exposed to digital invasions, it is the corporations that are in a far better position to monitor, undertake surveillance, micro-engage, and are both the conductor and orchestra. While together they chart the vision of our future cities irrespective of which country and economic condition of a country, corporations operate seamless defying any sense of governance boundaries, in deference to governance attempting to govern within its own jurisdictional space.

Roy has foreshadowed that 'Historically, pandemics have forced humans to break with the past and imagine the world anew. This one is no different. It is a portal, a gateway between one world and the next' **(Roy, 2020)**.

Recognising this scenario, **Newman AO (2020)** has theorized that a new wave of technological innovation will emerge out of the current COVID-19-driven economic collapse. Such innovations 'that appear to be emerging from the ashes of the economy laid waste by the COVID-19 pandemic [...] are likely to transform our cities of the 21st century through a business model that has been called Global Localisation' – the prospective business model for the post-COVID economy. Included this model is an emphasis upon emergent technologies including renewable energies, circular economies, and smart cities. In the energy and infrastructure realms it will emphasise battery technologies, electro-mobility including non-car movements, smart cities overall, hydrogen industries, circular economies and biophilic urbanism, aided by a movement system infrastructure that includes relocalised centres and the demise of traditional CBD's, districted infrastructure networks, transit activated corridors wit micro-mobility, and extensive use of AV. Thus, we are looking increasingly at a new urban smart city entity that is characterised by 'Relocalised centres with integrated local place infrastructure; Tailored innovations in each urban fabric; Less car dependence in most urban fabrics; Symbiotic partnerships to fund the new urban economy; Rewritten manuals for urban professionals', and thus a major decentralised work environment underpinned by digital infrastructure to communicate, work and generate industries **(Newman AO, 2020; Allam and Jones, 2020b)**.

Quality underlying technological infrastructure is critical to enable the construction of smart cities as this infrastructure allows for the availability and connectivity of data from different urban spheres. To obtain this data, a rich web of sensors, cameras and different 'smart' devices, aided by the availability of IoT platforms, are required, and these devices and platforms need to communicate either wirelessly or through physical wired-connections (Saeed et al., 2020). Thus, constructing the hard infrastructure to support internet connectivity, steady networks and other supportive infrastructure, is critical in enabling the realization of the Smart City concept for a city (United Nations, 2016). Such infrastructure is equally important in the processes of storage of the data, in its analysis and in communicating insights garnered to different nodes within cities. The apprehensiveness of installation and plugging these IoT devices into the existing urban infrastructure is linked to concerns about cost, maintenance, security and time required to install them. Buenrostro et al. (2018) observe that because of a lack of a standardized framework to control the implementation of protocols for these devices, different corporations have monopolistically often introduced their own unique devices. This action results in urban managers having to engage with different service providers to install, monitor and maintain said devices or to navigate between different service provider arrangements and platforms. This additionally results in cities investing in millions of devices installed for different specific services, rather than creating a holistic device platform negating multiple platforms, thereby leading to an expensive infrastructure investment. The cost implication, in turn, slows down the adoption of the Smart City concept, especially noting that such projects are publicly funded, which are minimal in most cities. In such cases, the most potent source of funding is through Public-Private Partnerships (PPPs), which require the interventions of policy makers to formulate frameworks and draft the terms of reference for such frameworks.

The projected expenditure on infrastructure overall around the world for the next 1-2 decades is staggering. Some estimates point to USD\$35 trillion, and most projects are being measured against their capacity of realising smart city objectives or outcomes. Of this, the UK Department for Business, Innovation and & Skills (BIS) has surveyed the global marketplace for smart solutions and has concluded that the scope is some USD\$524 billion by the end of 2020; obviously this figure may be post-COVID-19 revised, but the pace of investment appears not to declining despite the dramatic changes numerically in employment, domestic production and services, and daily services (Klingberg, 2020).

The financial burden coupled with the unavailability of supportive technological infrastructure, including network connectivity, which was a major negative characteristic of 4G wireless communication, compounds the challenge that the Smart City concept faced. Such factors, in many instances, have prompted the abandonment of the overall Smart City pursuit, or refocused it into pilot ventures. In most cases, the 'smart' city concept is only experienced and understood in a few sectors of the economy and city-making industries, and this can be attributed to high implementation costs, that would benefit from increased branding and re-structuring. For this reason, critics of the Smart City concept equate it to traditional real estate projects, where glossy lifestyle-inspired advertising rhetoric and image-making embodied in aesthetics are given precedence without real concern to issues like achieving 'wholeness' and tangible satisfaction of residents once they reside in these new places.

Despite those challenges, the proponents of the Smart City concepts have been relentless in their pursuit for this concept despite limited wireless communication, and this has led to expensive infrastructural costs (Chang et al., 2018; Trindada et al., 2017; Saeed et al., 2020). Such costs include network and database setups necessary for smart cities to be operational. Without these, data banks have been slim as only a few devices can effectively be relied upon. In addition, without a quality network, urban areas have not been able to benefit from the valuable data generated by residents through their activities (and social media interactions), who Weber (2019) acknowledges to be part and parcel of an effective 'smart' city.

Without incorporating such data, Samad et al. (2019) argues that the insights drawn from available data could be skewed, and should not be relied upon in providing accurate or quality representative knowledge. However, those challenges are expected to be overcome with the



advent of 5G wireless technology, which is already gaining popularity. The capability of 5G technology to sustain high connectivity speeds, coupled with the concerted effort demonstrated by different stakeholders in the urban realm, is expected to influence the advancement of IoT architectures, which in turn will support a myriad of smart devices. As more of these devices are being manufactured and installed in cities, the aspirational ‘smartness’ being pursued could be achieved, but, with time, the connectivity would still require to be both quality maintained and upgraded to ensure continued sustainability of those cities.

