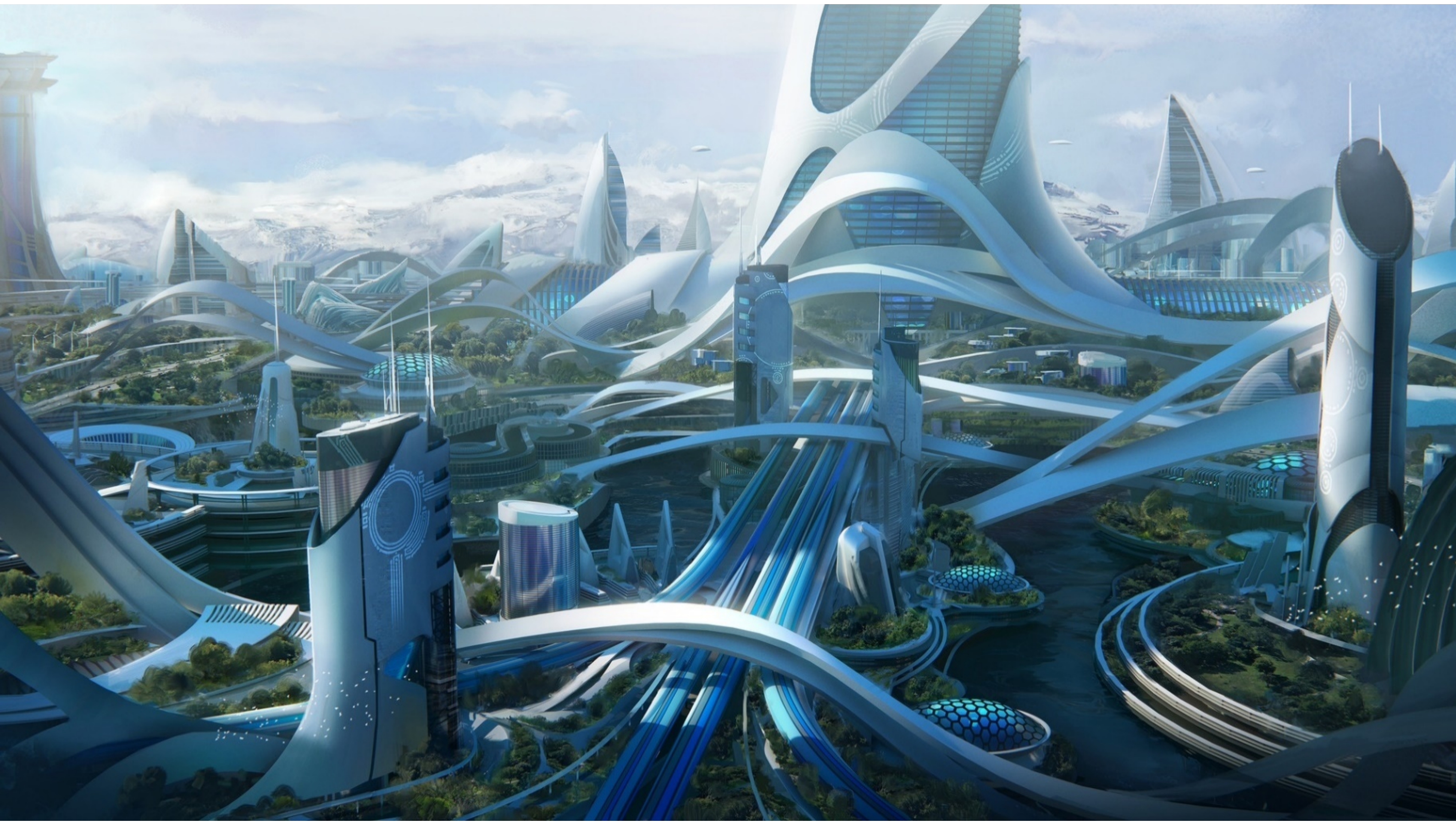
Built Environment Futures



Paper 3: Infrastructure

In Association with:

GCU Glasgow Caledonian University — University for the Common Good
Construction Scotland Innovation Centre
Robertson
Autodesk — Make anything.
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Foreword

At Robertson our vision for the future is to 'assure a sustainable future'. By this we mean we will work to ensure profitable growth which builds on a strong customer focus, consistent and predictable construction delivery, investment in our people, partnership with our suppliers, and adoption of new technology.

To ensure we were 'future-proofing' our business and operational strategy we identified a need to have a look further ahead to 5, 10 and 20 years down the line to understand how our customers and markets are likely to change. This in turn allows us to consider the impact or opportunity for our businesses and respond accordingly.

We were pleased to find willing collaborators in this endeavour in Autodesk, Scottish Enterprise and the Construction Scotland Innovation Centre, all of whom helped fund this work. We commissioned Glasgow Caledonian University to carry out a series of three research papers looking at the Construction, Facilities Management and Infrastructure Markets. The views expressed in the papers are those of Dr Michael Tong and his team of researchers, but they have been guided by the steering group of partners. We are also grateful to Autodesk for sharing with us the time of some of their global experts.

Since the reports were commissioned, we have experienced the unprecedented circumstances of the COVID-19 pandemic which has changed the built environment sector overnight, accelerating the use of digital tools and reconfirming the importance of front-line Facilities Management staff. Although business challenges have changed in the short-term, the risks and opportunities the reports highlight are still relevant. Some, such as the desire to become more resilient through a net zero carbon economy and by using digital technology have come closer, whilst others may have become less relevant or are likely to move on a slower timescale. Nevertheless, we value the insight and challenge they bring to our business.

However, whilst we take time to consider how these inform our strategy and business models, we are keen to share this insight with the wider built environment. We hope you enjoy reading the papers and that they stimulate conversations in your organisations and with your partners about the opportunities they present for our sector.

Elliot Robertson
CEO Robertson Group

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Executive Summary

The scale and complexity of the challenges facing our infrastructure needs in the coming decades is unprecedented. We must not lose sight that infrastructure provides essential services on which people and society depend and should be viewed as a complex system of systems that underpins and serves society. Infrastructure has been sustained over time through maintenance, repair and adaptation. The existing system is resource-hungry and inefficient, susceptible to environmental, economic, social and political pressures. These factors along with climate change and the impact of Covid-19 will all place challenging demands on our system which must become sustainable, not just sustained.

Similar to the preceding reports, the intention is to promote a freedom to imagine futures that would exist for other reasons than corporate or governmental advantage and to encourage decision-makers to ask the right questions. The proposed four step approach for the effective implementation of digital transformation, along with the United Nations Sustainable Development Goals introduced in the first report are equally relevant here. Similarly, the key themes which we believe will have the most impact on the infrastructure sector are examined through the lens of the World Economic Forum's three Future Scenarios (*1.Building in a Virtual World, 2.Factories Run the World*, and 3.*A Green Reboot*) by highlighting key trends, their time horizon, and their potential impact. These Scenarios are very much becoming a reality and their influence will undoubtedly increase in the coming years.

Scenario 1 explores the themes of *Smart Cities, Virtual Reality and Cloud Computing*. These themes reflect the increasing importance of building in a virtual world, originally harnessed as a way to promote connected workflows but has proven to be vital to enable remote working during the current pandemic. The benefits emanating from the identified technologies have the capability of making future systems much more agile to help us deal with the complexities we will face. The themes of *3D Printing* and *Autonomous Vehicles* explored in Scenario 2 relates to factories running the world. The factory in question relates to the application of Industry 4.0 advanced manufacturing techniques for the creation of customised 3D printed components either at a factory or at the project site and the utilisation of automated vehicles to prepare sites remotely. The trends and associated technologies could further add value to productivity and managing safety on challenging sites. Lastly, in Scenario 3 – a green reboot, the themes of *Net Zero Carbon*, *Electric Vehicles* and *Re-Powering* aims to address the sustainability of our current infrastructure system head on. These themes play their part in the reduction of the impact of our infrastructure on the planet and ecosystem to achieve Net Zero Carbon whilst considering the business opportunities that will be made available.

The UK Government has indicated that it will turn to infrastructure to resuscitate the economy when the coronavirus pandemic eases. Infrastructure is a tried and tested measure of success in stimulating economic growth. In making the case for infrastructure, there will now be a much greater expectation by the public on corporations and governments to have a strong environment, social and governance (ESG) proposition that has a long-term outlook. The pandemic will prompt a re-appraisal of societal concerns and for greater social value and the increased frequency of extreme climate events will further necessitate greater investment in the resilience of physical systems. The majority of this report was brought together prior to the Covid-19 pandemic and similar to the other reports, all key themes identified are still highly relevant despite recent developments, providing some assurances that they will continue to be relevant in the future. An opportunity for new thinking and action has been imposed on us and the uptake will need to be expedited.

1.0 The Future of Infrastructure

Infrastructure consists of physical assets that connect different points to one another. They can be broadly grouped into three clusters: Supply and disposal (e.g. energy and water); Communication (e.g. network connections for the transmission of data); Road and transport (e.g. land, water and air-based infrastructure assets). These clusters will undergo significant, albeit largely evolutionary changes, with the biggest transformation expected in communications infrastructure. Infrastructure and the way it is financed, built and operated will face considerable change in the near future due to two key factors. The first is because most industrialised countries have an urgent need to renew infrastructure as assets reach its end of life. Second, digitalisation and decarbonisation are changing requirements and blurring the boundaries between previously separate systems such as transport and communications[1].

