ENGINEERING REBELLION: SCENARIOS AND PERSONAE

SCENARIO AND PERSONA 1

Future civil engineer persona – a Resilient City

Scenario from American Society of Civil Engineers (ASCE): Resilient Cities

www.futureworldvision.org/scenarios/resilient-cities

Overview

While governments in this scenario are slow to react to climate change, civil engineers need not be.

Infrastructure design will need to account for encroaching sea water, extreme storms and growing populations. Digital systems that control water networks will need to be designed in a secure and integrated manner that responds efficiently to increased demand. Roads, bridges and ports will need to be elevated and redesigned to minimise environmental damage, while seawalls, levees and barriers will need to be built to protect cities from higher sea levels and more frequent natural disasters.

The construction industry, including owners, engineers and contractors, will need to move away from a short-sighted focus on build cost in favour of lifecycle costs. Otherwise, the costs of climate response will quickly become overwhelming, as infrastructure is replaced after one disaster only to be brought down again by the next one.

Civil engineers will need to integrate advances in materials science into future projects. Resilient materials will also be useful beyond the areas most prone to disasters, as society and engineers grapple with issues associated with increasing urbanisation and overcrowding.

The responsibility will increasingly be on civil engineers to understand the system dynamics of climate defence and sustainability. Improved materials will help, but not without integration into new mass transit infrastructure, smart buildings, and planning for the obsolescence of traditional defences such as levees and seawalls.

A civil engineer's key attributes in this Resilient Cities context:

Theme	Engineer's skills
Business models	▪ Whole-life cost expert and passionate advocate, including how to account for, and pay for, repeated repairs or replacements caused by repeated climate disasters. Also whole-life costs that allow for upgrades of assets as materials science develops. ▪ Successful in programme and project management. A civil engineer will need to ensure these schemes are developed on time and to budget to ensure increased protection from all repeated climate disasters. ▪ Includes focus on outcomes and relationships with supply chain to draw on their expertise and R&D (Project 13).

	▪ Focuses on customer needs, thinks proactively, works collaboratively and communicates their concerns and expertise for the greater good. Uses technology to enhance and expedite solutions and has an awareness of multiple disciplines so that they know who can help to solve the problem with them (Susskind). ▪ Finds the solution that gives a balanced set of outcomes for environmental, social, economic, materials use/manufacturing, health and wellbeing. ▪ Able to notice new instances where human creativity and ingenuity are needed, and to develop products and services based on these.
Construction profile and diversity	▪ May be university educated, but is equally likely to have become a professional via an apprenticeship, which may also be rooted in a discipline outside of traditional civil engineering – for instance, an environmental scientist, geographer or another engineering discipline involved with civil engineering. ▪ Proud of their construction skills and expertise, and actively curious about construction with new materials and how these will perform with existing materials, or under pressure from climate disasters (e.g. salt water, prolonged heat, repeated flooding). ▪ Strongly aware of what life is like in areas of increased urbanisation and overcrowding so that they can use these insights both to design infrastructure that minimises the problems of these, and to make use of the opportunities they offer for design improvements. ▪ Highly skilled – elevating existing roads, bridges and ports has many construction challenges. ▪ Able to relinquish past assumptions if necessary e.g. "We've had a seawall here for centuries so we must maintain it at all costs."
Digital	▪ Uses computer modelling techniques to finetune gut instincts that are borne from liaising closely with all stakeholders, including communities and their needs. ▪ Works towards developing a world digital platform for climate change monitoring. ▪ Uses a digital twin to test solutions. ▪ Understands how data can be used to justify building or not to build but adapt, upgrade or find a new way. ▪ Able to use data to operate water control systems (e.g. digitised SuDS networks; water distribution under drought conditions) and to design for digital systems that can detect increasing patterns of demand. ▪ Able to analyse data (with and without various digital technologies) to identify changing patterns of demand or stress on assets. ▪ Able to understand what data different infrastructure types (e.g. water, electricity) need from each other to enable more effective and efficient design and operation as an integrated system, at the same time as managing cybersecurity risks across different infrastructure types. ▪ Able to understand how missing data/signal from temporarily removed/damaged sensors (e.g. because of a storm) can be substituted.

Institution of Civil Engineers

	▪ Data analysis to plan for the future needs to be at the forefront of engineering design. ▪ Alert to potential new uses for data. ▪ Data is at the heart of their thinking and solutions – for the environment, for communities, heritage, culture, and so on. ▪ Makes use of data to inform decisions over adapting and upgrading before building new. ▪ Where the most sustainable solution cannot be implemented, can propose a transitional solution that accepts the constraints of now but builds in resilience to adapt to something better.
Sustainability and net zero	▪ Alert to climate change projections in relevant locales, their updates, and the implications of these for the design of future infrastructure. ▪ The development of sustainable materials will be critical, although if adapting to extreme climate events is critical, sometimes just the materials already available are used. ▪ Understands the implications of climate change projections for the vulnerabilities of existing infrastructure – for example, where does reinforcement/defence need to occur (e.g. higher walls around electricity substations in some areas, to protect against flooding)? ▪ Able to use methods that enable challenging sustainability targets to be achieved on projects (e.g Transition Engineering's InTIME method). ▪ Able to plan for, and persuade others of, the obsolescence of traditional defences such as seawalls. ▪ Aware of the multiple benefits, including physical resilience, that natural structures and environments can have (e.g. green spaces for excess water absorption, reducing heat island effects). NB: This scenario doesn't mention low-carbon concrete, changing electricity networks and moving away from fossil fuel dependence for urban transport systems – but it's fairly likely future engineers will need to work on these!
Productivity	▪ Is productive in methods of working and communicating, using BIM and other technology. ▪ Is focused on reducing errors and waste on site. ▪ Knows how to keep construction projects productive and therefore to programme. ▪ Is part of a diverse team of professionals that includes both generalists and specialists who are continually learning and keyed into developments around them. ▪ Design, fabrication and construction is now closely aligned to manufacturing, and infrastructure is built using standardised components, leading to reduced design and construction risks. ▪ Alert to the ways in which existing infrastructure is not performing well, and the reasons for it, and how increasing demand (from growing populations) and climate disasters can provide the pressures for rethinking.

	▪ Focused on reducing energy consumption in infrastructure system operation (e.g. BacTest that enables WWT to test whether treated water is now safe via bacterial presence rather than relying automatically on maintaining five days of continuously very high water temperature). ▪ Able to grasp opportunities for improved productivity e.g. via more collaborative business models, digital, more diverse workforce etc.
Systems thinking	▪ Alert to understanding what success looks like – the sum of parts e.g. not just the tunnel, but the functioning, of a new metro. ▪ New ways of system thinking needed – a more overall approach to how the world is adapting to climate change and adoption methods is needed. ▪ Alert to the need to include understanding of how multiple factors interact, including: ▪ Climate change projections with specific features of the locale (reduced vulnerabilities in some places, increased vulnerabilities in others) ▪ Different climate change features with each other (e.g. increased flooding and increased drought), and how these will then affect infrastructure and city performance ▪ New materials with existing materials, in different infrastructure types (mass transit, buildings, bridges, ports)
Foresighting methods	▪ Recognises the possibility of different future scenarios. ▪ Confident in using foresighting methods to test thinking and design assumptions and to engage city leaders, asset owners, colleagues and construction workers in novel insights that need to be integrated into business models, ways of working, asset design, etc. ▪ Aware of multiple foresighting tools or involved in groups (firm strategy, academic research) that are improving existing, or developing new, foresighting tools, so that new factors can be included as they emerge.
Embracing upskilling	▪ Will not necessarily have a traditional civil engineering degree. ▪ Recognises the pace of change in climate, digital and materials science and the effects of urbanisation and population growth – and is active in upskilling in all of these areas.