The quality and upgrade that would be sought to achieve quality smart city outcomes could be addressed by the introduction of the 6G technology. Samsung, their whitepaper, champions this goal as the future answer to connectivity challenges beyond our current use and acceptance of 5G technology. In particular this might be now brought forward as a consequence of this new ‘COVID-19-society’ that has already disrupted the momentum of installation and application of wireless technology. The current ‘pause’ offers reflectivity as to investments and priorities given the major at-home self-isolated society now enacted resulting in work place change that has occurred in developed countries (Dayaram et al., 2020). This new ‘COVID-19-society’ has dramatically escalated domestic-based use of the internet, whilst fixed office internet access has majorly declined. This societal change is promoting a major re-think by resident, governance and corporation alike as to cost-effectiveness of home-based-offices and therefore the delocalization theorized by Newman. This is witnessed through our use of 5G technology under this ‘COVID-19-society’ as stakeholders in the urban realm take stock of their achievement in the pursuit of increased connectivity, and in the Smart City concept overall. This is prompting the latter two stakeholders in re-imagine ways of getting back on track, making it worth exploring the possibility of shifting to a higher connectivity gear that is aspirationally-assured with 6G. But even as this possibility is put on the table for consideration, it would be relevant to take stock of the 5G technology as the former is still in an infancy stage and some of the teething concerns may be overcome with time as its application becomes universal. Therefore, the shift to 6G technology should not be seen as enabling an escape route for the failures experienced in the adoption and implementation of 5G, but it may offer as a true upgrade to hyper-connectivity in satisfying demands that would be beyond the capacity of the current 5G of wireless communication technology.

#### 4. Introducing 6G and its Potential Impact on Cities

The next generation of wireless connection (6G) proposes to offer numerous advantages over its predecessors, as summarised in Table 1 below.

**Table 1.** The evolution of network standards from 1G to 6G. Adapted from **Net Information** and **Yuan et al. (2020)**.

Features	1G	2G	3G	4G	5G	6G
Start/Development	1970/1984	1980/1999	1990/2002	2000/2010	2010/2015	2030-
Technology	AMPS, NMT, TACS	GSM	WCDMA, EDGE	LTE, WiMax	MIMO, mmWaves	Ultra MIMO, OAM
Frequency	30KHz	1.8 Ghz	1.6 – 2GHz	2-8 GHz	3 – 30 Ghz	95 Ghz-3THz
Bandwidth	2kbps	14.4 – 64 kbps	2 Mbps	200 Mbps to 1Gbps	> 1Gbps	1Tbps
Access System	FDMA	TDMA/CDMA	CDMA	CDMA	OFDM/BDM A	Not yet known
Core Network	PSTN	PSTN	Packet Network	Internet	Internet	Internet

In particular, the proponents of this technology are confident that it will offer over 1,000 times faster connectivity capabilities over 5G, which is already allowing users to enjoy speeds of between 1 to 10 gigabytes per second. **Rong et al. (2020)** all observe that the potential of 5G is and will continue to allow unprecedented benefits in terms of massive broadband and connectivity especially in respect to the IoT devices. However, they conclude that 6G will outdo these attributes and open new frontiers in connectivity, increase energy efficiency of devices and allowing the full exploitation of Artificial Intelligence (AI) in all urban spectrums. Such possibilities, in the past, have been seen to spark numerous R&D initiatives in different countries and within different ICT corporations, in a race for corporations to strategically position themselves to take the lead position heavily influenced by profit generation tied to first mover privileges.

In addition to faster connectivity, **Mehta (2020)** postulates that 6G will allow for the pursuit and proliferation of citizen devices; thus, boosting consumer-services with IoT-based devices, powered by AI technology. With increased interactions between these devices and humans, it will be relatively easy and cheaper to gather and act on data harvested on issues like personal health, pollution and toxicity levels, food quality and other issues that usually confront and are of concern to urban residents. This advancement will be aided by the ability of devices to increase reliability in areas like image analysis, location awareness, mimicry and detections amongst others and will, as a consequence, increasingly raise the ire of privacy concerns. Such concerns, for example, have negated majority citizen uptake per country of COVID-19 contact warning apps in many Western countries despite their designed capability for tracking and containing the coronavirus, for information and awareness campaigns and notifications, and for providing warning essential services to citizens (**United-Nations, 2020; Allam et al., 2020c**). Ironically, for Australia, the bushfire/emergency warning app has had historically a much greater uptake and citizen privacy acceptance.

6G technology is also perceived as having the potential to significantly influence the promotion of innovation and production of tools that will aid environmental digital resource mapping, including portable geographic information systems (GIS) and global positioning systems (GPS) synergies, thus, promoting landscape and natural resource management conservation, and tangible and intangible resource optimal consumption, exploitation and utilisation. According to **Vector ITC (2019)**, it is conceivable that most 6G AI powered devices will possess large and complex computing architectures that will allow them to not only gather environmental resource data, but also help in building large databases that can offer real-time information and insights to different sectors like agriculture, natural resource management, architecture, city and regional planning, landscape architecture, education, science, climate and many others.

In addition, 6G technology is expected to optimise and finesse location accuracy and location awareness. Hence, 6G technology will most likely assist in actualizing the possibility of autonomous cars, mass rapid transit systems and typologies, and other like applications linked to the movement of goods, people, services and even terrestrial, avian and aquatic wildlife. In the health sector, **Nayak and Patgiri (2020)** envisage that 6G will help to eliminating barriers of space and time in healthcare. This is making possible new technologies like telesurgery, Hospital-to-Home (H2H) services, and optimize the use of Intelligent Wearable Devices (IWD) amongst other benefits that have in concept been brought forward as feasible and urgent ideas in response to the present COVID-19 pandemic (**Allam and Jones, 2020a**).

In the information services sector, during COVID-19, the United Arab Emirates (UAE) moved quickly introducing a contactless paperless identity regime create a digital national identity footprint for its citizens, residents and visitors. This footprint platform enables their access to 5,000 government and private services as well as enabling the UAE's capacity to map and monitor this access in detail (**Soliman, 2020**). Such a strategy is potent even for other nations to adopt and embrace, especially as it has been acknowledged that with COVID-19, the chances of developing herd immunity are slim and recovered victims of the disease are still susceptible to being re-infected (Randolph and Barreiro, 2020). Therefore, globally, the 'new normal' demands the churning of traditional behavioural aspects and the embrace of new technologies that allow for

contactless approaches to containing the pandemic, as is already being observed and deployed globally (Allam, 2020c; Allam, 2020e).