The following two recent publications are worth reading to get a different perspective on the future of infrastructure. The first provides a refreshing take on tackling the complexities of the systems involved and the need to re-envision the role of people. The second provides a practical roadmap to restart over 4 phases.

1. Flourishing Systems: Re-envisioning infrastructure as a platform for human flourishing[2] proposes the development of a systems-based vision of infrastructure with renewed focus on:

- **People** – a focus on outcomes and human flourishing, because infrastructure provides essential services on which people and society depend.
- **Connection**s – a focus on interconnected infrastructure, existing as well as proposed, because infrastructure is a system of systems.
- **Sustainability** – a focus on the long-term viability of infrastructure and the society it supports, so infrastructure must be sustainable, secure and resilient as a system.
- **Digitalisation** – a focus on developing infrastructure as a cyber-physical system because digital transformation is key to unlocking greater value from the built environment.

2. Roadmap to Recovery[3] by the Construction Leadership Council (CLC) provides a three-stage plan to rebuild the construction industry and help steer the economy back into recovery. The plan will be carried out across three phases of **Restart, Reset** and **Reinvent**. It includes proposals on maximising employment, ensuring a pipeline of future work, boosting productivity, and industry transformation through technology and digitalisation. As part of the Restart phase, a working group on infrastructure, led by the Infrastructure Client Group (ICG) will be established to develop proposals for a future infrastructure strategy.

[1] Innogy - Future of Infrastructures
[2] Burgess et al. (2020) 'Flourishing systems' Centre for Digital Built Britain and Centre for Smart Infrastructure & Construction, Cambridge
[3] Construction Leadership Council (2020) Roadmap to Recovery

This report should be read in conjunction with Sections 1-6 of the first paper of this series of three which looks at the construction sector. Both papers utilise scenarios proposed by the World Economic Forum (WEF) that depict three extreme yet plausible versions of the future. Although the themes identified for this paper can be argued to have some influence on all potential scenarios, the research team have categorised them into the most relevant scenario.

In addition to grouping the eight identified themes using the three WEF Future Scenarios, Table 1 below provides an indication of the impact that each theme has on digital transformation in the next 5, 10 and 20 years based on the literature and expert interviews. Furthermore, each theme has a provisional assessment of its likely position in the innovation portfolio/pipeline for a typical infrastructure business. The impact on digital transformation for each theme is assessed either High (H), Medium (M) or Low (L).

Table 1: Analysis of the key themes (Timeline, Innovation Portfolio position and impact on digital transformation)

Theme	VIRTUAL			FACTORY			GREEN			Innovation Portfolio
	5	10	20	5	10	20	5	10	20	
Theme 1: Smart Cities	M	M	H							Transform
Theme 2: Virtual Reality	M	H	H							Adjacent
Theme 3: Cloud Computing	M	H	H							Adjacent
Theme 4: 3D Printing				L	M	H				Transform
Theme 5: Autonomous Vehicles				L	M	H				Transform
Theme 6: Net Zero Carbon							H	H	H	Core
Theme 7: EV Charging							M	H	H	Adjacent
Theme 8: Re-powering							M	H	H	Adjacent

By using the proposed Four Step approach as the foundation for effective digital transformation, the opportunities that are proposed in the following sections will stand a much better chance of success. The steps are:

Step 1 is to reflect on the future of work.
Step 2 is the need for reimagining construction.
Step 3 is managing innovation portfolios more effectively.
Step 4 is to enhance digital transformation without unnecessary disruption.

Each of the identified themes are introduced with a summary of the key trends of each theme, along with an indicative timeline of its application and its potential impact to a civil engineering or infrastructure business.

2.0 Future Scenario A: Building a Virtual World

Theme 1: Smart Cities
Theme 2: Virtual Reality
Theme 3: Cloud Computing

2.1. Theme 1: Smart Cities

Key Trends	Timeline	Impact
Key Trend 1 - Zero Emissions City A zero emissions city runs entirely on renewable energy; it has no carbon footprint and will in this respect not cause harm to the planet. Most cities throughout the world produce energy by burning coal, oil and gas, unintentionally emitting carbon. Renewable energy must supersede other non-renewable energy sources and become the sole source of energy, so a zero-carbon city is a renewable-energy-economy city. This transition which includes decarbonising electricity and zero-emission transport, is undertaken as a response to climate change. Zero-carbon cities maintain optimal living conditions while eliminating environmental impact.	**Future** (10-20 yrs)	**High**
Key Trend 2 - **Smart Grid** A smart grid is an electrical grid which includes a variety of operation and energy measures including smart meters, smart appliances, renewable energy resources, and energy efficient resources. Electronic power conditioning and control of the production and distribution of electricity are important aspects of the smart grid. Roll-out of smart grid technology also implies a fundamental re-engineering of the electricity services industry, although typical usage of the term is focused on the technical infrastructure.	**Next** (5-10 yrs)	**Med**
Key Trend 3 - **Biogas** Biogas refers to a mixture of gases obtained from the production of processed residual waste. It is a renewable energy source involving no combustion, which means there are no greenhouse gas emission. It can also significantly reduce the amount of garbage in landfills. Enough biogas is now being produced in the UK to power over 1 million homes. The technology has grown in popularity in the UK with plant numbers increasing almost 500% in just 5 years. This increase is largely related to the RHI and FIT schemes launched by the UK government which were created to incentivise the production of renewable energy and reduce the use of fossil fuels.	**Now** (0-5 yrs)	**Med**

Emerging technology trends are opening the door to new ways of ensuring what we build today will still be economically viable, socially inclusive and environmentally sustainable tomorrow – a new world of infrastructure awaits. From the invention of the tunnelling shield, to the steam shovel, to more recently the advent of BIM, the infrastructure sector has always been disrupted by technology. However, embracing new technologies, such as robotics, artificial intelligence, virtual reality (VR), the use of drones and cloud computing and smart cities have the potential to revolutionise the infrastructure sector.

Figure 1: Smart City (*Source*: Archdaily).

Cities occupy only three percent of the world's landmass but shelter 70 percent of the world's population with over two-thirds of the world's energy consumption and account for more than 60-80 percent of global greenhouse gas emissions. To prosper, they are challenged to accommodate growth arising from increased population and business activity, to create more sustainable environments that reduce local air and water pollution, meet carbon reduction targets and respect limited resources, and to remain competitive by creating the right environment for businesses to invest and citizens to experience their desired quality of life. And with 90 percent of the world's urban areas situated on coastlines, cities are at high risk from devastating impacts of climate change such as rising sea levels and powerful coastal storms. In response to these challenges, many cities are setting themselves goals to make improvements in sustainability, quality of life and economic growth. Becoming smart, especially in the use of energy, can play a vital role in achieving these[4].

A "smart city" is an urban area that uses different types of electronic Internet of Things (IoT) to collect real time data from sensors and other installed devices in different areas of city and then use insights gained from that data to manage assets, resources and services efficiently[5]. This includes data collected from people, devices and assets that is processed and analysed to monitor and manage traffic and transportation systems, power plants, utilities, water supply networks, waste management, crime detection, information systems, schools, libraries, hospitals and other community services[6].

[4] IEC, "Smart Cities - Why cities need to become smart now," *IEC*. 2016.
[5] S. Musa, "Professor Sam Musa," *Smart Cities: A Roadmap Dev.*, 2016.
[6] D. McLaren and J. Agyeman, *Sharing cities: A case for truly smart and sustainable cities*. 2015.

Usually, a smart city rests on three pillars: economic development, earth environmental issues, and social equity. Sustainability in its entirety can only be achieved if all three aspects are equally considered. From the perspective of geomatics, a smart city is the full integration of a digital city, the IoT, and cloud computing technology. A digital city provides a 3D geospatial framework for cities, while the IoT embedded in the ubiquitous sensor network (USN) realises the real-time sensing, measuring and data transmitting of still or moving objects. Cloud computing is responsible for massive and complex calculations, data mining and analysis and helps in automatic discovery of patterns, rules and knowledge and provides remote monitoring, control, and feedback to the real world for intelligent city management and public services.

The matrix of sensors installed inside a modern smart city collects a variety of data pertaining to the use of civic infrastructure. Similarly, street cameras connected to a digital network absorb information and generate data on instances of traffic collisions, human activity on pavements, and the movement of vehicular traffic on city roads which help urban planners to manage street spaces and extend or modify the urban space in tune with emerging requirements[7].

This Digital Twin concept is at the forefront of the Industry 4.0 revolution facilitated through advanced data analytics and the IoT connectivity. Such an IoT rich environment, coupled with data analytics, provides an essential resource for predictive maintenance in smarty city developments[8], while also aiding fault detection and traffic management in a smart city[9]. A digital twin is a computerised model of a physical device or system that represents all functional features and links with the working elements. A Digital Twin environment allows for rapid analysis and real-time decisions made through accurate analytics.

The IoT in a smart city should be capable of self-organisation and self-reconfiguration. Once a malfunction occurs in a single node or various nodes, the network locates the malfunctioning nodes and provides their detailed status. The topology of the network then is reconfigured by reorganising the functional nodes. Furthermore, dynamic routing is a routine task in the network to assure it will not be paralyzed due to failure of a node.