SCENARIO AND PERSONA 2

Future civil engineer persona – a Dispersed Settlement

Scenario from ASCE: Dispersed Settlements

www.futureworldvision.org/scenarios/dispersed-settlements

Overview

In this scenario, degradation in the quality of urban life, driven by ineffectual policy-making and inadequate funding in the context of climate change, leads to emigration from traditional cities into new, relatively isolated settlements. Advances in telecommunications infrastructure enable widespread virtual commuting rather than actual transportation networks, thereby decreasing the amount of overall travel. These new settlements are especially attractive given stagnating conditions in traditional cities.

Instead of planning for megacities, civil engineers will need to plan and design hyper-efficient, isolated, self-contained smaller cities.

Civil engineers will need to take a leadership position in advocating for protecting and supporting the increasingly important digital communications infrastructure, even though the inefficient policy-making is a challenging context.

Energy networks will look very different as these new settlements adopt solar and new solar storage technology. Instead of one-way distribution grids, they will need to be able to adapt to surplus and droughts in different locations. Civil engineers will be involved in developing this technology and planning how best and most efficiently to lay out a small community with fully-distributed energy generation and predominantly pedestrian transportation.

A civil engineer's key attributes in this Dispersed Settlement context:

Theme	Engineer's skills and some questions to ask
Business models	▪ Focus to be on outcomes not output but also becomes more specific to the needs – skills/availability and efficiency of supply chain/geography – of each settlement. ▪ Will there be inefficiencies owing to smaller-scale solutions, limited knowledge share and scope for scaling up innovation/R&D? Could there be large variations in cost per unit of work owing to variations across settlements? ▪ An upside of this scenario is that there might be better cross-discipline knowledge share (e.g. across health, finance and architecture). Re Susskind: may there be a greater risk of the profession becoming obsolete to the work of data scientists/digital experts owing to the reduced complexity of infrastructure systems in smaller urban settlements compared with cities, but high understanding of the power of digital among everyone? What would differentiate civil engineers? ▪ Some civil engineering skills could become obsolete e.g. large power station design. Is there a downside to this scale of civilisation and decentralisation e.g. standards, best practice? ▪ The engineer would buy into Sinek's 'finite game' thinking as this scenario is settled, but one wouldn't expect much to change over time. Perhaps they would be able to develop a range of successful business models that could be taken within a dispersed city. ▪ They are also able to develop business models: • Across multiple infrastructure types at smaller settlement scales i.e. affordable for a single smaller settlement • Across multiple small settlements for a single infrastructure type e.g. for cybersecurity

	• That are relatively low-tech solutions (due to restrictions on finance) so that dispersed settlements can handle most maintenance and repair issues themselves (alternatively, owing to regulatory freedom and absence of governments looking at cost savings in infrastructure, innovation could be key with major developments in these dispersed settlements) • For different lifecycle payment schedules e.g. solar energy production (only upfront capital costs), solar storage/electricity storage (currently extremely expensive) • Where stakeholders may have more than one role (e.g. electricity consumption, and storage or production; ditto water).
Construction profile and diversity	▪ This engineer is one of very few with the skills required for the job owing to a limited pool of people travelling between settlements. ▪ Their skills are also limited to what is expected from the settlement they work in; they would have limited opportunities to receive training except digitally. ▪ There is a relative lack of diversity and therefore skills, although gender equality will be very much improved owing to shortage of labour within each settlement; there will be a disparity of skills/backgrounds available to each settlement, which could foster greater inequality and availability of skills to the detriment of a particular settlement. ▪ The engineer will be proud to work in mostly one dispersed settlement or small network thereof, on multiple different types of infrastructure, rather than specialising in only one type and travelling to different settlements for work. ▪ Strong interpersonal skills – they will deal with multiple issues of overlap between multiple areas of infrastructure, overlap between architecture, design and construction, and also infrastructure failure within a given settlement. ▪ They reflect the many aspects of the communities of the dispersed settlement in which they work, although male-dominated construction stereotypes may continue to an extent. ▪ How valued is a civil engineer in this scenario? Are they paid well if it is largely data-driven and on a small scale, like a machine operator?
Digital	▪ Extremely savvy about cybersecurity and digital networks because these are critical to the functioning of the independent dispersed settlement. ▪ Sensors providing info for multiple different types of analyses simultaneously – surplus and droughts (water, electricity). ▪ With reduced urbanisation and consolidation of services, energy demand is not so high and, therefore, can be powered through locally produced energy supply. This would lead to less data. Will AI or robots be necessary? ▪ Aware of potential changes that bring risks e.g. viruses, aliens, as well as open to, and active in creating, innovations that improve performance.
Sustainability and net zero	▪ Self-sufficient and wary of other dispersed settlements so focuses on how new efficiencies of infrastructure systems or resources can be achieved.

	▪ Much less emphasis on new-build – the vast majority of work adopts a carefully thought-through adapt and re-use strategy.
Productivity	▪ The engineer may not be so aware of what 'good' looks like, so infrastructure in one settlement may not be performing as well as in another. ▪ Productivity reduced owing to a lack of diverse skills. ▪ A lack of decision-makers will increase productivity owing to faster decision-making about construction and infrastructure: however, sometimes sub-optimal decisions are made as a result, including poor-quality health and safety decisions. ▪ Limited scope for R&D in a formal way, but there is more scope to try out new techniques informally. ▪ Ability/need to re-use existing materials and structures because of local focus, although limited scope for formal R&D, and too small for DfMA (Design for Manufacture and Assembly). Informal scoping out of new techniques is important (requires curiosity throughout projects not as a separate process outside of projects). ▪ Pressure to avoid mistakes because of funding and resource constraints; ditto overlap between infrastructure types. ▪ Lack of robots, but not software, means productivity gains cannot all be achieved through reliance on digital tech (on the assumption that robots are expensive and require highly expert repair and maintenance that may not be possible for every settlement).
Systems thinking	▪ An upside of this scenario is that there might be better cross-discipline knowledge share (e.g. across health, finance and architecture). ▪ Focus is on co-dependencies of different types of infrastructure in one settlement, but not so much across the same type of infrastructure across different settlements. A sort of high-quality systems thinking at dispersed settlement/microclimate level leads to highly productive designs, construction, operation and maintenance for that specific context. ▪ The inclusion of systems thinking right from the start of all projects is expected as standard competent practice, always a critical consideration from the outset. ▪ Intense inter-local focus within the diverse settlement increases the importance of understanding interactions between different infrastructure types. ▪ Ditto, may give an advantage in understanding systems integration engineering. ▪ Need to deploy systems thinking to understand risks and potential threats to the settlement's infrastructure that come from unexpected outside sources. Strong intra-local focus makes neglect of 'outside context'/networks with other dispersed settlements more likely.
Foresighting methods	▪ May need to develop new foresighting methods for smaller-scale dispersed settlements on a case-by-case basis.

	▪ Foresighting methods for wider regional/national context still very important but insufficient granularity on their own.
Embracing upskilling	▪ The method of entering civil engineering becomes more apprentice-based or through passing skills from generation to generation, which might create inconsistency across the profession or limit how it develops. ▪ Civil engineers would not receive much formal training in this scenario. ▪ Multidisciplinary learning within the dispersed settlement, but a lack of access to a national professional accreditation scheme such as ICE's or ASCE's. ▪ Need for access to knowledge, learning and other civil engineers in other dispersed settlements via the internet, otherwise understanding could become parochial. ▪ However, if infrastructure is not changing a great deal and climate change has stabilised, there will be less of a need to upskill rapidly.