The UN had, in July 2020, recognised this current-COVID-19 digitization trend concluding that 'the current pandemic is accelerating trends such as digitalization, shifts to remote work, and virtual delivery of essential services [...] [creating] an uncertain future for city infrastructure and buildings, as demand for office space and housing could subsequently decline' (**United-Nations, 2020**). The pandemic is also accelerating digital urban inequalities raising equity of access and infrastructure issues for many households, schools and neighbourhoods. These places already operate in deprived urban areas that pre-COVID-19 experienced inability to access remote education, telemedicine and teleworking due to unreliable or unaffordable internet connectivity or lack of computers necessitating people being forced to leave the sanctuary of their homes within Lockdown 3 or 4 regimes in order to access work and services (**Joshi et al., 2020**). On internet access, the International Telecommunication Union (ITU) in 2019 estimated that around 3.6 billion people remained offline, and in Least Developed Countries (LDCs) the access statistics were much worse sitting at an average of just two out of every ten people is online (**ITU, 2020**).

As cities further their pursuit of digital solutions and innovations, towards achieving 'Smart City' designations, the above promises by 6G technology will directly impact cities. **Saad et al. (2020)** notes that 6G technology has the potential to not only increase the efficiency and performance of urban areas, and their micro-operations, as envisioned in the Smart Cities concept, but will provide cities with experiences in uncharted technological terrains. They single out the impact this technology will have in allowing the maximum capitalization of AI technology, and thus redefining standards already set within 5G technologies. For instance, they envision an urban environment that will be amassed with Blockchain and Distributed Ledger Technologies, self-sustaining networks, massive availability and utilisation of data. There is also an unprecedented interest and increase in wearable devices and smart body implants that may even prompt the phasing out of smartphones (as a tool) because they will function much better through the optimisation of cutting-edge technologies like AI.

The limit to the number of new technologies that will emerge is not known for now, but buying from how much potential 5G already has exhibited in opening new technological frontiers, 6G technology, which is potentially far more superior may unlock technological spheres with cutting edge innovations, like as discussed below. Such will not only improve the experiences from where the 5G technology renovated global connectivity, but, if the optimism expressed by researchers on 6G is warranted, diverse urban dimensions will experience positive disruptions including novel data collection, and storage and computation methods that would be handy in addressing even challenges like those posed by COVID-19. Hence, there is a need to address these matters before they spill-over and cause massive setbacks like those being witnessed globally. Such potentials are what the succeeding sections in this paper survey in perspective.

Cities and urban areas, which have also been seen to be increasing in rapid rates, will be prime beneficiaries. The reason being because these cities are projected to be the main holding areas for most of the global population and are prone to varying challenges of urbanization, especially those touching on sustainability due to the unprecedented rises in their demand for resources, service delivery and improvements in areas including infrastructure, housing and others.

#### *4.1. Digital Replica (Digital Twins)*

Amongst the new technologies that 6G wireless connectivity will inspire is that of 'Digital Replicas', also known as 'Digital Twins'. The concept is the digital representation of the physical and biological worlds through the help of technologies such as AI, crowd computing, Big Data and other communication technologies. According to **Samsung (2020)**, the signature quality is that users of the technology will have the potential to experience, explore and monitor the reality in a virtual world without encountering the constraints of space or time. According to **Yrjölä. (2020)**, people in different professions will be able to create a mirror world where physical objects could be replicated virtually and with that, they will be able to observe changes, detect errors and make

alterations and corrections remotely be initiating the physical changes on the actual objects. Thus, the realm of real time scenario modelling that some 30 years ago was dependent upon clunky and slow GIS software, rooms of hardware that struggled with dealing with seas of data layers and information, and now redundant computer software languages like the universally-adopted imperative programming language Fortran. Fortran, derived from 'Formula Translation, invented in the 1950s by IBM, was purposefully invented to numeric computation and scientific computing.

The advantages of Digital Replicas are that it could allow for intricate and complex operations or activities within a remote site in real-time, without the user being physically present. For instance, **Yrjölä. (2020)** is confident that, with the help of 6G technology and the Digital Replica concept, it will be possible for engineers or operators to have full, virtual images of such things like industrial production facilities, and with such replicas, be able to observe, detect and make changes remotely using technologies like robotics. In this way, this technology could then allow people to start and operate large business enterprises in remote areas many kilometres away from the actual site. Such technologies, for instance, are already occurring in many iron ore mining excavation and ore movement activities in the Pilbara region of Western Australia from Perth or Karratha. Similarly, 6G technology is envisaged as helping in reducing risky incidences within complex terrains and environments, and also the delimitation of human closeness to fragile or toxic ores and or chemicals. Already, in the energy sector, 5G technology is seen to have unlocked the potential to increase energy production by rendering 'smart' systems and improving on and offline security structures. Additionally, with 6G, **Alsharif et al. (2020)** note that it will be possible to create Digital Twins of existing software and the main operating systems, and this will help not only in simulation but in ensuring and attaining high performance objectives.

In urban areas and our post-COVID future cities, the emergence of a 6G environment may advance the concept of Digital Twin even further and make smart cities even smarter. For instance, **Castro (2019)** notes that having a digital replica of a city will allow stakeholders, including residents to visualize and interact with different virtual objects before they are implemented in the real world. Simplistic digital visualization models, enabling fly-thru's and the insertion on new proposed buildings or sets of new urban forest vegetation exist already for many cities.