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[7] Smart Energy, "Data analytics: The key to delivering smart cities."
[8] A. Bilberg and A. A. Malik, "Digital twin driven human–robot collaborative assembly," The International Academy for Production Engineering (*CIRP Ann)*, vol. 68, no. 1, pp. 499–502, 2019.
[9] A. Fuller, Z. Fan, and C. Day, "Digital Twin: Enabling Technology, Challenges and Open Research," 2019.

2.1.1 Case Study 1: Masdar Smart City, Abu Dhabi

Founded in 2006, Masdar is a wholly owned subsidiary of the Mubadala development company, formed by the Abu Dhabi Government. While Abu Dhabi has always been known as a global energy actor, through Masdar, it is demonstrating what a "responsible" producer of oil can do to create a balance between hydrocarbons and renewable energy to address both climate change and energy security. It is the first example of a fully sustainable city. The foundation stone of the first "sustainable satellite zero emission city" was laid in at less than 20 km from Abu Dhabi in 2009 with a projected investment of 22 billion dollars. It may host about 50000 inhabitants with self-sufficiency, zero waste equipped with technologies to harness solar thermal energy, wind energy and its energy needs will be covered without producing pollution or harmful emissions of carbon dioxide[10]. The energy required for cooling of buildings is reduced by regulating the orientation and shape of the buildings. In the streets and in the open areas a balance between sun and shade is created, thus promoting the natural cooling. The cooling air is implemented through condensation systems that exploit solar energy directly, instead of a common compressor. Also water consumption is kept to a minimum, thus reducing the energy required for water desalination; in addition, 80 % of water is recycled through underground collection systems. As compared to a conventional city of the same size, Masdar City is expected to consume 75 % less energy which will be produced entirely from renewable sources, 80 % of which just from the sun through a large plant just outside the city and roofs of buildings installing solar panels.

2.1.2 Case Study 2: Amsterdam Smart City, Netherlands

Amsterdam is the Netherland's capital, known for its artistic heritage, elaborate canal system and narrow houses with gabled facades, legacies of the city's 17th century Golden Age. The Amsterdam Smart City program, launched in 2009 and resulting in it winning Europe's Capital of Innovation award by the European Commission in 2016, is a good example of an initiative organized and financed by a mix of public and private funds. The fundamental first step for Amsterdam was to inventory what turned out to be 12,000 datasets across 32 city departments. The Amsterdam Smart City initiative encompasses projects across eight categories: smart mobility, smart living, smart society, smart areas, smart economy, big and open data, infrastructure, and living labs. Many of these projects involve stakeholders outside of government.

One of the most significant aspect of the Amsterdam Smart City Project is the implementation of a smart grid. The Amsterdam tram and underground, the town hall and the public lighting system are all powered by the waste of the city. In addition, the excess heat generated during combustion is used to provide district heating and hot water to dwellings and enterprises. Solar panels are installed on buildings of the city centre as well as micro wind systems, contributing to a distributed power generation system. The future modernization of urban infrastructures also allows families to sell the energy generated by small wind turbines or photovoltaic panels. Energy end-use efficiency, use of renewable energy, smart grids and recharging facilities for electric vehicles are some of the elements that have been composed to achieve a single final goal that, according to the administration, will lead to a reduction of 40 % in CO_2 emissions by 2025, compared to 1990 levels and of 75 % by 2040[11].

[10] A. Lau, "Masdar City: A model of urban environmental sustainability," *Stanford Undergrad. Res. J.*, vol. 11, pp. 77–82, 2012.

[11] L. Mora and R. Bolici, "How to Become a Smart City: Learning from Amsterdam," in *Smart and Sustainable Planning for Cities and Regions*, 2017, pp. 251–266.

2.1.3 Case Study 3: Stockholm Smart City, Sweden

Stockholm is Sweden's most densely inhabited city with about 20 % of the Swedish population living in it. Stockholm is a "green city" rich in parks and open spaces to cross and to spend time: 90% of the population lives less than 300m from a green area. This choice was further enhanced in the new city plan, which shows that it is a "Walkable" city. Stockholm has already reduced CO2 emissions by 25% compared to 1990. Currently they are less than 4 tons per capita, half the Swedish average. 69% of households have access to district heating, in which the share of renewable energy is close to 70%. The biogas is produced in plants for the treatment of waste water through the digestion of organic sludge. In the eco-district of Hammarby, the waste water from a single house produces sufficient biogas to cover the gas demand for cooking use. Most biogas is currently used as fuel in cars and environmentally friendly buses. The city has an excellent system for the treatment of waste and uses innovative production methods as an underground transport system of municipal solid waste which works by suction. 25% of the waste produced by the Stockholm is recycled, 73.5 % is recovered for use (by incineration) in district heating plant and 1.5 % is biologically treated.

Public transport is very efficient and popular, the transport networks are well integrated and 90% of the population live less than 300m from a bus stop, on average 60% of commuters uses public transport and, during rush hour, the same share reaches 80%. All city buses are powered by bio-fuels and all subways and trains are powered by electricity produced from renewable sources. The goal is to reach 2025 without public transport powered by energy derived from oil. Today half of the buses use alternative energy sources. On the housing front, there are many actions for sustainability with energy reclamation and strict saving strategies, starting with public buildings. The challenge for the future is the spread of the biogas produced with urban waste, through which CO2 emissions could be reduced by 85%. For this purpose, the Bromma waste treatment plant has been expanded and is now able to produce 1.5 million litres of biogas each year that can be used for cars, heating and homes.

Figure 2: Stockholm has been chosen as the Smart City of 2019 (*Source*: Intelligent Transport).

2.1.4 Future and Challenges of the Smart Cities Concept

There are many forecasts which aim to predict the growth of smart city markets. According to Ivan Fernandez, Industry Director for Frost & Sullivan, Australia and New Zealand, a consulting firm promoting growth through globalisation, the global smart city market will be valued at US$1.565 trillion in 2020.

In the UK, London and Birmingham, have already issued their 'smart' plans. Local Enterprise Partnerships (LEPs) are also incorporating smart initiatives in their Strategic Economic Plans and the Government has created a £1.7 billion transforming cities fund[12] for smart projects and establishing forums for collaboration[13].

The future offers ample opportunities for the Civil engineering sector in several areas. For a smart transportation system, a lot of sensors need to be embedded into new and existing roadways, buildings, bridges, posts and signs that continuously gather data from passing vehicles to enable uninterrupted connectivity to shared networks. The lighting systems, fire protection systems, security system, CCTV, HVAC have to undergo a complete overhaul in existing buildings to become smart. Another important technology is the adoption of smart concrete sensors. These sensors are embedded within concrete at the time of placing and are able to relay necessary information like the concrete's health could help with improved predictive maintenance of structures that could bring significant benefits. A smart sewerage management system could be installed in Infrastructure projects to manage the flow of waste through low volume and high volume periods and, occasionally, at times of high precipitation that brings in a heavy influx of water, making the way into the sewers. These are some potential opportunities of utilising smart technologies for infrastructure[14].

The smart city concept also invokes concern for privacy and a cybersecurity threat due to the increasingly interconnectedness of infrastructure in future. Ben Parr, Co-founder and CMO, Octane AI commented, "automation will make our streets cleaner, our cities more efficient, and our neighbourhoods safer. IoT can help us figure out when trash needs to be picked up, automated vehicles can deliver our trash... Alternative forms of energy can power the whole thing. So I'm hopeful, though I will caution that we risk our privacy the more we buy into smart cities. Cameras are needed for AIs and smart cities to work, and that is a trade-off we need to seriously discuss for the future"[15].

[12] "Smart Cities - UK opportunities and potential - GOV.UK"
[13] Dolgikh E.I., Antonov E.V., Borushkina S.M. "Smart Cities: Approaches and Technologies, Urban & Real Estate Market", vol. 3, no. 3, pp. 42–49, 2014.
[14] E. Cosgrave, "The smart city: challenges for the civil engineering sector," *Proc. Inst. Civ. Eng. - Smart Infrastructure. Constr.*, vol. 170, no. 4, pp. 90–98, 2017.
[15] M. G. Institute, "Executive Summary Smart Cities: Digital Solutions for a More Livable Future-Executive Summary," no. June, p. 28, 2018.

2.2 Theme 2: Virtual Reality

Key Trends	Timeline	Impact
Key Trend 1 – Building for Tomorrow with Virtual Reality Adopting new technologies on projects allows teams to deliver higher quality buildings while decreasing construction costs, enhancing project schedules and improving job site safety. Virtual Design and Construction (VDC) and virtual reality (VR) can help bridge the boundary between client, design and construction teams and help enhance collaboration for project delivery.	**Now** (0-5 yrs)	**Med**
Key Trend 2 - Collaborative Virtual Environments The use of VR in infrastructure projects can help all parties involved by eliminating miscommunication between construction professionals, designers and their clients. From improving the drawing process to offering a VR tour of a construction site or finished project. The benefits of collaborative virtual environments (CVE's) are new forms of communication and co-operation: these enable the participants to develop new ways of using data which are then utilised in the real world. This is a dynamic and innovative way of working which enables people to interact, change or amend the data within these environments. This is in contrast to the static, linear way of working in which information is passed from one person to another and negates the chance to explore this in a variety of ways.	**Next** (5-10 yrs)	**High**
Key Trend 3 - Augmented Reality (AR) Augmented reality, or AR for short, is one of the most talked about technology trends in construction. Using advanced camera and sensor technology, AR combines one's physical surroundings with computer-generated information and presents it in real-time. While the technology has been used in video games for years, this "augmented" experience is recently making waves in construction, offering immense opportunities to improve the project lifecycle	**Next** (5-10 yrs)	**High**

In recent years, many new visualization and interactive methods have been developed. While 3D modelling software was a game changer as it was quick and cheap and also could be shared across teams, the most recent Virtual Reality (VR) technology offers the potential to enhance the efficiency and effectiveness of all stages of a project from initial conceptual design to construction completion. Sherman and Craig (2018) defined virtual reality as *"a medium of highly interactive computer simulations that senses a user's position and replaces and augments the feedback of senses - giving the feeling of being immersed or being present in the simulated situation"*[16].