SCENARIO AND PERSONA 3

Future civil engineer persona – Extinction Express

Scenario from Arup's 2050 Scenarios: Extinction Express

www.arup.com/perspectives/publications/research/section/2050-scenarios-four-plausible-futures

Extracts from the original text

Overview

An obsession with pursuing economic growth has caught up with the planet and affected humanity's quality of life. The depletion of Earth's natural resources has necessitated the expansion of new extractive frontiers in space and the deep sea. The absence of social services makes coping with the health implications of air pollution, job insecurity, destruction of property from extreme weather events, and drought-induced food insecurity only possible for affluent people. Consequently, domestic and international political stability has broken.

Sample features

- Geo-engineering and GMO crop development are the only way to feed the global population
- Large-scale air domes have been constructed in many of the world's most prominent cities, to create safe havens for some of the populations
- Extreme weather, high wealth gap, 2.5C increase in global temperature, low global cooperation, 23% renewable energy

Detailed description

Climate change and the inexorable consumption of Earth's resources has resulted in fundamental destabilisation of natural systems. Resource, energy, water and food shortages are pervasive across the world. Environmental consciousness is largely non-existent.

The established world order has shifted, and the global centre of power has moved to the East. China has a strong economic presence and position globally and dominates the research and manufacturing of technologies. To meet the global population's growing demands, resource colonies on the moon and in the deep sea have been established.

The Amazon rainforest, one of the world's largest carbon sinks, is almost entirely cleared. The Brazilian government sold large portions of the forest to online retailers in the 2030s to provide resources for their ever-increasing shipping needs; packaging is in high demand. Space and deep-sea mining are booming as demand for natural resources have surpassed the previous all-time high. The incentive to reach and operate in these inaccessible and inhospitable locations is greater than ever; access means the ability to harvest rare materials and resources that are increasingly scarce on Earth. While the US, China, Russia and Europe conduct the vast majority of extractions, Japan, India, Indonesia, Iran, Brazil and others are expanding their presence, leading to an increase in resource conflicts.

Natural resources that were previously taken for granted and considered basic human rights – such as water, air, ozone, land and the oceans – are now genuine commodities. Water sources are highly regulated with restricted access; corporations now hold a monopoly over the majority of the global water supply. Those who can't afford to pay for the premium cost of water must rely on localised, often contaminated water sources. Similarly, clean air is accessible only to those who can afford it. Large-scale air domes have been erected over many of the world's most prominent cities, including Shanghai, Delhi and London, to create safe havens for some segments of their populations. Individuals restricted from accessing air domes experience increased rates of asthma and lung cancer that go largely untreated.

Agricultural systems suffer extensively from the transformed climate and regularity of extreme weather. Geo-engineering and GMO crop development are the only way to feed the global population. Seeds are controlled by Holycrop, a US-based business, which monopolises the market. Crop strains are continuously being updated and improved to withstand the ever-more serious climate shocks and new threats from insects and microbes. To maintain productivity, farm land is regularly treated with the newest artificial nutrients and fertilisers, leading to continued and severe soil degradation. Agricultural producers must subscribe to expensive and ever-changing upgrade plans with restrictive user agreements limiting where they can sell, who they can sell to, and what types of fertilisers they can use. Consequently, many small farmers have been pushed out of the industry and agricultural activities are almost exclusively completed at an industrial level. The farmers continue to struggle, with their livelihoods controlled by the corporations.

Most nations have adopted a nationalist agenda. They only look outwards to engage in bilateral agreements for the exchange of natural resources or food. Mass climate migration and resource wars are daily occurrences. Governments are widely criticised by their constituents, accused of willfully shirking their responsibilities towards ecosystem health. Small guerrilla communities are common in localised areas attempting to undermine the dominating empires. Governments seek these groups out and contaminate land and waterways in surrounding areas to cut off all access to resources.

Isolationism has been on the rise for years, and society is driven by a fear of the 'foreign' and 'different'. This has been exacerbated by an unheralded number of climate refugees. Europe was the first region to implement an immigration cap and put in place asylum bans and is the driving force behind 'solving' the migration crisis through the modernisation of refugee camps – city-sized camps on remote islands and in desert areas to house the world's poorest, far away from the rest of society. Those who live in these camps refer to them as 'controlled hells'.

There is a stark division between the have-lots and the have-nots. Goods are easily accessible, but only to the wealthy few. The global middle class is almost non-existent. Information and knowledge exchange across borders is shaped by protectionism, and five independent internets have developed. The ubiquity of social scoring systems has resulted in a new type of caste system, in which few people can choose their jobs freely. Previously high-income, high-status tech work is widely automated, and the world has seen a resurgence in low-paying service jobs, with the lower classes, the majority, scrambling for any work. Food and resource processing take place in industrial factories where workers have little protection and few rights. These roles, where humans work alongside robots, keep a large portion of the human population busy.

These changing human conditions have resulted in rampant use of 'smart' and 'happy' drugs that manipulate the human brain, helping to cope with daily life. Reliance on these drugs has led to an increase in perceived health while new types of resistant bacteria continuously threaten large portions of the population. Very few people can rely on, let alone afford, access to healthcare, but those that can use precision medicine and genome editing, further dividing society along the lines of basic human needs.

Timeline of developments

2022: Smog domes for the wealthy

2024: New food patents soar – Holycrop progresses towards monopolistic control of seeds for foodstuffs

2026: China tackles food constraints – struggles to find space, food, energy and resources to sustain its population

2030: Illegal Arctic Sea mining for minerals

2033: China-Russia Arctic Alliance – technology and seabed mining access exchanged

2031: Increasing number of climate migrants owing to large-scale coastal flooding and collapse of coastal biodiversity; stringent refugee immigration limit in the EU

2039: Another 'safe hell' opened – to house climate refugees, either floating islands or in deserts to keep 'them' far away from the rest of the population

2039: Ban on foreign students in Australia and New Zealand; isolationism and 'fear of the foreign'

2040: Moon and deep-sea mining by corporates: extraction of water, rare elements and rare minerals controlled by the highest corporate and state spenders

2045: The one-millionth designer baby is registered; the world's top 1% fly to China's premier fertility clinic to select their future baby's attributes

2049: Toronto experiences its first Zika epidemic

A civil engineer's key attributes in this Extinction Express context:

Theme	Engineer's skills
Business models	▪ Able to develop business models for critical resources that have very tightly controlled value chains (e.g. water) designed to prevent the loss of any value to the poor. ▪ Able to identify opportunities for new trades with China in exchange for access to its world-leading technologies and resources. ▪ As engineers themselves may be part-paid in access to good quality resources (e.g. water, food, air), they need good understanding of how to calculate this. ▪ Can incorporate the costs of very strong barriers and protective walls/structures as a common theme running throughout many types of infrastructure (both against extreme weather damage, but also against guerrilla communities). ▪ Can create robust business models encompassing multiple risks for deep sea and moon resource extraction – very high value, very high new tech, and very remote equals uncertain outcomes. ▪ Can work with health professionals (respiratory experts) and insurance industry for new types of infrastructure – e.g. air domes – to quantify the benefits from new infrastructure types and hence evaluate affordability of new tech proposals. ▪ Able to develop cheap business models focused on initial upfront costs not asset lifecycle for 'safe hells' and service sector factories/premises. ▪ How to build in costs to cover increasing frequency of damage from extreme weather events?