As examples, the City of Melbourne Council's urban forest dataset documents some 70,000 trees across the municipality, enabling the community viewer to extract data and to visually represent and map it, to be a 'citizen science' expert on Melbourne's forested urban domain (**Melbourne, 2020**). In this way, the user will be able to visualize and model the impacts of any given project (including e.g. energy consumption, solar reflectivity and absorption, vegetation species longevity, building material and construction life cycle costs, water runoff and drainage, etc.) even before it is initiated and this will ensure that only projected with perceived positive benefits like increasing sustainability, liveability and resilience of cities will be actualised. The Northern and Western Geelong Growth Areas (NAWGGA), the largest urban growth project in regional Victoria about to host some 110,000 new Geelong residents, is already venturing into this arena with a projected hybridised 5G model and 2D/3D visualisation framework model (**Geelong, 2020**). For both examples, in a 6G environment, these deliberations and software construction tasks including modelling/scenario decision-making processes will thereupon be quicker and visually 'dynamic concrete'.

Abstractively, while policies and laws formulated to guide different urban aspects have historically been based upon 'pre-dynamic concrete' insights borne from historical land use planning related extensive research, it fails to successfully deal with digitally rich environments, and multiple levels of digital fluency by citizenry. The new 5G and beyond arena 'post-dynamic concrete' will offer digital simulations and first-hand virtual experiences to non-digital fluent land use decision makers and an eager multi-aged community who appreciate the richness of visual representations. This is in contrast to, unfortunately, the 'old-school' drawing culture and impersonal AutoCAD representations due to practice and digitally-rich student contemporary addiction to digital narrative rich television shows and movies both of which already base a large portion of their content in this arena.

In the health sector, the availability of high connectivity, especially 5G is promising unmatched benefits like telemedicine, medical imaging, thermal imaging and a different dimension of Robotics, Some of these, as noted by Chamola et al. (2020), have already been applied in countries like China and Thailand to combat the effects of COVID-19. Within the digital twin concept that 6G is anticipated to actualise, such technologies will be enhanced even further by overcoming the limitations of time and distance. This way, the numerous cases of infections that people in the frontline of COVID-19, and close associates of victims would be avoided in future if such a pandemic were to occur, as 6G has the capacity to allow for teleworking and in real-time. More still, with digital twin, Dembski et al. (2020) note that urban planners and designers will allow for novel approaches, including infrastructural dimensions and urban planning systems that would allow for remote working. This can help in the presentation of effects of COVID-19 that is causing unceremonious shutdown of economies and social spheres, allowing some levels of economic activities to continue. In particular, as this technology involves the replication of real-life scenarios, people working in factories and manufacturing sectors will enable people to continue working remotely, should their domestic workplace be appropriately equipped; thus delocalisation envisaged by Newman AO (2020).

#### *4.2. Immersive Realities (XR)*

Another revolution to be brought about by the 6G environment, in respect to imaging, is that of immersive XR technology. In definition, XR (Extended Reality) is the technological term denoting the bridging of all real and digitally simulated worlds like Augmented Reality (AR), Virtual Reality (VR), 360° videos, live events and Mixed Reality (MR) amongst other technologies. The XR technology charts the potential to unlock unprecedented opportunities in different spheres including entertainment, healthcare, manufacturing, education, architecture and science, due to the increasing popularity of human-machine interactions and increasing smart wearables (**Chowdhury et al., 2019**).

In existing smart cities, with the available wireless connections, XR has gained some ground servicing areas. An example is transportation where people are using navigation mobile applications (apps) that use their devices' cameras to allow for an augmented navigation experience and related contents on their phones. XR technologies have also become very useful in emergency responses, in urban planning, education and in medical services. Within the 6G environment, the possibilities and innovations will continue to increase because this technology will unlock the wireless capacity that XR users have been waiting for. For instance, it is noted that the majority of available existing technologies do not have the capacity to support the 8K display required for a seamless user experience in cases like media streaming. It is expected that 6G will solve this by allowing users to experience a data rate of approximately 1Gbps, which is almost double the capacity of 5G technology (**Nawaz et al., 2020**). 6G is also expected to provide low latency and reliable connectivity that will ensure users experience true immersive extended reality. **Perfecto et al. (2019)** note that with the near zero latency that is associated with 6G technology, a seamless telepresence will be made possible, enabling immersive reality to function in real-time with no 'motion sickness' associated with higher latency.

An additional front that Immersive XR is about to transform is the economic sector through the sale of different devices. For instance, Digi-Capital notes that the VR market size will reach a high of USD\$90 billion while that of AR will be beyond USD\$87 billion, as those devices continue to gain in popularity (**Digi-Capital, 2018**). Already, **Marr (2019)** notes that by 2022, the entire XR market will be valued above USD\$209 billion and most of these revenues will be flowing into different cities where ICT corporations manufacture and base their corporate offices.

Going to 2030, when 6G will be fully in use as opined by Samsung, more startups offering XR services will emerge and that these will directly impact upon the economic standing of urban areas and cities as a whole. In addition to the economic value attached to this technology, it is expected that it will influence urban areas in diverse ways. For instance, in terms of cultural heritage conservation and urban regeneration, more so of heritage products, the availability of immersive XR is expected to play a critical role on various levels. On this, already, this technology has been

adopted and has been very productive in environmental conservation more so of endangered species like the Gorillas (under Habitat XR) (Oberholzer, 2019). In urban arenas, the conservation of cultural heritage – both tangible and intangible – can be improved. With XR, it will also be possible to visualize available urban data. Hence, planning decisions on areas including infrastructure development, residential construction and expansion and many other will be done after a simulation on the impacts of such project have been virtually been witnessed by stakeholders including urban dwellers. Thus, XR may afford an opportunity for everyone to participate in, and contribute to, the urban fabric they reside or work in.

An example of such application is the HoloCity – augmented reality cityscapes (Lock et al., 2019)- adopted and being explored in Sydney, Australia, where different stakeholders are able to collaborate via XR to understand high-volumes of data generated from IoT devices and sensors. Through this, they are able to influence designs to align such with their values to real issues like weather, transport networks and other infrastructural developments (Lock et al., 2019).