2.2.1 Scope of Virtual Reality

3-D models and the use of BIM to higher levels are not ubiquitous and are a pre-requisite for wider use of VR. The ability to review and rehearse a construction design in a 3D interactive and immersive environment increases the understanding of design intent and minimise changes and abortive work that can be detected prior to the start of construction. VR can be used to simulate real world situations and scenarios, and to give workers hands-on experience and training prior to entering a construction site. There are already countless applications for VR technology in the construction industry and many

[16] W. R. Sherman and A. B. Craig, "Introduction," *Understanding Virtual Reality*, pp. 102–106, 2018.

others are likely to become apparent over time. The benefits in terms of training, marketing and planning are obvious, but they also have the ability to improve efficiency and worker safety.

Looking to the future, Augmented reality (AR), is expected to surpass VR use in construction. Whereas virtual reality is strictly a digital experience, augmented reality combines real and digital into one immersive environment. AR projects 3D images on a person's physical surroundings as they walk through with a mobile device (tablet or other device), special hard hat or headset. Currently modelled information needs to be converted from a 3D model into a virtual reality model through an intermediary process. In order for VR and AR to become integral parts of the design and construction of buildings, the technology needs to seamlessly integrate with the software most commonly used by the design professions, namely CAD and BIM.

2.2.2 Case Study 1: Gilbane Uses VR to Validate Prefabricated Construction and Build Faster

With a tight deadline to construct a new building for the Wentworth Institute of Technology (WIT) in Boston, Gilbane turned to prefabricated construction and virtual reality to get the project completed within a challenging 15 month timeframe in 2018. The four story 78,000-square-foot new academic building for Engineering Innovation and Sciences housing labs, classrooms, and presentation spaces for WIT's biomedical, civil-engineering and biological engineering programs.

To meet with the deadline, Gilbane resorted to prefabrication technologies and VR simulation. The Gilbane team used VR models from the earliest stages of the project to help stakeholders visualize the building and provide input on decisions. They also used VR simulation to help their contractors visualise the exact output that was required and its actual dimensions and to validate the finished work. VR was also used for internal quality checks as they had to ensure that everything was going to line up perfectly. The company faced a couple unique challenges in the project which VR simulation was able to help with. For example, the project site was a very tight urban site, so they had to determine what could fit on trucks, fit in the neighbourhood and then get in the building because they had limited access both on the front and the back of the building.

Figure 3: A laptop screen displays a VR rendering of the academic-building systems. (*Source*: Autodesk)

2.3 Theme 3: Cloud Computing

Key Trends	Timeline	Impact
Key Trend 1 - Cloud Based Systems In a typical infrastructure project, there are different stakeholders that are essential for a project such as architects, engineers, consultants, suppliers, and contractors who need to work together. Using cloud technology, construction companies can manage communication with their employees more effectively, equipment/asset management, and bid/proposal management. A cloud-based system offers real-time management, remote access i.e. available for 24/7 and unlimited storage. Moreover, the system provides employees with updated data and information which can be uploaded from any device.	**Now** (0-5 yrs)	**Med**
Key Trend 2 - Blockchain Technology Blockchain technology integrated into the cloud and using BIM is expected to revolutionize construction where centralization is unnatural and privacy is important. Blockchain could provide solutions to challenges in construction information management and could be built into generic IT infrastructure on top of which construction applications are built, rather than used directly by authors of construction related software. It has the potential to make construction processes less centralized and more secure than cloud.	**Next** (5-10 yrs)	**High**

2.3.1 Cloud Based Systems

Cloud computing is typically organised in three layers. The bottom layer, which the average user rarely sees, is all about infrastructure such as the hardware, memory and bandwidth of the network. Cloud services for this layer are called infrastructure as a service (IaaS). Next comes platform as a service (PaaS), the middle layer which looks after the software platform such as the operating system. Finally, there's the topmost layer, software as a service (SaaS). This is the part of the cloud with which the average employee interacts. Cloud technology is changing the way construction projects are executed by providing better data storage, access, sharing and analytics. The impact of cloud computing makes it simple to take measurements or compare plans on any of your devices, from any location. Cloud-based collaboration's ability to improve productivity is a key factor driving adoption.

Cloud-based collaboration and coordination are poised to transform the way people work together on infrastructure projects. The shift to the cloud has the potential to deliver productivity increases similar to those enabled by BIM tools—but without the learning curve associated with engineering tools and processes. Every construction project has a large amount of stakeholders, and sharing data across all these parties is often time consuming. Cloud solutions make sharing simple by providing real time communication and collaboration capabilities. It is also particularly useful when dealing with large files (e.g. a single point cloud can be well over 10 GB). The use of regular aerial imagery could mean that point clouds alone could take up hundreds of GB on a device, well beyond the storage capacity of most mobile devices.

As the adoption of Cloud Computing systems increases, so do security issues. This is both an essential and delicate point that requires the utmost attention both from providers and from companies that use their systems. With the general increase of all forms of data along with the introduction of GDPR (General Data Protection Regulation) in the European Union, cybersecurity has become even more urgent. Looking to the future, "Serverless," known as, FaaS (Function as a Service) is one of the main Cloud Computing trends. The real innovation of these systems is the possibility to run applications without worrying about the underlying infrastructure. The first serverless model was released by Amazon in 2014 (known as AWS Lambda); Microsoft, IBM, and Google soon followed with their own serverless offerings. The next big thing in the construction industry would be the ability to apply automation to differentiate parameters and measure the progress of daily tasks using the Internet of Things and its devices. With cloud evolving in its computational capabilities, the idea of its services slowly moving away from just storage into a concept of Big Data Analytics (the use of advanced analytic techniques against very large, diverse data sets that include structured, semi-structured and unstructured data) could become feasible.

2.3.2 Blockchain Technology

Blockchain technology, which is in many ways a "Cloud 2.0" with even more innovative potential will be an important trend in the future of construction[17]. Block chain is a type of Distributed Ledger Technology (DLT) developed as the underlying technology of Bitcoin. A distributed ledger is a simple database which is scattered around multiple locations in a shared manner. Instead of having only one source store with multiple access points, there are multiple stores (as ledgers) scattered which are simultaneously being updated. A distributed ledger is also a network in which participants can directly exchange information without the need of any intermediaries thus offering confidentiality[18]. Along with confidentiality, the issues like provenance tracking; monitoring channel and ledger metrics; disintermediation; non-repudiation; change tracing; multiparty aggregation; traceability inter-organizational recordkeeping; and data ownership are also expected to be addressed by the Block chain technology[19]. Blockchain technology has the potential to improve efficiency and digital workflows by shifting current payment and project management systems towards a more transparent and fair practice. By reducing late payments, remediations and disputes, with the potential to reduce cash flow risk to SMEs. Instead, the industry as a whole can become a more trusted entity. Through smart contracts, business processes and administrative tasks can be automated to increase efficiency and always be aligned with the agreed contractual terms. This can result in significant cost savings, helping with the low margins of the industry, and better control project costs. Good examples of potential application include releasing offsite payments, managing house purchase contracts, and assuring sub-contractor payments.

[17] Z. Turk and R. Klinc, "Potentials of Blockchain Technology for Construction Management," *Procedia Eng.*, vol. 196, no. June, pp. 638–645, 2017.
[18] B. Penzes, "Technology in the," *BLOCKCHAIN Technol. Constr. Ind. Digit. Transform. High Product.*, no. December, 2018.
[19] M. Safa, S. Baeza, and K. Weeks, "Incorporating Blockchain technology in construction management," *Strateg. Dir.*, vol. 35, no. 10, pp. 1–3, 2019.

3.0 Future Scenario B: Factories Run the World

Theme 4: 3D Printing
Theme 5: Autonomous Vehicles

3.1 Theme 4: 3D Printing (3DP)

Key Trends	Timeline	Impact
Key Trend 1 – 3DP Gaining Momentum in Construction Infrastructure providers are realising the potential of 3D technologies and their impact on the future of construction. The market for 3D printing in Construction is estimated to have a compound annual growth rate of 33%[20]. Companies such as XtreeE (a French platform that enables project owners, architects and engineers, designers and contractors to design and produce optimized large-scale 3D printed components) are gaining momentum.	**Next** (5-10 yrs)	**Med**
Key Trend 2 - Extra-terrestrial Buildings with 3DP Extra-terrestrial buildings probably will be built through additive construction using a large-scale 3D printer. Ideally, the additive-construction process would be entirely robotic. NASA has set its sights on building homes on Mars. The US space agency has selected five winners of the latest phase of its "3D-Printed Habitat Challenge" to design 3D printed houses for the arrival of astronauts on the red planet.	**Future** (10-20 yrs)	**High**

Getting new construction projects designed and built quickly and perfectly with the lowest possible total cost of ownership (TCO) a priority. To make construction fast and cost-effective, the infrastructure sector uses both automation and advanced manufacturing processes on a large scale to produce assets from prefabricated, mass-customised modules. Large-scale adoption of prefabrication with 3D printing, and the use of autonomous vehicles tilts the infrastructure sector's focus from building businesses around projects to building businesses around products. There is an opportunity to work closely with innovative manufacturing companies to develop a range of customised products that could see wider market application.