Construction profile and diversity	▪ Low skilled work is undertaken by machines so there is very little work – using digital technology and robots is the only way civil engineering as a profession survives. ▪ Designing and building gigantic and/or complex structures – follies for the rich – as well as air domes and underground dwellings to provide respite from pollution and heat respectively. Engineers designed low-cost (and low-quality) mass manufactured modular units for 'safe hells' initially, but this work is now carried out using robots. ▪ The race for resources has required new settlements to be built in more bizarre locations including the depths of the sea and on the moon. Civil engineers have adapted their skills to design equipment that extracts and transports these resources and the logistics of distribution. ▪ Strong security and trust issues for all personnel working on infrastructure for the wealthy – e.g. air domes, water systems – so utmost confidentiality and project and employer loyalty are key attributes required from all infrastructure professionals; personality characteristics may become as important as technical ability. ▪ Very difficult to enter the profession unless earlier generations of your family were also involved in this form of work; do the citizen digital monitoring systems need to make special allowances/find incentives for new entrants to the profession to ensure sufficient employees?
Digital	▪ Working with robots on joint tasks as standard. ▪ Robots perform all tasks performed by early-career engineers in 2020. ▪ Need for very sophisticated digital skills, especially to manage barriers between five different internets, with ad hoc nation-specific exchanges between them as new resource exchange treaties are negotiated. ▪ 'Safe hell' manufacture and monitoring is almost completely digital to keep costs extremely low; ditto poor quality materials used; but does need human sign-off when ready to be used, and also some human involvement in moving refugees into a 'safe hell' (with strong element of robot assistance).
Sustainability and net zero	▪ No recognition of the need for net zero, or any action on this front; acceptance of increasing rates and intensity of extreme weather events only required insofar as infrastructure systems and key resources for the wealthy (water, food, valuable minerals) are maintained/controlled. ▪ Strong focus on design, operation and monitoring of infrastructure assets to prevent any contamination by pollutants, whether from the resource systems of the poor, or novel insects and microbes. ▪ Greater understanding of effective measures to defend against novel insect invasions and new pathogens.
Productivity	▪ Since civil engineers work on such bespoke products because of the efficiency of robots, productivity cannot be compared. Machines, however, are being designed to be ever more productive.
Systems thinking	▪ Need high degree of awareness of interactions of factors but not to identify and optimise synergies across infrastructure types across areas, cities, or regions, but to identify and then prevent the occurrence of interactions so that the city areas and farming areas for the wealthy are not contaminated in any way by the poor world. ▪ Similar thinking applied for the destruction of guerrilla resistance settlements. ▪ Need to replicate current large-scale systems – e.g. a river basin – within smaller, within-city systems, in some form – or to prevent access to that system by others permanently. ▪ Greater understanding of the requirements of large-scale artificial food production systems Design out user involvement in effective and efficient use of infrastructure; for the wealthy, all-enclosed self-functioning systems are required that keep all assets and resources flowing within that system with no input required from

	wealthy users; for 'safe hells' or poor areas, need to prevent user access to controls or barriers of system in order to protect the wealthy.
Foresighting methods	▪ Use of foresighting methods primarily to identify new sources of threats from outside the nation state so that defensive actions can be taken without attempting to address underlying causes e.g. new areas from where refugees will originate; resource wars with other countries; and type and frequency of extreme weather events.
Embracing upskilling	▪ Early career work involves shadowing or co-working with robots on the manufacture and assembly of structures, following machine-led designs. ▪ Engineering knowledge is not as freely available as at present (five different internet systems and very strong national boundaries) so opportunities to learn from fellow professionals in other internet systems will be very highly prized, especially those in China. ▪ ICE has gone underground as its way of thinking for the greater good of society and the environment is unpopular with the wealthy. It continues to share knowledge with its small but loyal membership. Membership numbers are steadily rising from an all-time low and a rebellion is in the planning.

SCENARIO AND PERSONA 4

Future civil engineer persona – Greentocracy

Scenario from Arup's 2050 Scenarios: Greentocracy

www.arup.com/perspectives/publications/research/section/2050-scenarios-four-plausible-futures

Extracts from the original text

Overview

Climate action and biodiversity recuperation are top of every national and transnational agenda. Many countries, including China, India and the US, have powerful scientific advisory boards that directly influence national legislation. The scale and speed of environmental degradation of the first quarter of the century, with extreme weather events, rising urban air pollution and climate migration, has driven governments and major global cities to act swiftly, and strictly, on climate action. Popular unrest and ardent civil demand leads to unanimous agreement that everyone must help the planet to heal.

The results of the galvanised global efforts have been unprecedented for the environment, but not without significant sacrifice from people who are realising the trade-offs did not quite work out for them. Achievement of the targets have come at a much greater expense to society than expected – the changes to where people live, what they eat (70% of meat-like products are lab-produced) and how they travel are sudden and extreme.

Humanity now lives in self-imposed servitude to the environment under the mantra of 'happy planet, happy people'. Extreme urban densification, driven by urban growth boundaries for land-use regeneration, has led to a premium on space – most apartments have an average of $8m^2$ per person. Protected lands have expanded worldwide, and significant resources have been allocated to restoring ecosystems. The effects of climate change can still be felt and sea levels continue to rise, yet the impacts are less severe than expected.

Myriad new job types have been created, but most are dangerous and undesirable, as workers are tasked with cleaning up environmental pollutants and processing materials for re-use. Pervasive carbon taxation and individual carbon allowances have severely slowed consumerism.

Key features

- The global population has increased in line with 2020 predictions, but humans have to tread lightly on the planet and answer to sustainability/planetary health scientists to ensure the health of the planetary ecosystem. These sustainability/planetary health scientists are evolved civil engineers – this new role has increased the breadth of the role of civil engineer.
- Only projects with the highest environmental values are implemented, generating ‘green bucks’ for the economy. Prioritising climate change and environmental issues has limited the choices available for humans but enabled step-change innovations in the name of sustainable planetary engineering design – new-build and adaptation. This is aided by good global cooperation with everyone aiming for the same common goal. Although the air is clean and most energy is renewable, people travel less, rarely eat meat and life is highly controlled and digitised. People live in dense megacities, served by smart infrastructure. Communication is digital rather than face-to face for activities such as work, education and shopping. Leisure time is spent outdoors in praise of nature and human relationships and as such mental wellbeing and health is very good. This is also experienced globally.
- To achieve these outcomes, there have been medium levels of global cooperation, and an almost total use of clean energy which have helped to stabilise the climate. However, there continues to be some sea level rise (ongoing heating as a result of past climate heating) and there is a very large wealth gap so that consumerist goods and lifestyles are out of reach for most people in all societies around the world.[1]

Timeline of developments

2024 - MANDATORY ECOLOGY AND GREEN TECH EDUCATION

STEM education, especially ecology and green tech education, has become mandatory curricula in most countries, driven by scientific advisory boards assisting government decision-making.

2026 - COP32 RATIFIES SBT FRAMEWORK

Global acknowledgement of overfishing and the ratification of science-based targets as an accepted global framework are agreed at COP32 in Singapore.

2027 - ‘PLANET FIRST’ GUIDES GLOBAL DECISION-MAKING

CoCA (Cities of Climate Action) agree on ‘planet first’ as a guiding principle above all else at their annual meeting at the Virtual Planet Meeting room – no physical travel was necessary. In line with global agreements and regulation, the most powerful cities across the globe are driving massive change.

2028 - CARBON QUOTA TRIALS

Facilities opened in Copenhagen and Los Angeles to introduce personal carbon quotas to their populations, intended to become mainstream by 2035.