#### *4.3. High Fidelity Mobile Hologram*

Another realm that is deemed potent arising from the introduction of 6G technology is that of the mobile hologram. It is envisaged that mobile hologram will have high levels of fidelity within the 6G environment thus enabling their exponential use and acceptance. While current hologram technology concentrates on rendering media into 3D displays, future technology will go beyond these simplistic representations enabling human gestures and facial expressions to be rendered into holographic displays. More still, the gestures and facial expressions will not necessarily need be real-time capture. Such could instead be derived from transmissions, or from 3D rendering techniques powered by AI, or from digital facial recognition technologies being currently used in conjunction with closed-circuit television (CCTV) networks in countries like China, Hong Kong, Singapore and the USA as well as quietly being applied inside several airport transfer/customs areas. After the targeted content is obtained, through mobile holographic technology, the content will be displayed as part of real-time services so that the required information or insight can be derived from. This was previously not possible, since the available wireless connections (1G, 2G, 3G and 4G), including 5G, did not have the capacity to allow the high data rate transmission required.

In addition to human holographic displays, current technologies have not aided in achieving actual 3D holographic displays that could help change how people see different objects. For instance, **Elgan (2018)** has tabled an example where a concept design drawn in a computer is only visible to those facing the computer screen directly, while those in front of the computer will only see its back. However, with a holographic display, the image could be displayed in 3D form for all to see, reminiscent of images in the Matrix film (**IMDB, 1999**).

In cities, for instance, with the capability of high fidelity mobile holographic capability, it would be possible to present concepts like buildings, new infrastructural projects and others in a way that everyone is able to visualize and mentally engage with. The **Australian Government (2020)** notes that by using holographic technology, it will be possible to enhance decision-making as stakeholders are able to visualize the city in different scenarios, particularly when this technology is coupled with immersive XR. In addition, with holographic technology, and leveraging on availability of technologies like AI and Big Data, that are expected to help build super datasets for different urban fabrics, it would be possible to create and view unlimited 3D city models, critical in smart cities conversions and constructions.

The availability of 6G will particularly be novel in ensuring the success of the holographic displays by enabling transferability of large datasets required for visualisation to be effected. With the mobile holographic technology, cities of the future, as noted by the Australian Government (2020), will be designed having considered the inputs from all the stakeholders, as everyone will manage to have an opportunity to view the 3D design of identified projects before their approval and implementation. Conceptualisation of new projects through digitally enhanced computer renders and fly-thru's already exist but the visual 'journey' of experience through the 'place' or building is determined by the digital designer and little determined by the actual community.

Digital games, and the dramatic evolution of expertise in this sector offers the platform to quickly enable dynamic visualizer-friendly access into these 3D worlds. Through this digital avenue, areas of a project that may later raise concerns possess the opportunity to be streamlined and mediated to the satisfaction of all participants. Ensuring that the view of all stakeholders are given maximum attention, as noted by Samad et al. (2019) will not only help in building large databases, where individuals can voluntarily share data and information, but also allow for acceptance of projects by local populations. With holographic technology, coupled with other advanced technologies including immersive XR, it will also become easier to solve common urban challenges. An example is vehicular traffic, as it will be easier to investigate and identify the cause and possible permutations of a challenge virtually by rendering the map of the affected area into a 3D holographic image that is easier to visualize, navigate and understand the scale and complexity of issues.

## 5. Technology Enablers for 6G and Future Smart Cities

The services and benefits that 6G promises, as presented in the previous sections, are faced by various challenges that need to be addressed. First, the underlying set of technologies that match its capabilities, and that would allow 6G to be fully actualized, are either in their infancy stages or are non-existent yet. For instance, one such technology is AI, which though it has been around for a while now, new possibilities from AI are still being discovered. With faster connectivity technologies, more of those possibilities are expected to be realised. This is true with such areas like Artificial Neural Networks (ANNs), which promises a vast array of possibilities, but again is still in its infancy stage (**Zorins and Grabusts, 2015**). Additionally, for 6G to be effectively launched, it would also require that an array of networks and systems be remodelled and re-engineered across our cities to ensure that they are compatible with anticipated new technologies, and ensuring equity of access to users (to the benefit of corporate service providers).

In other instances, there will be the need for new sets or types of devices because our existing ones will be rendered obsolete. Such echoes the words of **Packard (1968)**, who would be reveling in today's corporate values and marketing strategies, whom criticized the USA's 'disposable' culture, and its beguiled easy acceptance of planned obsolescence through styling or the calculated perishability of the product. As **Rees (1961)** translated Packard's thesis, 'American society overemphasizes consumption, especially the quantity rather than the quality of what it consumes, and that it therefore sacrifices culture, prudence, and a proper concern for the future [resting such] .... distorted values on the business community, especially on the marketers and advertisers who have beguiled the public into accepting false standards'.

Secondly, the 6G technology would experience the challenge of achieving supportive infrastructures, both hardware and software. It is worth noting that its predecessor (5G), which is currently being utilized in a number of cities is facing similar challenges. Thus, unless concerted efforts and increased public and private research and development investment is pursued, the infrastructural technology will remain a challenge. **Taheribakhsh et al. (2020)** further notes that infrastructural challenges arise due to issues like cost implications prompted by the need for new technologies, and the need for extensive upgrades to existing networks to address compatibility issues.

While those challenges are real, they will open new frontiers for new technologies to emerge and also prompt an improvement in existing ones. All these endeavours will in turn benefit urban areas and cities and help speed the targeted goals of sustainability, improved liveability and resilience, as outlined in the SDG 11 of the UN (**Allam et al., 2020b**).

Table 2, below, highlights some potential technologies that are expected to play a significant part in future cities through the enabling of 6G technology after it has been actualized. Their maturation and full implementation will impact upon different aspects of the urban world and hopefully lead to meaningful transformations. The latter rider recognizes that, for example, it very is evident that 'Zoom calls drain your energy' and will prompt new teaching and community engagement technologies.

In particular, these technologies can be expected to be increasingly relevant, as the world has been forced by the outbreak of COVID-19 to re-imagine a 'new normal', requiring less face-to-face human interactions, especially in work settings, and an increase in the use of different technologies to compensate for the foregone interactions (Jiang, 2020).