3.1.1 3D Printing

3D printing (3DP), an automated production process with layer-by-layer control, has been gaining in importance. For decades, 3D technology has been used in the manufacturing sector and has recently been trialled in the construction sector to build components of buildings, bridge parts and housing. The technology brings significant benefits to the construction industry in terms of increased customization, reduced construction time, reduced manpower, and construction cost[21]. An industrial leader in the world of 3D printing for construction components is a French company called XtreeE. They specialise in concrete printing and have used the technology to print storm water drains that are prefabricated in a warehouse and then dropped in place on site. They can be printed and finished in only 9 hours.

Contour Crafting Corporation has proposed a new method of autonomous construction of tall concrete towers (wind turbine towers, bridge pylons, water towers). The method employs a set of coordinated vertically climbing robots that carry a special Contour Crafting nozzle system.[22].

[20] Transparency market Research 2020 https://www.transparencymarketresearch.com/3d-printing-construction-market.html
[21] I. Hager, A. Golonka, and R. Putanowicz, "3D Printing of Buildings and Building Components as the Future of Sustainable Construction?," *Procedia Eng.*, vol. 151, pp. 292–299, 2016.
[22] Contour Crafting Corporation https://contourcrafting.com/infrastructure-construction/

3.1.2 Case Study 1: 3DP Inspection chambers in Roubaix

This project was undertaken in an old underground brick gallery. Three inspection chambers were to be installed, but a traditional solution would have required a piercing of the vault, with a risk of propagation of rupture and general collapse. It was proposed to make concrete manholes, adapted to each existing geometry, in order to fix them to the vault and thus provide local stiffening, making drilling suitable.

A survey of existing geometries was carried out, combining traditional methods and 3D scanning. By cross-checking the information, XtreeE was able to use it as an input into the printing paths algorithmic development, thus ensuring a final shape perfectly adapted to its context for all the three cases. A test for the resistance to chemical actions of the soil was also carried out. Two days were devoted to excavation, a third to scanning, a fourth to printing, and finally two days of installation and backfilling.

Figure 4: 3DP Inspection chambers in Roubaix (*Source*: XtreeE)

3.1.3 Extra-terrestrial Buildings with 3DP

Contour Crafting technology has the potential to build lunar and Martian structures, habitats, laboratories, and other facilities before the arrival of human beings. These structures can include integrated radiation shielding, plumbing, electrical, and sensor networks.[23]. 3DP in construction is expected to march towards extra-terrestrial presence

[23] Contour Crafting Corporation https://contourcrafting.com/space-applications/

3.2 Theme 5: Autonomous Vehicles

Key Trends	Timeline	Impact
Key Trend 1- Autonomous construction vehicles Autonomous construction vehicles promise to help infrastructure companies meet the need to carry out repetitive tasks on a construction site in a precise manner and to reduce the risk of on-site accidents. They also offer solution for skilled workforce shortage. To meet the growing pressure on budget and time as well as concerns over safety, budget and time, autonomous construction vehicles are gaining momentum in construction sector with more and more companies developing heavy duty vehicles that can operate autonomously without human interaction.	**Now** (0-5 yrs)	**Med**
Key Trend 2 - Construction Equipment transformed to Robots with sensors AI and Robotic technology is rapidly transforming AEC sector with invention of new sensors that transform manually operated construction equipment into autonomous machines. Transformation of existing heavy duty machines irrespective of their brand into Robots by retrofitting an autonomous stack would be a boost for automation.	**Next** (5-10 yrs)	**High**

Autonomous construction vehicles are essentially self-driving machines that can be used to transport materials across the construction site and to haul heavy items without posing a risk to workers. For example, machines can be fitted with robotic technology solutions and sensors that enable forklifts, diggers, trucks, and other similar equipment to operate without a driver in the cabin. By creating relevant paths, providing GPS capabilities, and programming movement of the machine itself, construction site workers can remotely manage machinery and enjoy more efficient processes. The efficiency could come from the availability of skilled operators and the ability to reduce human errors.

The scope of automation within the construction and infrastructure sectors is broad, encompassing all the stages of construction life from initial planning and design (AI/machine learning), through construction of the facility (3DP/robotics), its operation and maintenance (IoT), to the eventual dismantling and recycling of buildings and engineering structures. Autonomous vehicles (bulldozers, cranes, diggers, drones and the like) are changing the nature of construction work with the potential to revolutionize the industry and transform building sites. For example, the use of vehicles and heavy equipment remain a major source of construction fatalities and injuries and by reducing the number of operatives on site, this could be minimised. Activities during the construction stage have significant impact on the overall performance of sustainable buildings regarding pollution, construction waste, resource consumption, work conditions and skills, etc., which can be controlled for better outcomes through automated and robotic technologies[24].

[24] M. Pan, T. Linner, H. Cheng, W. Pan, and T. Bock, “A Framework for Utilizing Automated and Robotic Construction for Sustainable Building,” 2018, pp. 79–88.

3.2.1 Case Study 1: Komatsu Smart Construction

Komatsu, a Japanese multinational corporation that manufactures construction, mining, forestry and military equipment is one the world's largest construction companies. But in its home country, Komatsu has been struggling with an ageing population, a trend that has left few young workers available to operate its machines. To get around this problem, Komatsu introduced in 2008 an automatic driving system that lets large dump trucks drive efficiently along pre-set routes. The latest service is called Smart Construction, trucks use GPS to move around without a driver. Each truck can go much longer than conventional trucks. Bulldozers and excavators can automatically perform tasks such as levelling the ground and excavating, enabling novices to handle difficult jobs. Robotic vehicles are guided in their work by a fleet of drones, which map the area in three dimensions and update the data in real time.

Komatsu's Intelligent Machine Control eliminates the need for site operatives to check actual surface levels. By reducing the number of workers in the area around the machine, site safety hazards can be minimised. Data from detailed usage reports can also be produced to help plan and manage progress of site activities.

Figure 5: Intelligent Machine Control (*Source*: Komatsu)

3.2.2 Case Study 2: Built Robotics

In October 2017, Built Robotics created a sensor system that is capable of transforming heavy equipment into autonomous machines. The company transforms construction equipment such as excavators and bulldozers into fully autonomous robots. The company's automated guidance systems can be installed on existing equipment from any manufacturer, while maintaining complete manual operation capabilities. The robots can then autonomously perform functions such as digging trenches, excavating foundations, and grading building pads. It uses a combination of cameras, LiDAR and GPS. The GPS is used for location and elevation information, while the LiDAR, camera and on-board machine learning handle real-time obstacle detection and job completion status. After workers specify the GPS coordinates, they can leave the rest to the excavator, which will drive itself to the starting point and dig thousands of feet in a day. One worker—not necessarily an excavation specialist—needs to stay on hand in case of problems. The autonomous fleet can be managed via a web-based platform, which allows remote equipment operators to supervise the robots. Vehicles with Built Robotics' equipment don't need regulatory approval if they work off public roads.

Figure 6: A completed wind tower foundation using a robotic excavator (*Source*: Built Robotics)

3.2.3 Challenges and the Future of Autonomous Vehicles

As with any new technology, autonomous vehicles face their fair share of challenges, with the key concern being cyber security. If Governments and regulators believe that autonomous equipment is not safeguarded from hacking, they could impose heavy restrictions or even ban the technology outright. For this reason, it is likely that the use of autonomous vehicles in the construction industry will be accompanied by security technology designed to protect data and control from hacking or malicious aims. This will add a barrier to entry for most companies due to the increased costs and complexity of integrating both technologies.

4.0 Future Scenario C: A Green Reboot

Theme 6: Net Zero Carbon
Theme 7: EV Charging
Theme 8: Re-powering

4.1 Theme 6: Net Zero Carbon

Key Trends	Timeline	Impact
Key Trend 1 - Energy Efficiency is the Way to Go Being a major source of greenhouse gas emissions, the infrastructure sector faces the challenge of transformation into less hazardous industry. The need to meet emissions targets and find alternatives drive the industry to shift towards building using methods/products that are low carbon as well as reducing the operational impact of the asset in terms of energy use. The depleting fossil fuel reserves also adds up to worldwide demand to switch to renewable sources for building operations.	**Now** (0-5 yrs)	**Med**
Key Trend 2 - Net Zero Energy Buildings Globally, the World Green Building Council has issued a Net Zero Carbon Buildings Commitment, which challenges companies, cities, states and regions to reach net zero operating emissions in their portfolios by 2030 and advocates for all buildings in operation to be net zero in operation by 2050. Limited awareness among consumers has limited the adoption of green buildings in the past. However, with significant government initiatives and substantial investments, the development of net-zero energy buildings has accelerated significantly.	**Next** (5-10 yrs)	**High**
Key Trend 3- Towards 100% Net Zero energy built environment The signing of the Paris Agreement in December 2015 marked the start of the most important race in our existence – the race to curb global greenhouse gas (GHG) emissions so that global temperature rise remains below 2 degrees Celsius and, ideally, below 1.5 degrees Celsius. It also set a clear timeline for how quickly the world must change its course so that, by 2050, all major business sectors are operating in a state of essentially zero carbon emissions. Since the building and construction sector is responsible for a high proportion of global energy consumption and the associated global greenhouse gases, the Governments and regulatory bodies along with industry players all over the globe are striving to innovate renewable energy solutions.	**Future** (10-20 yrs)	**High**

4.1.1 Introduction to Net Zero Carbon

New infrastructure development is essential if we are to meet the food, water and energy needs of a growing global population and deliver on the Sustainable Development Goals. Yet expected public and private investment in major projects between now and 2030 will double the amount of infrastructure on Earth and could potentially degrade the natural systems on which we all depend. In order to achieve Net-Zero Carbon targets, the embodied carbon related to new infrastructure as well as the carbon impact of operating new infrastructure should be among the top priority for the Government to address. New networks will need supporting while the capacity of existing grids needs to be expanded, with greater flexibility, like strengthening electricity distribution grids to support electric vehicles and heat pumps. A rollout of low-carbon hydrogen production and carbon capture and storage is needed to capture carbon dioxide produced from fossil fuels and prevent it from entering the atmosphere.