2032 - FIRST ECO-RE-EDUCATION FACILITIES OPEN

C40 cities open pilot ‘Eco-Re-education’ facilities for citizens who repeatedly violate environmental codes of behaviour.

2033 - SYNTHETIC FOOD PRODUCT TAX BREAKS

Considerable tax breaks are introduced for synthetic food products – as edible fish stocks, the world’s most important protein source, are nearing depletion and biodiversity is at an all-time low, governments recognise synthetic food products as the only option to feed their populations.

2040 - NUTRIENT DEFICIENCIES FROM LABFOODS

Nature journal article rebuking LABFoods Surrogate Pseudo-Proteins claims that a significant share of the global population may be suffering from severe micronutrient deficiency or ‘hidden hunger’. Followers of *Nature* and members of the burgeoning ‘SunGrown’ movement demand investigation of the issue – knowledge of previous nutrient deficiencies cases has been suppressed.

2042 - EXPANSION OF MARINE PROTECTED AREAS

UN expands Marine Protected Areas (MPAs) across the globe and cruise liners are banned in the North Sea, Baltic Sea and the North Atlantic by UNEP-backed Northern Nature Alliance.

2046 - GLOBAL CARBON XCHANGE OPENS

Global Carbon Xchange (GCX) opens in Lagos, a city that became a leader in the CoCA initiative following the successful agreement of 2027.

2049 - GHG TARGETS ACHIEVED

Global carbon levels have declined to 1950 levels.

2050 - SECOND GLOBAL MARCH FOR THE PEOPLE

The second global march ‘People first - not planet’ takes place in most CoCA cities across the globe.

Suggested infrastructure for Greentocracy

The overwhelming priorities are an enormous reduction in both greenhouse gas (GHG) emissions and removal of excess GHG from the atmosphere, biodiversity increase and ecosystem regeneration, and persistent maintenance or increase of these actions over time. Infrastructure is understood as a part of the whole planet’s functioning, and valued primarily for its essential role in preserving, and regenerating, a functioning biosphere and increased biodiversity. Exclusively human benefit is an optional second.

The following life-preserving or life-generating functions are essential for infrastructure:

- **Massive removal of GHG emissions** from the atmosphere (e.g. 97% renewable energy; very restricted meat production; carbon capture and storage, CCS; biochar where feasible) so that GHG levels are brought down very rapidly, and then kept down constantly.
- **Creating hyper-high-rise buildings** for residential, industrial or commercial purposes in intense-density megacities to leave the vast majority of the planet as ‘life-generating zones’; health and safety will need to be a key consideration in this (e.g. Grenfell).
- **Protecting massive ‘life-generating zones’** against all human presence and activity with high-tech security and strongly punitive sanctions (e.g. high security walls and checkpoints around all such zones that are constantly monitored).
- **Protecting against rising sea levels and extreme storms** by prioritising ‘ecological engineering’ methods that utilise non-human lifeforms (e.g. seagrass replanting can reduce coastal erosion and sequesters CO2) whenever possible; adopting ‘blue-green city’ (in tandem with landscape architects) or even ‘floating city’ methods (in tandem with naval architects) where flood and coastal erosion protection is not possible; more collaboration with other professions and increasing the breadth of civil engineers to achieve this.
- **Generating and transporting energy using the most energy-efficient and earliest-deployment methods**, repurposing existing fossil fuel infrastructure wherever possible rather than constructing new infrastructure (e.g. hydrogen as an energy vector from offshore windfarms to onshore locations, via old oil and gas pipelines; requiring all humans to use energy-generating pavements for a minimum amount each day).
- **Constant R&D to improve the EROI** (energy return on investment) on whole lifecycle of renewable energy assets i.e. ensure that the energy expended in operation and construction is less than that generated during operation.

In addition, there have been changes in the way infrastructure is required to operate, and the ways civil engineers work with other professionals and their expertise.

The focus on operating infrastructure with maximum usage at all times to achieve the ‘greatest societal bang for the least environmental buck’ has created a very low ‘down time’ expectation for infrastructure, with correspondingly far higher rates of wear and tear. For instance, road, rail, ship or plane journeys only happen if cargo or passenger capacity is full, and roads that are not utilised at least 85% of the time have been converted to other pro-biosphere uses such as SuDS. This has significantly increased the pressures involved in performing timely and high-quality maintenance and repair of infrastructure, as well as the frequency with which repairs are needed. Unfortunately, this has also reduced the limited work-life balance of construction professionals.

Very high density living means that extremely tall buildings (600m-plus) have now become the norm, not only for residential uses but also industrial and commercial uses. The structures of such hyper-tall buildings need to be capable of supporting extreme forces as does the ground – foundations of some of these buildings are more complex or extensive than their superstructure height. New build, maintenance, or repair of adjacent structures (e.g. water and electricity mains; new tunnels) are even more risky and complex.

The observations of ecosystem, infrastructure, and built environment performance – from ecologists, landscape architects, farmers and civil engineers – are *the* critical inputs that are used to determine future consumption and activity levels for the global population, and hence permitted infrastructure use, repair and construction. Monitoring these systems (ecosystem, infrastructure in hyper-megacities) is also essential to detect potential lapses in biosphere-protecting performance. Consequently, civil engineers need to be able to engage in highly skilled discussions with these other professions.

A civil engineer's key attributes in this Greentocracy scenario:

Theme	Engineer's skills
Business models	In tandem with strong understanding of financial capital and the financial costs of infrastructure projects, the engineer also needs: ▪ Very strong understanding of the GHG consequences of all forms of infrastructure, throughout the asset lifecycle, and how this can be expressed in natural capital valuations. ▪ Skills to create business models that prioritise the preservation of existing natural capital and its regeneration. Business model based on huge investment in sustainability-focused innovation and R&D; overarching compulsory methods for sustainability are implemented across whole companies. ▪ Skills in using automation, new technology and data to inform value and outcome-based decision-making. Value is skewed – through planetary business model – towards maximising 'natural' capital. ▪ A collaborative business model is necessary to some extent to deliver projects, but the pyramid places the civil engineer and planet's health at the top. ▪ Huge planetary responsibility. Governments look to civil engineers for guidance on everything. This has affected the kind of person entering the profession. ▪ Able to include slack in business models so that there are the resources available to cope with new unexpected sources of GHGs e.g. during operation or to adapt solutions for when new technology emerges. ▪ Skills in funding are not so important, so much as the argument for achieving the ultimate end 'goal' of global ecosystem stabilisation. ▪ Able to imagine new purposes for existing infrastructure. ▪ Able to bring new stakeholders to an existing business model when necessary (e.g. landscape architects, coastal ecologists).