As case in point have been the mad scramble by architecture schools in Australia to digitally replicate face-to-face design studios for March-June 2020 teaching tri/semester (and continuing now into their July-November tri/semester) through software like Zoom, Padlet, Issuu, Blackboard Collaborate and Mural. Such has prompted much digital and philosophical ponderings about both digital technology use in tertiary design teaching but also its legitimacy in architecture professional education accreditation regimes, as well as major investments and applied explorations of their use, possibilities and performance where previously it was 'foreign country'. It has also prompted major teaching locational re-thinking. For example; an Australian-based design studio or class can be successfully taught by an instructor in Barcelona; sessional and continuing staff can be physically located anywhere in Australia but still operate what is notionally a Melbourne or Sydney-sited design studio or class; and, that enrolled students can reside in China, Hong Kong, India, or Singapore yet dial-in through the web to access and participate in USA-based, Canada-based or Australian-based learning respectively (Kvan, 2001).

The possibility of virtual and remote working that 6G promises is one avenue that is bound to help actualise this objective. In addition, the emergence of these technologies is expected to assist urban areas to optimise resource consumption, more so with the increase in big data, data sharing and computational technologies. For instance, with the emergence of the Duplex technologies, as shared by Hsiao et al. (2016), will ensure overlapping between downlinks and uplinks over-time frequency resources. Uptake of duplex technologies will ensure an uninhibited sharing of data from one node to the other. With fast sharing of data, especially from open sources that are being pursued, urban fabrics are expected to become even more robust and consolidate the number of smart wireless devices, unmanned vehicles, robotics and others will become conventional over time.

**Table 2.** Technology enablers for the actualization of 6G.

<b>Identified Technology</b>	<b>Description</b>	<b>Source</b>
Terahertz (THz) Wireless Communication Technologies	The use of a wide spectrum of bandwidth to allow for wideband channels; hence, enable generation of high data rate required to support 6G technology.	Alsharif et al. (2020); Saeed et al. (2020)
Novel Antenna Technologies	The use of advanced and high directional antenna technology allowing for smaller wavelengths, synonymous with THz, which also allows for greater number of elements, such as OAM (Orbital Angular Momentum), to be incorporated.	Yuan et al. (2020)
Evolution of Duplex Technology	Technology that allows for the overlapping between downlink and uplink over time-frequency resources.	Hsiao et al. (2016)
Evolution of Network Topology	The reconfiguration of networks elements, including how nodes and links are arranged to relate to each other. In regard to 6G technology, the evolution will allow for non-terrestrial networks like satellites to support different devices, service continuity among other transformations.	Çelik et al. (2019)
Spectrum Sharing	The possibility to use a spectrum by different entities; hence, maximize on the spectrum licenses that are usually underutilized; thus promoting a seamless coverage by	GSMA (2010)



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	different devices communicating with each other.	
Comprehensive AI	The deployment of AI technology in all technological spheres and systems	Drexler (2019)
Split Computing	For the use of different computing technologies available in the network, instead of relying on a single computing technology. The need for this will be warranted by the increasing number of devices that will be configured differently from how many are today. Similarly, those will generate complex datasets that will require to be computed in real-time to achieve the high performance that future cities will demand.	Samsung (2020)
High Precision Network	Allowing networks to maintain deterministic low latency and minimize variations within them to below microsecond levels. This will then make it possible to achieve high interactive services between different devices and networks.	Yuan et al. (2020)

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## 6. The Tech-powered Post-COVID Economic Measures

While the current prospects of 5G and probability of having 6G as from 2025 have been very promising, advancements on this front have slowed down due to the COVID-19 global pandemic that has overwhelmed every part of the world.

Even at the time of writing this paper, the pandemic is still live in many countries, and cities across the globe, and in some cases some cities are witnessing the second/third wave of the pandemic. The challenges of 2020 directly echo the challenges of the mischievously-named ‘Spanish Flu’ pandemic that resulted in new urban city greening, city beautification, new urban parklands and greened roadway policies and initiatives because the biophilic ‘green lung’ properties of cities were recognized as the savior of many who escaped the cities. The Spanish Flu was an influenza-based pandemic from the H1N1 influenza A virus. Affecting the world internationally from February 1918 to April 1920, it infected 500 million people in four successive waves. It’s human toll is typically estimated to have been somewhere between 17-50 million, and to contextualise this toll some 20 million deaths and 21 million wounded occurred in the First World War between 28 July 1914–11 November 1918.

The prolonged existence of the COVID-19 pandemic means that most combative health measures proposed by the World Health Organisation (WHO), and that of local governments worldwide, continue to remain in force, despite their unprecedented, negative social, political and economic impacts. The economic impacts have been such that reputable institutions like the International Monetary Fund (IMF) (**Wearden and Jolly, 2020**) and the World Bank (**The World Bank, 2020**) have warned of the global economy to potentially plummet by more than 5.2%, with developing economies projected to have their economies contract by over 7%. **Dorothee Allain-Dupré et al. (2020)**, of the OECD, have predicted that the global economic shrinking would be between 6% to 7.6% for the year 2020 on the assumption that the pandemic is contained inside 2020.

Though the impacts of the pandemic are diverse, the common denominator is that all cities across the globe have been affected. For instance, New York City experienced a -14% growth in its GDP compared to 2019 figures, equating to approximately USD\$445 billion loss (**Boston Consulting Group, 2020**). For the city of London, as of April, losses of approximately USD \$23 to \$33 million were reported (**Newcombe, 2020**) following lockdown measures, resulting in the grounding of transportation and the closure of businesses.