Globally, 39 percent of energy related greenhouse emissions occur from buildings, with 28% coming from the operations of buildings themselves. In terms of energy use, buildings and construction together account for 36% of global final energy. Additionally, people spend 90 percent of their time in buildings, and there is a consistent association between unhealthy indoor environments and negative human health impacts[25]. The World Green Building Council and the Green Building Councils (GBC) participating in the Advancing Net Zero Project (Project Steering Committee) are dedicated to supporting market transformation towards 100% net zero carbon buildings by 2050.

The Infrastructure Carbon Review in 2013 showed that the infrastructure industry controls 16% of the UK's total carbon emissions and has influence over a further 37%. Data from the Infrastructure Carbon Review indicates that the UK's infrastructure sector needs to reduce its total carbon emissions to 34 MtCO2e/year by 2050 from a baseline of 157 MtCO2e/year in 2010. UK-GBC is recommending the establishment of a whole life carbon target for the infrastructure industry based on climate science and from which organisations can derive commensurate targets[26].

4.1.2 Market Penetration of Net Zero Buildings

It is estimated that approximately 500 net zero energy commercial buildings and 2,000 net zero energy housing units exist worldwide which is less than 1% of all buildings – a major shortfall in the 100% aimed by 2050[27].

It is estimated that commercial office projects represent the second largest quantity of net zero projects worldwide. Development of commercial net zero projects has steadily increased in the last decade, the majority of which are publicly-owned properties[27]. However, a growing number of privately-owned properties have been built or converted to net zero in the last five years, reflecting new commercial interests and attention. The education sector has made the most notable progress through net zero primary schools and university campus buildings in recent years[27].

4.1.3 Barriers to Uptake of Net Zero Carbon

The National Infrastructure Committee (NIC) has provided a sector by sector analysis in Power, Heating buildings and energy efficiency, Surface water and Waste. They provide recommendations to address the urgency demanded by the climate emergency and achieve net zero greenhouse gas emissions by 2050 by advising on the most cost effective way to decarbonise infrastructure whilst meeting the UK's long term infrastructure needs. The recommendations are now more urgent, or will need to go further, to help achieve net zero. It also highlights several areas within the Commission's remit where it may make recommendations in the future to support decarbonisation, including passenger rail, wastewater, aviation, shipping, greenhouse gas removals and infrastructure required to decarbonise industry (such as hydrogen or infrastructure for carbon capture and storage)[28].

[25] N. Franklin, "World Green Building council launches case study library of best practice - Workplace Insight," 2019.
[26] L. Amorim *et al.*, "Delivering Low Carbon Infrastructure," *UK Green Build. Counc.*, no. July, pp. 1–32, 2017.
[27] NBI, "2016 List of Zero Net Energy Buildings," *New Build. Inst.*, 2016.

[28] National Infrastructure Committee (2020) NET ZERO: Commission recommendations and the net zero target

4.1.4 Case Study 1: Hanergy's Renewable Energy Centre, Beijing, China

United States Green Building Council's (USGBC) LEED (Leadership in Energy & Environmental Design) certification authority has announced the prestigious LEED Zero certification to Hanergy's Renewable Energy Centre in 2019 which is one of the first three "net-zero" projects. Hanergy's Renewable Energy Centre was judged to uphold the three level energy efficiency concept of self-sufficiency, surplus storage, and grid independence, while exhibiting green environmental protection design, technological innovation, and sustainable development. Furthermore, the exhibition centre's case was strengthened by the annual estimation of reducing carbon dioxide emissions by 314 tonnes, which is equivalent to planting 13,745 trees. This all-solar green building, covering 7119 square metres features Hanergy's HanWall, flexible thin film solar modules on the top and sides of the building and HanBrick on the walkway.

4.1.5 The Way Forward

The 2030 and 2050 goals are essential to combat climate change, but there is a long way to go. These goals pose great challenges to the Infrastructure sector. The Institution of Civil Engineers (ICE), has pointed out some of the changes required across the UK's infrastructure networks to help deliver its 2050 goal. In the transport sector, but roads in particular, the National Infrastructure Commission has made a clear recommendation to the government on the need to prepare for 100% electric vehicle (EVs) use by 2030. As the CO_2 emissions figures for the residential sector demonstrate, there's clearly a lot to do in order to decarbonise heating networks.

The development of more sustainable construction materials (which contain lower embodied carbon) would be a priority on the sustainability agenda for the construction industry as the manufacture of cement is responsible for about 8 per cent of overall global CO2 emissions. Another major focus in improving long term sustainability of built assets requires a shift away from purely targeting delivery of the built asset and towards design for performance of that asset. Advances in technology, data capture, the use of Building Information Modelling (BIM) and automation of construction processes should all help with a performance-focussed design approach. The Infrastructure sector will have to shift towards more and more digital technologies and automation to manage sustainable performance of their projects.

4.2 Theme 7: Electric Vehicles (EV) Charging

Key Trends	Timeline	Impact
Key Trend 1 - Sustainable Transportation Transportation is a major source of greenhouse gas emissions worldwide. Reducing greenhouse gas (GHG) emissions from transportation is key to slowing climate change and making sure our planet stays a healthy place to live. Electric vehicles (EVs) are an important part of meeting global goals on climate change. Electric vehicles (EVs) fight climate change by powering transportation with electricity, not fossil fuels. Driving an EV can cut fossil fuel emissions in half, or get rid of them entirely when renewable energy sources are used.	**Now** (0-5 yrs)	**Med**
Key Trend 2 - Smart Charging Electric vehicles (EVs) hold the key to unlocking synergies between clean transport and low-carbon electricity. Just as future transport must be increasingly electrified, future power systems must make maximum use of variable renewable energy sources. Smart charging for EVs minimises their load impact and unlocks the flexibility to use more solar and wind power. The vehicle-to-grid (v2g) technology for EV charging stations and renewable sources of energy for electricity are also opportunities for the sector.	**Next** (5-10 yrs)	**High**

4.2.1 Introduction to Electric Vehicles (EV) Charging

Finding an optimal path to a sustainable and low-carbon economy is important to decrease the carbon emissions that are a fundamental determinant of global warming. Scotland's first Low-Emission Zone (LEZ) came into effect in Glasgow from Dec 2019. However, the challenges posed by climate change and zero emission targets demand more aggressive infrastructure innovations.

Infrastructure is an important part of the modern economy, essential for our society to function. Therefore, future-ready sustainable infrastructure systems are especially needed. Transportation is needed as one of the key aspects of infrastructure to catalyse the shift toward climate-resilient economic growth and due to its heavy consumption of fossil energy, a sustainable and clean transportation system has long been advocated.

The rapid development of electric vehicles (EVs) is an important factor in sustainable transportation which ensures national energy security, reduces the consumption of petroleum energy and minimizes the environmental pollution caused by cars. As a recent development, the UK ruled that any cars reliant on diesel or petrol would be illegal by 2040.

4.2.2 Challenges of EV Transportation

Rapid growth in electric vehicle sales will require vehicle-charging infrastructure to match. The number of charging points worldwide was estimated to be approximately 5.2 million at the end of 2018, up 44% from the year before. Most of this increase was in private charging points, accounting for more than 90% of the total installations[29]. Service stations will no longer be the only place to do this. As a result, significant charging infrastructure will be needed in various building sectors. These charging-point capacities are likely to lead to large load increases in buildings if appropriate infrastructure is not designed. Total charging-energy demand for the EV vehicle population across China, Europe, and the United States could grow dramatically from 2020 to 2030, increasing from roughly 20 billion kilowatt-hours to about 280 billion kilowatt-hours.

4.2.3 Smart Charging

As future transport is being electrified, future power systems must make maximum use of variable renewable energy sources. Smart charging minimises the load impact from electric vehicles and unlocks the flexibility to use more solar and wind power. Smart charging is a way of optimising the charging process according to distribution grid constraints and local renewable energy availability, as well as the preferences of drivers and EVSE site hosts. If charged smartly, EVs can not only avoid adding stress to the local grid but also provide services to fill flexibility gaps in demand on the local level and on the system level[30].