Construction profile and diversity	▪ A head for extreme heights! ▪ Civil engineers call the shots. Sustainability is the main religion. Civil engineers are extremely valued by society and every child wants to be one and attain their kind of god-like status. However, the training is extremely demanding. It takes 10-15 years to become a civil engineer, including intense education and spells of apprenticeship and further life-long learning (comparable with the process of becoming a doctor: five-year degree, two foundation years and specialist training until you are no longer classed as a junior doctor). ▪ Children are identified as early as nine years old as having the right combination of imagination and technical competence. Governments track these children and shower them with the best education (including spiritual, music, sport and art, both as valuable in their own right, and as rich source of skills in leadership, communication, focus, working under pressure, as well as creativity) and experiences to nurture them and keep them. ▪ There is potential for much diversity across the profession, but the ultimate selection process often comes down to the mental capacity of the individual to deal with the enormity of the job. This is why their education involves plenty of emphasis on spiritual, music, sport and art to get the balance right. ▪ It is a huge honour for families to have such a child and they attract huge future incomes through salaries and sponsorship deals. A downside is that these offspring are often genetically engineered in the first instance and/or to maintain that level of status in subsequent generations. Governments want such people to also be kind and have a high sense of societal value, but this is difficult to maintain when guided so strongly by science. The aim is to have, for example, Stephen Hawking, Jonathon Porritt and Nelson Mandela in a single person. ▪ This engineer has a background that has exposed them to every part of science so they have the tools to design hugely complex solutions that meet the extreme needs of society, currently global ecosystem stabilisation. ▪ The type of person attracted to the profession is highly intelligent and a skilled communicator. They may also be motivated by money and status. ▪ Collaborative skills diminish in this new civil engineer as they get used to calling the shots. There is large scope for corruption as so much value is based on so few people, so few decisions and such long timeframes for implementation (infinite game).
Digital	▪ Adept at using data to monitor asset performance, likely GHG emissions, and predict maintenance and repair schedules. ▪ Highly conscientious in collecting digital analyses of infrastructure performance throughout the asset lifecycle. ▪ Skilled at analysing datasets from other hyper-megacities or ecosystems to improve performance. ▪ Skilled at creating new software routines to perform analyses of infrastructure performance, especially where unexpected increases in GHG production have occurred. ▪ Masterminds huge digital thinking factories (humans, AI and robots) to develop and analyse the effect of new technology and solutions in digital twin models.

Sustainability and net zero	▪ Sustainability is the guiding force for good – the new religion. ▪ Always a net zero first focus – is there any need for new build at all or can new benefits be achieved from existing assets? ▪ Able to understand infrastructure within the global biosphere context of GHG emissions and biodiversity. ▪ Sensitive to early signals of GHG increases above permitted levels for the infrastructure asset. ▪ In active ongoing conversations with ecologists about infrastructure's impact on the ecosystems where it's located, or about unexpected lifeforms in residence near infrastructure, or unexpected GHG emissions.
Productivity	▪ Civil engineers are high-level thinkers. The supply chain – a mixture of AI, robots and humans – are all under tight control to be productive and led by civil engineers. Manufacturing and civil engineering is carried out under the same roof. There is very little new build unless it is a huge demolition job, followed by a subsequently even bigger new build where construction is undertaken as a factory-type activity. ▪ Vast, highly standardised solutions will make maximum use of DfMA for new build: for example, 1km-high living cities. Some buildings are being built while earlier sections are being upgraded. ▪ Highly skilled at recognising wasteful use of energy, transport, materials and time. This informs whether to build new or adapt or find a no-build, data-driven solution, which can have huge impacts on human activity. ▪ Highly skilled at developing and implementing systems to monitor and reduce wasteful usage (e.g. combination of digital, onsite and offsite construction practices, new business models). Able to recognise when coastal or defence methods are no longer bringing GHG or human life benefits and abandon them for new methods (e.g. move population, floating cities designed with naval architects). ▪ Adept at using new technologies, working methods and collaboration to perform repairs under very high-stress conditions. ▪ Either highly skilled in geotechnics or able to work very closely with geotechnical and structural engineers to ensure that hyper-rise building foundations are optimal in terms of robustness, absent or low GHG emissions, and financial cost. ▪ On the lookout for innovations that achieve multiple purposes e.g. seagrass can sequester CO2 and also reduces the power of waves reaching the coast.
Systems thinking	▪ Combination of digital twins and systems thinking is the basis for how cities are run. ▪ A systems thinking-first approach, with a special focus on the parameters for a life-sustaining climate. ▪ Skilled at understanding infrastructure from a wide variety of perspectives (e.g. different infrastructure purposes, or different professions – civil engineering, planetary health practitioners), so that novel uses for existing assets can be developed – for example hydrogen as an energy vector via existing oil and gas pipelines.

	▪ Able to recognise the ways multiple factors can contribute to productivity problems e.g. project culture plus high GHG-producing materials plus professional skills plus stakeholder expectations could lead to funder demands for lax GHG standards.
Foresighting methods	▪ Skilled at using foresighting methods to suggest new ways in which GHGs might increase unexpectedly and how these have an impact on ongoing projects and society. ▪ Foresighting skills will need to include transitionary steps so that vast infrastructure solutions do not need to be demolished and rebuilt owing to changes in future scenarios or obsolete technology. ▪ Foresighting tools and models will often need to be developed in tandem with planetary health biologists so that relevant interactions between carbon-based lifeforms, infrastructure and society are recognised, understood and fed into infrastructure design, construction, operation and decommissioning.
Embracing upskilling	▪ Geotechnical expertise is a core essential skill for all civil engineers regardless of which type of infrastructure they have chosen to work in and regardless of whether they train via apprenticeships, university degrees or other methods. However, its far greater importance necessitates a larger component of both core training and lifelong learning to be geotechnical. ▪ For some children selected to have a particularly strong aptitude for civil engineering, training will start at school. ▪ This engineer will be extremely enthusiastic about learning about new technologies for life-sustaining purposes e.g. CCS, hydrogen as a vector, or new stronger materials for hyper-rise buildings. ▪ They constantly update their awareness of new predictions and models about GHG emissions and climate function as a core 'baseline' understanding that enables them to achieve the purpose of infrastructure. ▪ They also constantly update their awareness of possible points of GHG production throughout the asset lifecycle, and how these can be reduced. ▪ Methods of systems thinking and digital analysis are continually refined. Continual learning to stay abreast of new technology and even tuning into new thinking to counter any human revolution against greentocracy. ▪ A huge programme of mentoring ensures there is a pipeline of civil engineers with the right skills to sustain this way of living, including recognising how to maintain good mental health. ▪ CPD will have stringent requirements for lifelong learning.

SCENARIO AND PERSONA 5

Future civil engineer persona – Covid-19 scenario

Sourced from online publications from leading civil engineering firms about Covid-19; weblinks listed at the end of this document.

Overview

Covid-19 is the disease caused by a novel virus, Sars-CoV2, that shows strong variability in its effectiveness (i.e. how easy it is to catch it) and disease severity (i.e. how likely you are to become seriously ill or die from it). To date, older people, men, those from BAME backgrounds or those with pre-existing conditions (e.g. diabetes, obesity, respiratory disease) have been more vulnerable to becoming seriously ill, or dying from the disease than healthy young people.

The novelty and dangerousness of the virus led most countries around the world to adopt various degrees of 'lockdown' in which people's daily activities were restricted to the bare minimum necessary for survival (buying food, seeking medical treatment). Travel was hugely curtailed and 'physical distancing' (e.g. 1.5m, 2m) between people was recommended or enforced. National and regional lockdowns have since been reversed in many countries, although in some cases with subsequent more localised restrictions.

In the short term, this has had profound impacts on the ways people can, or are being compelled to, use infrastructure and the wider built and natural environments, permitting usage only if social density and interactions are at a sufficiently low level. It has also exacerbated differences and pressures between those working on essential physical tasks (food production and supply; critical infrastructure maintenance – water and sewerage services, electricity, digital; and health and social care) and those capable of working via digital technology.

Most noticeable are the challenges to commercially viable transport networks – air travel is recognised as a key mechanism that enabled rapid global transmission, and occupancy of small, enclosed spaces (e.g. planes, train carriages, buses) for more than several minutes is a source of high transmission and infection rates. However, since the virus can also be transmitted on surfaces, or through close contact between people, other forms of infrastructure and construction sites in general have also needed to change.