Noting the economic burden that cities across the globe have been made to shoulder, national governments from different parts of the world have proposed stimulus packages targeting economic bailouts to businesses as well as urban residents whose livelihood have been greatly impacted by the pandemic. Among the targeted sectors by the governments fiscal sectoral

support include that of the ICT sector, which has also been greatly impacted, despite its influence in not only contributing to the economic growth of cities, but also in combating the COVID-19. For instance, in Kenya, the government, through the central bank has argued for the urgent advance and use of cashless technologies in an attempt to redress the transmission of the virus (Hall, 2020). While this may be seen as a containment measure, it plays a significant role in supporting financially-oriented technologies, and would encourage even more innovations in the sector. In the United States, a USD\$2 trillion stimulus package also targeted Fintech companies that would actively enable them to seek protection from the uncondusive environment created by the virus (Cates, 2020). In France, the tech industry has benefited from financial stimulus packages from BPIfrance that offered over EUR 100 million (USD\$116 million) accessible in the form of Convertible Bonds to tech start-ups as a way of accessing capital (OECD, 2020). The Israeli government further released a NIS 650 million (USD\$190.46 million) fiscal support for the tech sector through the Israeli Innovation Authority to ensure that the sector continues to remain active, further contribute to innovations that would lead to fighting the pandemic in the country (OECD, 2020). Japan also advanced financial subsidies targeting work-at-home programs, online schooling and other sectors that relies on the tech sector. Such supports targeting supporting and accelerating investments in the tech industry are critical, and would be instrumental in future programs, including 6G technologies. Their success in keeping the technological frontier aloft amidst the pandemic is testament that governments, including urban governance structures, have a key role to play in ensuring that this pivotal sector of the economy is not only supported during such a period, but even in the post-pandemic period to accelerate the numerous potential that this sector holds. For instance, as noted above, the market share for different devices and technologies are anticipated to continue grow, and such would have a bearing in influencing the economic standing of urban areas.

As more IoT devices continue to be manufactured, such are expected to stir a new wave of innovation to complement the ongoing one, in sectors like transport where car-sharing and other startups are becoming ubiquitous (Gambella et al., 2019). In other sectors, like tourism, which serve as mainstay of numerous cities across the world, the availability of 6G will be synonymous to the introduction of new frontiers, including the arts and the conservation and presentation of cultural artefacts/products/places in 3D dimensions through holographic and immersive XR technologies. These technologies will also mean a re-engineering of available business models rendering concepts cashless economies to be deployed and become new trading marks.

## 7. Challenges and Future Research

While the potency of 6G wireless technology, as well THz (terahertz) wireless communication being a prospective 6G technology for sensing and communication in smart cities (Saeed et al., 2020; Akyildiz et al., 2014), and the underlying capacities it holds, are still in R&D stage and are not expected to emerge until 2025, there are some foreseeable challenges that will need to be overcome.

First, 6G wireless technology will encounter the limitation of infrastructural capacity, which has already derailed the roll-out of 5G technology. Among such infrastructures include the transceivers and antenna that are anticipated to have different designs from the current ones being used in all other wireless applications. Transceivers and antenna will need to be designed to support smaller wavelengths required for THz, spectrum sharing and split computation. As Elmeadawy and Shubair (2019) have theorized, such will need to be in the size of nanometer (equal to one billionth of a metre) and micrometers (one millionth of a metre) so as to also allow for technologies like holographic and immersive XR.

Secondly, 6G technology will open a new frontier in network security as connectivity scope increases. The potential to actualize automation of different urban fabrics through technologies like AI, XR and Smart Cities will demand an upscaling of existing security architectures to ensure seamless operations.

Thirdly, 6G technology is expected to escalate the challenge of device compatibility and capacity. Already, with 4G and 5G technology, this has been a perennial issue as manufacture of

different devices and sensors has been reported to prompt the designing of products with unique protocols incompatible with those of their competitors. Such trends have increased the call for drafting and agreeance of unified frameworks to ensure that standardized protocols and networks are pursued. Unless those calls are adhered to, it will be daunting to have devices that are already designed to seamlessly support 6G technology. The requirements for 6G technology will also prompt unprecedented energy consumption, in their use, manufacture and energy dependency, and will prompt devices that are fashioned for energy efficiency that can support different charging methods and tools. Currently such devices are few and come at a high price tag. An analogy is trying to locate an electric car-charging 'pump' compared to the volume of petrol, diesel and biogas service centres presently available.

In addition to these challenges, the issue of the cost of bringing to fruition this novel wireless technology is something that cannot be overlooked. Already, with 5G, it is amongst the reasons why the technology adoption is lagging, and this without doubt will be the Achilles heel in the implementation of 6G technology.

Therefore, the authors call for further research in areas of tentative costs for implementing the 6G technology, and to explore how compatibility issues and transitions between new devices and components can be resolved with upcoming technological changes warranted by 6G technology. Finally, it is expected that a number of ethical and moral issues, that was not part of the scope of this paper, but which is an area that is key to comprehend, may derail the application of the technology in each country.

## **8. Re-envisioning the Urban Economy in the Wake of 6G – Discussions and Conclusions**

Since the conception of Smart City, the world has been experiencing unprecedented technological innovations backed by availability of a wide range of smart technologies, IoT devices, fast network connections and increasing the amount of data and its storage. Those innovations have been instrumental in the COVID-19 period when almost all countries have been battling severe health and socio-economic impacts. For instance, through the use of technology, countries like China, South Korea, USA, Australia, Israel, Germany, Singapore, Canada, UK and many others across the globe have been using mobile Apps to reputedly track the spread of COVID-19 infected persons, conduct quality contact tracing and also in some cases, use the Apps to ensure adherence to containment or lockdown measures (**Apple, 2020; Yamey, 2020**).

Across the globe, it is not unusual that governments, academia, business and general populations are relying on technologies like Zoom, Skype and other video conferencing technologies to sustain communications amid lock downs and restricted movements. Using advanced devices like drones and robots (Chamola et al., 2020), other countries including Australia and China have managed to deliver essential medical supplies to rural, regional and or remote areas, thus ensuring the medical personnel are protected and also that there was reduced human-to-human contacts. Technologies such as thermal sensors, smart helmets and robots are now popular in different nodes like airports, subways and bus stations, supermarkets and other public places and are assisting in detecting individuals who may have signs (e.g. High body temperatures) of the coronavirus (**Sison, 2020**).