Smart charging not only mitigates EV-caused demand peaks but also flattens the energy load both at the system level and locally, at the shorter term time scales. More specifically, adjusting charging patterns that today stand idle in parking for most of the time (90-95% of the time for most cars) could contribute to; peak saving; ancillary services supporting real-time balancing of grids by adjusting the EV charging levels to maintain steady voltage and frequency and behind-the-meter optimisation and "back-up power".

4.2.4 Types of Smart Charging and Their Implementation

The simplest form of incentive – time-of-use pricing – encourages consumers to defer their charging from peak to off-peak periods. It has relatively low technical requirements for implementation, usually a smart meter integrated in the Electric Vehicle Supply Equipment (EVSE), and it proves to be relatively effective at delaying EV charging until off-peak hours at low EV penetration levels[31].

Direct control mechanisms enabled by the EV and the charging point will be necessary as a long-term solution at higher penetration levels and for delivery of close-to-real-time balancing and ancillary services. Such mechanisms range from basic switching on and off of the charging or unidirectional

[29] IEA, "Global EV Outlook 2018 – Analysis - IEA." 2018.
[30] IRENA, *Innovation Outlook - Smart charging for electric vehicles*. 2019.
[31] D. Hall and N. Lutsey, "Emerging Best Pratices for Electric Vehicle Charging Infrastructure," *ICCT White Paper*, October, 2017.

control of vehicles or EVSE (also called V1G) that allows for an increase or decrease in the rate of charging, to more challenging bidirectional vehicle-to-everything (V2X).

Fast and ultra-fast charging is an attractive proposition and can have significant influence on the growth of EVs. However, slow charging is better suited for smart charging than fast and ultra-fast charging. Solutions such as battery swapping, charging stations with buffer storage, and night EV fleet charging might become relevant in combination with fast and ultra-fast charging. As battery ranges increase, cable charging will likely remain the most common charging technology for light duty vehicles for years to come.

Currently, the trend is to install a small number of charging points, that are as large as possible within car parks. While the impact of a few vehicles charging may not be significant on the overall load of a building at the moment, this may not be the case in future. Load mitigation methods have to be incorporated in the construction sites in future to reduce the impact that EV-charging points on the overall load on buildings. One of the main methods is to install a load-management system which works by regulating the power to each charging point.

4.2.5 Implications of EV and Smart Charging for the infrastructure sector

By 2050, it is predicted that EVs will account for two-thirds of all vehicles on UK roads. With the government tasking the construction industry with building 300,000 new homes a year by the middle of the next decade, infrastructure companies need to prepare for the impact EVs will have on the power supply for residential developments. Understanding the diversity of EV charging options and what will be most suitable now - and into the future - is crucial. The challenge developers face is to use new technologies to deliver smart solutions to meet the needs of homeowners and businesses by implementing a future-proof energy infrastructure. Progressive house builders have an opportunity to differentiate themselves by installing charging points at new developments – this could boost house prices and sales, raise their brand profile and help meet sustainability targets. This is already happening and required in affordable developments.

Installing communal charging areas could also provide an ongoing source of income from residents paying to charge EVs, and communal charging facilities could potentially be sold as part of the development to management companies. In time, there is even the possibility of EV batteries using the shared facility and being combined as part of an energy storage solution (Vehicle-2-Grid system), providing an income stream by selling energy back to the grid. For mixed use schemes, considering how commercial and residential spaces will share the energy infrastructure will be essential. On larger schemes, commercial areas could provide space for decentralised energy generation to support increased electrical demands across the entire site.

Off-grid renewable power supply solutions - such as waste to energy plants, PV or wind turbines - would not only facilitate EV power requirements but would also secure future energy supply on site. In addition, such schemes would go towards meeting developers' environmental targets. There is a clear window of opportunity for progressive developers to maximise the commercial potential of EVs and carve out a market-leading brand position.

4.3 Theme 8: Re-Powering

Key Trends	Timeline	Impact
Key Trend 1: Re-powering Wind Power Plants With many onshore wind farms typically having 20 or 25-year design lives, owners are keen to maximise utility of existing assets and implement life extensions of five years, 10 years, or even more, as an economical alternative to repowering. With the need to decommission, reconstruct and deploy modern equipment, often repowering is comparable in both cost and manpower to building a new project. Often bigger and better turbines are not compatible with existing foundations and bigger machines also mean turbine spacing and layout needs to change, adding both planning and engineering costs.	**Next** (5-10 yrs)	**High**
Key Trend 2: Future Scope of Wind Energy and Re-powering €52bn was invested in wind energy industry in Europe in 2019. Governments and policy makers see the technology as a major driver to transition from fossil fuels and conventional power assets. Onshore wind is a mature and proven technology attracting a wide variety of investors. Wind energy already meets 15% of Europe's power demand but even with installations up 27% in 2019 compared with 2018, the rate of installations needs to double to reach the goals set out in the European Green Deal of making Europe climate neutral by 2050. There are positive signs that the financial markets will continue to support wind energy projects. With borrowing costs expected to remain low, wind energy projects make an attractive investment in the long-term.	**Future** (10-20 yrs)	**High**

4.3.1 Introduction to Re-Powering

This section will focus on Re-Powering wind power plants as it is identified as a market with significant opportunity for growth. Re-powering is the process of enhancing the capacity or efficiency of older power stations by replacing the whole or part with newer ones which results in a net increase of power generated e.g. Solar and Wind power plants. Re-powering entails two types of actions. In Solar plants, Re-powering is designed to increase the performance and the energy yield of the plant. Solar Photo Voltaic (PV) plant Re-powering is applied to existing plants and can be utilised for extending the life of new plants at the end of their initial design life, projected at about 20 to 25 years. Revamping applies to distressed PV plants, those underperforming to their original specifications.

For Wind power stations, which will be the focus of this report, full Re-powering refers to the complete dismantling and replacement of turbine equipment at an existing project site, including the tower and foundation. With full Re-powering, some of the existing project infrastructure is assumed to be utilised in the new project. There is also the potential to offset Re-powering costs by recycling or selling older equipment. Partial Re-powering is defined as installing a new drive train and rotor on an existing tower; some peripheral components may also be replaced. Partial Re-powering allows existing wind power projects to be updated with equipment that increases energy production, reduces machine loads, increases grid service capabilities, and improves project reliability.

4.3.2 Re-powering Wind Power Plants

As wind power facilities age, project owners are faced with plant end-of-life decisions. Technological advancement suggests that project owners might be able to increase their profits by refurbishing or replacing older equipment. Re-powering first emerged in the early 1990s in the California and Danish wind power markets and was followed by the Dutch and German markets in the 1990s and 2000s[32]. There has also been interest in Re-powering in India and other parts of the world. Denmark and Germany have generally been the most active Re-powering markets, followed by California.

Denmark was the first country to actively promote Re-powering. Public policy support for Re-powering was first instituted there in 1994. In 2001, policy support was adjusted to provide an additional premium on top of the standard feed-in tariff for repowered projects that previously used turbines smaller than 100 kilowatts (kW). Additional incentives beyond the standard feed-in tariff remain in place for repowered projects that previously used turbines smaller than 450 kW. In the UK, only 19 onshore wind farms have exceeded 20 years of operation as of November 2016: of these eleven are still in operation (through lifetime extension), two were decommissioned, and five projects were repowered. In total fourteen Re-powering projects have been completed or approved in the UK since 2010. These wind turbines will soon reach the end of their designed service life, which is typically 20 years. As a consequence, the wind industry needs to prepare for upcoming challenges, such as maintenance of aging assets, assessment of structural integrity, lifetime extension decision making, and decommissioning of turbines. Lifetime extension is appealing in that it can increase returns on investment of existing projects, but experiences to date are limited[32].

Operators must decide which option is best for their aging wind farms; options include: i) lifetime extension, ii) Re-powering, and iii) decommissioning of the site. Technical, economic and legal aspects drive the decision-making process. For lifetime extension, wind turbines must have sufficient structural life remaining that their safety level is not compromised. In addition, wear-out of components translates into higher operation and maintenance (O & M) costs and turbine downtime. Wind farm operators must sell the produced energy at the spot market or find bi-lateral agreements if no governmental subsidies exist. Changes in legislation prohibit Re-powering of some existing wind farm sites. Uncertainties make the decision process complex.

As one of the first nations to invest heavily in wind power, the UK's first wave of UK onshore wind farms are now approaching the end of their terms. These wind farms were installed around the turn of the millennium, when turbine technology was less developed and costs higher. The Energy and Climate Intelligence Unit (ECIU) which is predominantly funded by the European Climate Foundation and the Grantham foundation, published a study *Repower to People*[33] suggesting that the UK could and should repower some sixty (750 turbines) onshore wind farms over the next five years and so gain a net increase in capacity of more than 1.3GW, and an electricity output of more than 3 terawatt hours (TWh) per year. This is enough to power nearly 800,000 homes, based on conservative estimates. As well as offering potentially lower costs compared with developing a new site, Repowering is also logical given that many of the earliest wind farms are in locations that have the best wind resource. Similarly, the RenewableUK report, "*Onshore Wind: The UK's Next Generation*" published in April 2019 warns that more than 8 gigawatts (GW) of onshore wind – which currently generates nearly a fifth

[32] European Wind Energy Association (EWEA) "Wind in power - 2015 European statistics"
[33] Energy & Climate Intelligence Unit (ECIU), 2018. Repower to People

(17.5%) of the UK's entire renewable power output – could be retired over the next two decades. It sets out the case for building new projects with more powerful turbines on existing wind farm sites. Replacing older turbines with more efficient models means that fewer turbines would be installed than are currently operating at each site.