Vaccination programmes have offered hope of a return to normality, although their long-term effectiveness is as yet unproven. Furthermore, while the origin of this particular virus is currently unclear, many experts who predicted a pandemic in the past expect there to be future pandemics from previously novel-to-human viruses, driven by increased exposure of human populations to wild animals (as a result of loss of wildlife habitat, climate change, and 'wet markets' supplying humans with captured wild animals as food).

This is therefore both a challenging context for civil engineers and the operation of infrastructure. It also provides some exciting opportunities to lead change that was previously recommended or imagined, but seemed impossible.

Note: digital seems particularly important for continuity, designing for adaptability for short-term changes and to reset to go back on programme, to interrogate computer models for design, fabrication, programme, costing, etc. It is also important for continuing work virtually while things cannot progress onsite, to revise numbers e.g if populations decrease, or for endorsing whether the final product is needed or fit for purpose.

A civil engineer's key attributes in this Covid-19 scenario:

Theme	Engineer's skills
Business models	▪ Alert to the ways in which physical distancing delivers radical threats to existing business models (e.g. trains for domestic transport) and able to develop alternatives that have been costed and where physical changes are understood (e.g. re-dedication of rail for freight, removal of freight from roads, and use of roads for the transport of people in vehicles with sufficient physical distancing). ▪ Open to new opportunities for civil engineering and construction skills, such as emergency project management offices (PMOs) to be set up within 72 hours to ensure continuity in food distribution systems.

	▪ Designs for the reality of a range of people's vital needs and pre-existing infrastructure access e.g. not assuming all children have access to the internet for home learning. ▪ Ensures everyone is paid on time, and that all partners on a project are recognised (because infrastructure is only as good as its weakest link). ▪ Understands how economic impacts may be delayed (e.g. lockdown in March-May, but many job losses not expected until October-November). ▪ Focuses not only on 'shovel ready' projects during economic challenges, but also 'shovel *worthy*'. ▪ Develops nimble capital plans that support multiple possible futures. ▪ Ability to recognise stark truths (e.g. air travel-enabled global transmission, and many transport networks' financial viability is now seriously compromised) as a prelude to developing alternative business models. ▪ Able to argue for new business models e.g. tolling and road pricing. ▪ Comfortable with designing mixed-use business models to avoid over-dependence on a narrow sector of users. ▪ Able to calculate how to stop or delay all non-business-critical spend on projects temporarily. ▪ Integrates supply chains into project and programme business models even more than before, so that all parts of the industry are protected and can provide business continuity. ▪ Able to think outside the box of traditional business models based on at-scale operations and mass aggregation of efficiencies to deliver breakeven points.
Construction profile and diversity	▪ Sensitivity to the vulnerabilities of older workers and designing physical distancing methods and revised work practices that shield them (while also taking opportunities to increase pro-healthy lifestyle messages). ▪ Welcoming of team diversity and skilled at enabling multiple perspectives to be utilised under high-pressure conditions of 'crisis PMOs' through ongoing iterations of data collection, analysis, sharing and co-learning. ▪ Understands the supply chain impacts on construction materials and negotiating those with construction colleagues. ▪ Enables and enforces health and safety compliance in the pandemic context. ▪ Persuades colleagues of the need for increased use of offsite manufacture to keep construction happening. ▪ Helps colleagues onsite to prepare for potential further waves safely, supporting ongoing mental health and wellbeing needs. ▪ Prepares colleagues for potential site-specific local lockdowns. ▪ Repurposes existing technology for new uses e.g. thermal cameras for monitoring colleagues' health/general public health, at site entrances.

	▪ Open to sharing data to enable test, track and trace of virus spread to keep people working. ▪ With digital communications capability, the future civil engineer from any background will be able to seamlessly continue working (designing) and be productive. ▪ Site operatives already trained to use robots or remote-controlled machinery to maintain social distancing. ▪ Welfare facilities that are inclusive of the whole workforce.
Digital	▪ Adopts digital first wherever possible, and at speed. ▪ Gets digital newbies on board at speed. ▪ Skilled at using multiple technologies and to convert between non-digital and digital, or to enable effective co-operations e.g. using radio and SMS in parallel to deliver education in East Africa where not all families have access to the internet. ▪ Uses digital as a critical tool to rehearse actions and new plans in advance. ▪ Uses DfMA (design for manufacture and assembly) to provide additional capacity for backup structures e.g. virus testing centres, additional workplace hygiene facilities, additional schools or prisons.
Sustainability and net zero	▪ Able to see the sustainability and net zero possibilities in physical distancing requirements e.g. increased cycling and walking. ▪ Has a clear focus on 'critical national infrastructure' (water, food, sanitation, clean air), how they inter-relate and how to deliver them in crisis. Workforce plans to ensure these systems continue to function even with a high proportion of staff sick. ▪ Makes cities more liveable i.e. more green space for individual health reasons, plus more mixed-type of dwellings. ▪ Mixed-use and potential multiple uses of assets and structures over time (e.g. needing to repurpose central business districts). ▪ Has a re-use mindset. ▪ Manages safe disposal of waste e.g. mass disposal of PPE without enabling new transmission of virus; possibly a temporary increase in waste disposal capacity or waste disposal transportation? ▪ Accepts there might be some short-term setbacks in sustainability, but to programme in a way to get back on track. ▪ Understands how climate change increases the risk of other illnesses through increase of disease vectors (e.g. mosquitoes following extended periods of flooding), and what the points of entry into infrastructure could be for these diseases to design out pathogen pathways. ▪ Virus resilience is seen as a new domain of sustainability? Requiring robustness assessments. ▪ Understands that sustainability is not necessarily the same as resilience. ▪ Evolution of streets to enable more physical distancing.

	▪ Emergency backup e.g. generators for wastewater treatment if electricity systems fail. ▪ Redesigns fomite use (handles, rails etc) and manages safe current use – ditto elevators and tall buildings. ▪ Understands towns and smaller cities as the new focus of economic activity, with people needing strong reasons to travel to large city centres. ▪ Understands the difference between 'simple' roles that can be performed via remote digital working, and more complex roles that require attendance of an office with multiple other workers. ▪ Understands biological and time constraints on safe infrastructure operation e.g. closing down and re-opening wastewater treatment plants.
Productivity	▪ Takes opportunities to develop innovations in construction and onsite working that improve productivity. ▪ Able to phase operations according to disease vector characteristics, and design re-opening in ways that work for all colleagues onsite. ▪ Understands the details of working practices and how using PPE or other health-necessary equipment may affect them (e.g. will construction be slower if teams have to wear masks?).
Systems thinking	▪ Adopts whole-system and no-gaps thinking – because any unintended gap could be a new niche for the virus to exploit. ▪ Able to see wider and unexpected impacts. ▪ Able to work with new professional colleagues to understand what safe and effective infrastructure performance means e.g. biologists to understand disease transmission mechanisms, behavioural scientists to understand how and why people are likely to behave. ▪ Understands how different types of disease vectors are likely to interact with human social activities and infrastructure operation (e.g. cockroaches laying eggs underneath the plastic casing around silicon chips on commercial catering equipment). ▪ Understands the fragmented nature of the supply chain and how Covid-19 can compromise its effective operation. ▪ Incorporates crowd management understanding (behavioural scientists, data analysis). ▪ Identifies user/passenger touchpoints at all stages of infrastructure use. ▪ Alert to wide range of methods for controlling disease transmission e.g. very strong 'isolate and contract trace' systems in Vietnam as an alternative to lockdown.
Foresighting methods	▪ Aware of the difference between a known risk and the unexpected; able to use foresighting methods to engage with uncertainty. ▪ Able to consider effect of short-term derailment of projects during lockdown, say, and reprogramme to ensure intended outcomes are needed when required.