Such contributions of technology in the fight against the COVID-19 pandemic, and also in sustaining some economic activities such as work-at-home programs, and in supporting contactless financial services. These have been recognized by governments, as noted above, warranting their offering of financial support. Adding to this, the emergence of urban concepts as a response to the pandemic societal fragments, such as the '15-Minute City' of Carlos Moreno, proposed for implementation by Mayor Anne Hidalgo in Paris is commendable and set to follow suit in numerous other countries (White, 2020). The concept is expected to gain from the advent of technological frameworks, like 6G, to encourage data sharing to benefit the proximity-based agendas that it promotes. Such government interventions are necessary, especially in promoting research and development, which, as noted by **Yrjölä (2020)**, is important not only in improving the technological landscape but also in influencing legal and policy frameworks.

For instance, with the emergence of different technologies like AI, crowd computing, AR, 5G and others, the amount of data being generated have been increasing rapidly. This has raised a number of issues including security, ethical issues, access and usage among others. Such can only be streamlined through legislations and firm policies, and therefore governmental support of the sector is critically important.

The UN has already concluded that 'the pandemic has accelerated digitalisation in service delivery, including telemedicine, shifts to remote work, and the application of technology to various aspects of crisis prevention and management' (**United-Nations, 2020**). Therefore, 'COVID-19 has accelerated progress in these areas and made the application of digital solutions and innovation to plan, manage and govern cities and urban infrastructure imperative. Addressing digital inequality within and between cities, while ensuring that fundamental and digital rights are safeguarded, will be key in this endeavour' (**United-Nations, 2020**).

Further, governmental support would aid in the acceleration of 5G deployment, which, though already being implemented in a number of cities and countries, has been facing a myriad of challenges including limited infrastructural developments high costs, geopolitical wrangles, moral and ethical concerns and lack of policy frameworks for its implementation (**Yuan et al., 2020**). With this, the success of 5G implementation will have a bearing on anticipated 6G wireless technology that is projected to be in use by 2025.

Already, as noted in the white paper by Samsung (**Samsung, 2020**), the implementation of this technology are projected to experience substantial limitations including technological infrastructure development, data storage and other matters that the current technology landscape is facing. It is also expected to help address challenges linked to legal concerns, ethics concerns, global-politics, unprecedented infrastructural development requirements, and a massive amount of financial support, to name a few. Despite those challenges, 6G is projected to impact the world, especially cities in unprecedented way, including in areas including climate, education, agriculture, traffic, infrastructural development, and change in economic models in addition to the actualization of the Smart City Concept. Through it, as noted above, barriers like time and space that always have been a hindrance in different urban sectors will be eliminated allowing the emergence of technologies like telesurgery and the proliferation of intelligent wearable devices. The high speed associated with this technology will also allow new business innovations and models and new ways of doing things, especially with technologies like digital twins, immersive XR, mobile holographic and others.

The emergence of 6G and the associated technologies that are expected to emerge because of its role in transforming the economic landscape of urban cities. For instance, before the outbreak of COVID-19, there had been criticism that governments were biased in favouring large ICT corporations in the implementation of Smart City products, at the expense of and disenfranchising local small to medium-sized businesses (SMEs). For instance, the European Commission defines an SME as 'An enterprise which employs less than 250 people; has an annual turnover of less than €50m and/or balance sheet assets of less than €43m; and has no more than 25% of its capital or voting rights owned by a larger firm or public body' (**Commission, 2003**). Despite their purported 'small-size', their value and contribution to urban economies, in deference to the large ICT corporations cannot be under-estimated as they are socially and economically important in the EU, representing 99% of some 23 million enterprises that generate around 75 million jobs being two-thirds of the EU's overall employment profile in different economic sectors (IFC, 2017). However, despite their unmatched contribution to the economy, those oriented in the ICT sector have been overlooked when opportunities for services including data collection, storage and computation are being sought, and mostly handled by large corporations in most designated smart cities (Guma and Monstadt, 2020). The same trends are evident with the provision of infrastructure, smart devices and diverse technologies. These also benefit from digital non-taxation regimes existing in different countries. Such practices have historically depriving local SMEs from opportunities to expand their scopes, despite start-up initiatives, and to show case their potentials in deference to well and larger politico-financed competitors. However, one can witness the various country post-COVID-19 stimulus packages and strategies that embrace new

digital technologies, a move that is critical in achieving a competitive technological landscape, thereupon allowing the actualization of the aforementioned 6G enablers.

Of relevance also is the current calls for the cessation of the World Trade Organisation (WTO) moratorium of 1998 on the non-imposition of custom duties for electronic transmissions. Cessation is expected to benefit local economies (**WTO, 2019**) with the local SMEs and start-ups being key beneficiaries in their bid to compete for opportunities to participate in installation of Smart City infrastructures, including in the deployment of 5G and the 6G technologies in the urban areas. Additionally, the increasing rate of transactions coupling both data and financial, will render the emergence of new models of market-based instruments, such as those riding on the Blockchain network (**Shahab and Allam, 2020**) and the pursuance of reducing transaction costs and speed (**Shahab et al., 2018; Shahab and Viallon, 2019**) in the spirit of achieving transaction optimization across IoT networks in future Smart Cities. In this vein, it is expected that 'Smart City Economics' would stand as an emerging field, coupling dimensions of Urban Planning, Economics and Information, Communication and technology (ICT).

Going forward, while research and development in these critical wireless technologies (5G and 6G) are being pursued, it is obvious that numerous opportunities like those presented by digital twin, hologram, and XR among others will emerge and have a major role and affect upon cities and not just smart cities but urban and regional settlements and landscapes overall. It is therefore necessary to ensure that all sectoral players are given an equitable opportunity to share and contribute to the building of future smart cities that will embody sustainability and inclusivity dimensions, as envisioned in UN SDG Goal 11 to 'Make cities inclusive, safe, resilient and sustainable' (**Nations, 2020**).

Finally, the development and application of 6G, noting its numerous potential benefits in tackling varying urban challenges, including the environmental dimensions, needs to be accompanied by political policy agendas supporting sustainability transitions in an equitable fashion. This will, in effect, potentially help guide the pursuance of the development of IoT devices in their design, manufacturing and operation to be more sustainable and more focus their application pathways to align with current and future climate-resilient policies.

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