Onshore wind is the cheapest source of new electricity generation capacity. Electricity from repowering projects is likely to be even cheaper than that from new sites. Even with an additional 'flexibility' cost to account for output variability, power from these repowered wind farms would save more than £77 million per year compared with obtaining it from gas-fired power stations, lowering energy bills as well as reducing carbon emissions and dependence on imports fossil fuels. Repowering would benefit a supply chain based increasingly in the UK as well as local communities through payments from the developer. These community funds are already the most popular way for wind farm owners to give back to the local area, with a potential pay-out of more than £100 million from this first wave of repowering projects. As many of the oldest wind farms are based in Scotland and Wales – which also benefit from both community and political support – more than 80% of these community payments would flow to regions in these countries.

4.3.3 Future Scope of Wind Energy and Repowering

In 2019 the wind energy industry invested €52bn in Europe, €19bn of which was for the financing of new wind energy projects. The remaining €33bn included investments in new assets, refinancing transactions, mergers and acquisitions at project and corporate level, public market transactions and raised private equity. Investments in new onshore wind farms alone were €13.1bn which will finance the construction of 10.3 GW of new projects[34].

Governments and policy makers see the technology as a major driver to transition from fossil fuels and conventional power assets. Onshore wind is a mature and proven technology attracting a wide variety of investors. Wind energy already meets 15% of Europe's power demand but even with installations up 27% in 2019 compared with 2018, the rate of installations needs to double to reach the goals set out in the European Green Deal of making Europe climate neutral by 2050. The Scottish government remains committed to onshore wind as the lowest-cost new-build electricity generation in the UK. The Office for National Statistics (ONS) released data that shows that almost half (45.8% - £1.5 Billion)[35] of the UK's turnover from onshore wind activities was generated in Scotland in 2016 with an installed capacity of 7.3GW.

There are positive signs that the financial markets will continue to support wind energy projects[36]. The economic slowdown likely to result from the COVID-19 pandemic will very unlikely result in central banks increasing interest rates which in turn will keep borrowing costs low, making it a good time to take on debt for long term investments. Wind energy projects make an attractive investment and in the long-term there should be plenty of capital available to finance them.

[34] Wind Europe - Financing and investment trends The European wind industry in 2019
[35] Office for National Statistics - UK Environmental Accounts: Low Carbon and Renewable Energy Economy Survey: 2016
[36] BBC News - RJ McLeod wins £67m deal to build 240MW onshore farm

5.0 Conclusions

As the three scenarios illustrate, the infrastructure sector could look quite different in the near future. Current business models, strategies and capabilities will not be sufficient in any of these future worlds. This report has examined eight identified themes through the lens of three Future Scenarios. Key trends along with their potential impact were highlighted for further consideration, summarised in Table 2 below.

Table 2: Summary of Key Trends of Eight Identified Themes

Theme 1: Smart Cities	Timeline	Impact
Key Trend 1: Zero Emissions City	Future (10-20 yrs)	High
Key Trend 2: Smart Grid	Next (5-10 years)	Med
Key Trend 3: Biogas	Now (0-5 years)	Med
Theme 2: Virtual Reality	**Timeline**	**Impact**
Key Trend 1: Building for Tomorrow with Virtual Reality	Now (0-5 years)	Med
Key Trend 2: Collaborative Virtual Environments	Next (5-10 years)	High
Key Trend 3: Augmented Reality	Next (5-10 years)	High
Theme 3: Cloud Computing	**Timeline**	**Impact**
Key Trend 1: Cloud Based Systems	Now (0-5 years)	Med
Key Trend 2: Blockchain Technology	Next (5-10 years)	High
Theme 4: 3D Printing	**Timeline**	**Impact**
Key Trend 1: 3DP Gaining Momentum in Construction	Next (5-10 years)	Med
Key Trend 2: Extra-terrestrial Buildings with 3DP	Future (10-20 yrs)	High
Theme 5: Autonomous Vehicles	**Timeline**	**Impact**
Key Trend 1: Autonomous construction vehicles	Now (0-5 years)	Med
Key Trend 2: Construction Equipment transformed to Robots with sensors	Next (5-10 years)	High
Theme 6: Net Zero Carbon	**Timeline**	**Impact**
Key Trend 1: Energy Efficiency is the Way to Go	Now (0-5 years)	Med
Key Trend 2: Net Zero Energy Buildings	Next (5-10 years)	High
Key Trend 3: Towards 100% Net Zero energy built environment	Future (10-20 yrs)	High
Theme 7: EV Charging	**Timeline**	**Impact**
Key Trend 1: Sustainable Transportation	Now (0-5 years)	Med
Key Trend 2: Smart Charging	Next (5-10 years)	High
Theme 8: Re-powering	**Timeline**	**Impact**
Key Trend 1: Re-powering Wind Power Plants	Next (5-10 years)	High
Key Trend 2: Future Scope of Wind Energy and Re-powering	Future (10-20 yrs)	High

In the first Scenario, **Building in a Virtual World***,* the identified themes of *Smart Cities, Virtual Reality and Cloud Computing* were examined. Cloud-based solutions have proven to be vital to enable remote working during the current pandemic and the potential of some of the technological trends that were highlighted could become essential in future pandemics. This Scenario is very much here ***now*** (albeit at an early stage) and will continue to develop in the ***next*** (5-10 years) and ***future*** (10-20 years) time horizons.

The second Scenario, **Factories Run the World**, examined the themes of *3D Printing* and *Autonomous Vehicles*. This scenario and the associated themes are making rapid progress in many sectors, driven by Industry 4.0. In the Infrastructure sector, there are signs that the application of advanced manufacturing techniques such as 3D printed components and automated/robotic vehicles to prepare sites remotely could add significant value to productivity and manage challenging sites more safely. This scenario will flourish in the ***next*** (5-10 years) and ***future*** (10-20 years) time horizons.

The final Scenario, **a Green Reboot***,* examined the themes of *Net Zero Carbon*, *Electric Vehicles* and *Re-Powering.* It aims to address the sustainability of our current infrastructure system through an examination of trends that aims to seize opportunities to reduce the impact of existing and future infrastructure on the planet and ecosystem to achieve Net-Zero Carbon. This Scenario needs to be considered across all three time horizons given the pressing nature of the climate emergency. The key trends highlighted requires urgent implementation.

It must be noted that these Scenarios are not mutually independent and their evolution is very much driven by each other. The rapid developments in the virtual world can significantly enhance the value of factories that can integrate digitalised workflows and this will undoubted have a significant impact on enabling a green reboot through the generation of sustainable methods and materials.

The majority of this paper was brought together before the Covid-19 pandemic, which has brought to the fore a profound set of challenges to how we all do things currently. The fact that all key themes identified are still highly relevant despite recent setbacks gives some assurances that they will continue to be relevant in future. In McKinsey & Co's May 2020 report entitled *"How construction can emerge stronger after coronavirus"*, both its short and long term trends include *increased digitisation* and *further investments in technology or digitisation and innovation of building systems*. In addition, it proposes a set of actions for success which include: *accelerate rollout and adoption of digitisation* and *identify opportunities to shift work off-site*.

The identified Key Trends in Table 2 could help a civil engineering or infrastructure business organisation assess the potential opportunities that are most closely aligned to its current strategy or used as a starting point for developing a more radical alternative. Understanding trends is an important prerequisite to preparing for the strategic implications mapped out in the scenarios and implementing scenario-based actions as soon as it is appropriate. The actions organisations take to prepare for the future should include finding and retaining talent with right skills, and allowing them to flourish. Actions should also include embracing digitalisation to foster rigorous use of data and digital models, as well as adopting other advanced technologies at scale. Finally, companies must pursue new opportunities through a green reboot across the value chain with the aim of achieving Net-Zero Carbon to achieve a sustainable and resilient infrastructure system.

Glossary

Artificial intelligence: the theory and development of computer systems able to perform tasks normally requiring human intelligence.

Autonomous: denoting or performed by a device capable of operating without direct human control

Biogas: gaseous fuel, especially methane, produced by the fermentation of organic matter.

Cloud computing: the practice of using a network of remote servers hosted on the Internet to store, manage, and process data, rather than a local server or a personal computer.

Data mining: the practice of examining large pre-existing databases in order to generate new information.

Decommissioning: withdraw something from service.

Drone: a remote-controlled pilotless aircraft or missile.

Emission: the production and discharge of something, especially gas or radiation.

Extraterrestrial: of or from outside the earth or its atmosphere.

Fossil fuel: a natural fuel such as coal or gas, formed in the geological past from the remains of living organisms.

Low-Emission Zone (LEZ) set an environmental limit on certain road spaces, allowing access to only the cleanest vehicles and can help to transform towns and cities into cleaner, healthier places to live, work and visit.

Software as a Service (SaaS) cloud-based service where instead of downloading software your desktop PC or business network to run and update, you instead access an application via an internet browser.

Smart grid: an electricity supply network that uses digital communications technology to detect and react to local changes in usage.

Virtual reality: the computer-generated simulation of a three-dimensional image or environment that can be interacted with in a seemingly real or physical way by a person using special electronic equipment.

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