	▪ Alert to other novel disease vectors that may occur, and how all actions/design can provide a 'filter' for unexpected evolution of other micro-organisms. ▪ Aware of the unintended limitation of pre-existing assumptions – actively using foresighting methods to challenge assumptions. ▪ Uses modelling to provide insight for decisions in crisis situations. ▪ Skilled at disaster scenario planning – to know when something is new and needs a new approach.
Embracing upskilling	▪ Enthusiastic adopter of new area of skill 'infrastructure epidemiology' – understanding the touch-point between humans and physical assets in infrastructure systems in the context of a specific disease vector, and what is needed for interventions/new practices to be effective. ▪ Able to learn and apply new types of information quickly e.g. new biological information or crowd behavior information. ▪ Able to adapt or interrogate BIM or common data environments/computer models and analysis to identify new problem areas and where new solutions can be found. ▪ Alert to materials, layouts of spaces and build-up of surfaces that help or hinder disease transmission in existing infrastructure/structures and how to upgrade to be safer, as well as design to be safer for all new projects. ▪ Understand when new building will become more important as a new, clean space to inhabit (e.g. Nightingale hospitals). ▪ Adept at designing flexible-use temporary structures and fixtures to create new facilities e.g. clinics, schools, shops.

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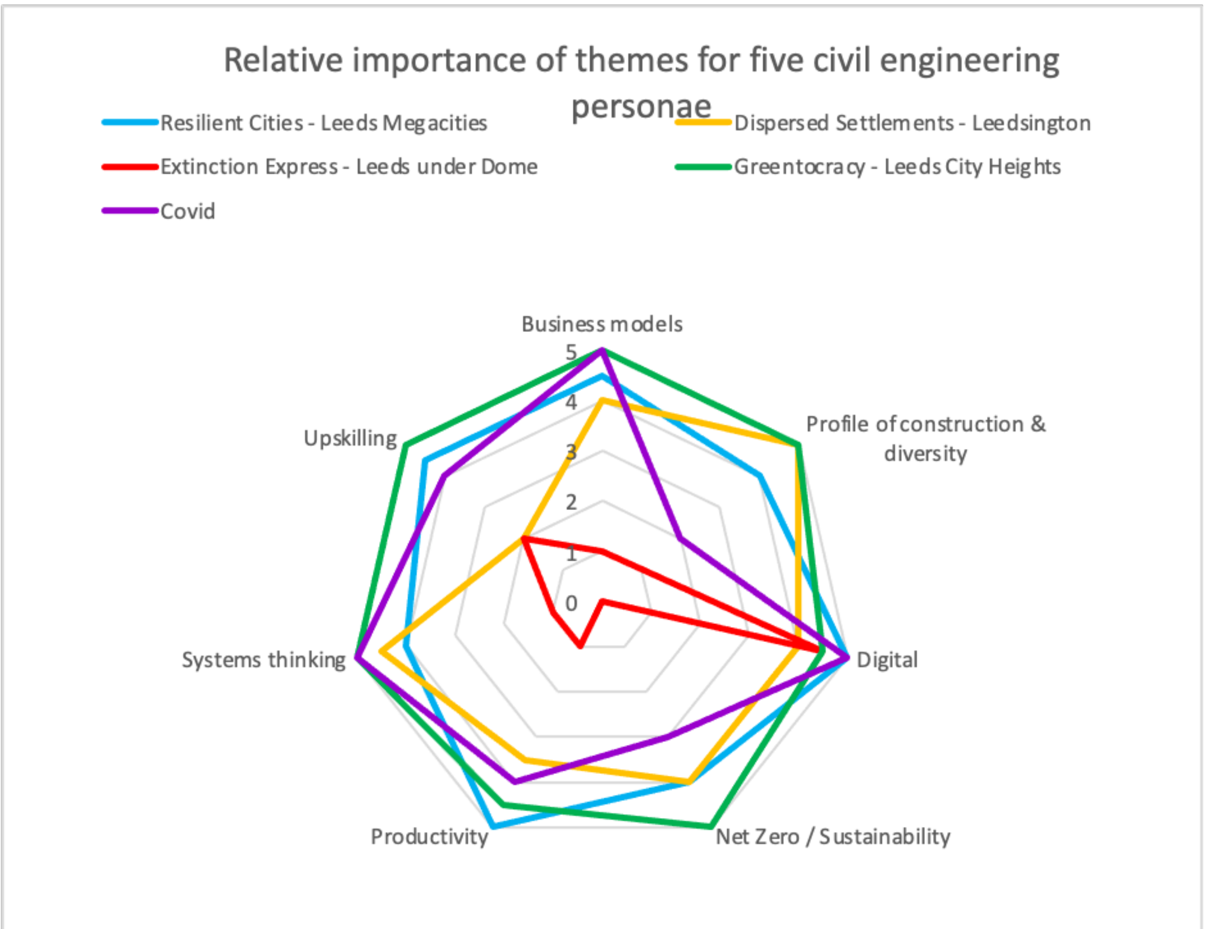
Radar chart



Radar chart explanatory notes

While there is some variation in the importance of themes in each scenario, digital, systems thinking and business models emerge consistently as the most important. The distinctive features of 'dispersed settlements' and 'extinction express' mean that they each show some differences from this. Summary explanations are in the boxes below.

Resilient Cities (source: ASCE's Future World Vision project)

This scenario compels civil engineers to take a leadership role on climate change at a city level, owing to a failure in national political leadership. All skills from the nine themes, therefore, are highly developed. The need for digital and productivity are particularly pertinent owing to the intensity of design and build output required to create ever more resilient infrastructure amid the climate crisis.

Dispersed Settlements (source: ASCE's Future World Vision project)

This scenario forces civil engineers to take a hyper-local focus owing to city governance and funding failures. Civil engineers do the best they can to deal with current and future climate change impacts within their settlements, but there is strong distrust between settlements, making cybersecurity to safeguard the settlement's energy generation and water systems paramount. On the positive side, profile of construction and diversity is very good because civil engineers are sourced from their own communities. A downside is that there are constraints on sharing knowledge and upskilling. All civil engineers' skills under themes, therefore, are highly developed, except upskilling.

Extinction Express (initial source: Arup's 2050: Four Plausible Scenarios document, but with additional infrastructure-specific content added by Engineering Rebellion core team)

This scenario compels civil engineers to work mostly for the extremely wealthy and powerful, delivering complex and elaborate infrastructure to protect them amid global ecosystem collapse. The majority of the population is impoverished. Importance of net zero carbon/sustainability is nil and all other themes are similarly low scoring. Upskilling is required to support digital and new structure development, which is the key enabler for delivering for the elites.

Greentocracy (initial source: Arup's 2050: Four Plausible Scenarios document, but with additional infrastructure-specific content added by Engineering Rebellion core team)

This scenario forces civil engineers to focus entirely on global ecosystem recovery as climate change is dealt with as the most urgent priority over all others. There is local, national and global political backing for this. All skills under themes are, therefore, optimally developed. Relatively, digital and productivity are not so important.

Covid-19 (sources: 119 industry reports and webpages about responses to Covid-19)

In this scenario civil engineers must focus on managing virus transmission through the use (or not) of infrastructure, and how and whether new infrastructure is built. There is regard for climate change and some support for civil engineers' role in enabling society to flourish. Radical changes in society reveal the vital importance of business models, systems thinking and digital. The scenario also forces change in the profile and diversity of the workforce owing to men, older people and people from some ethnic minorities being more vulnerable to the virus so upskilling and productivity have become more important for retention and recruitment.