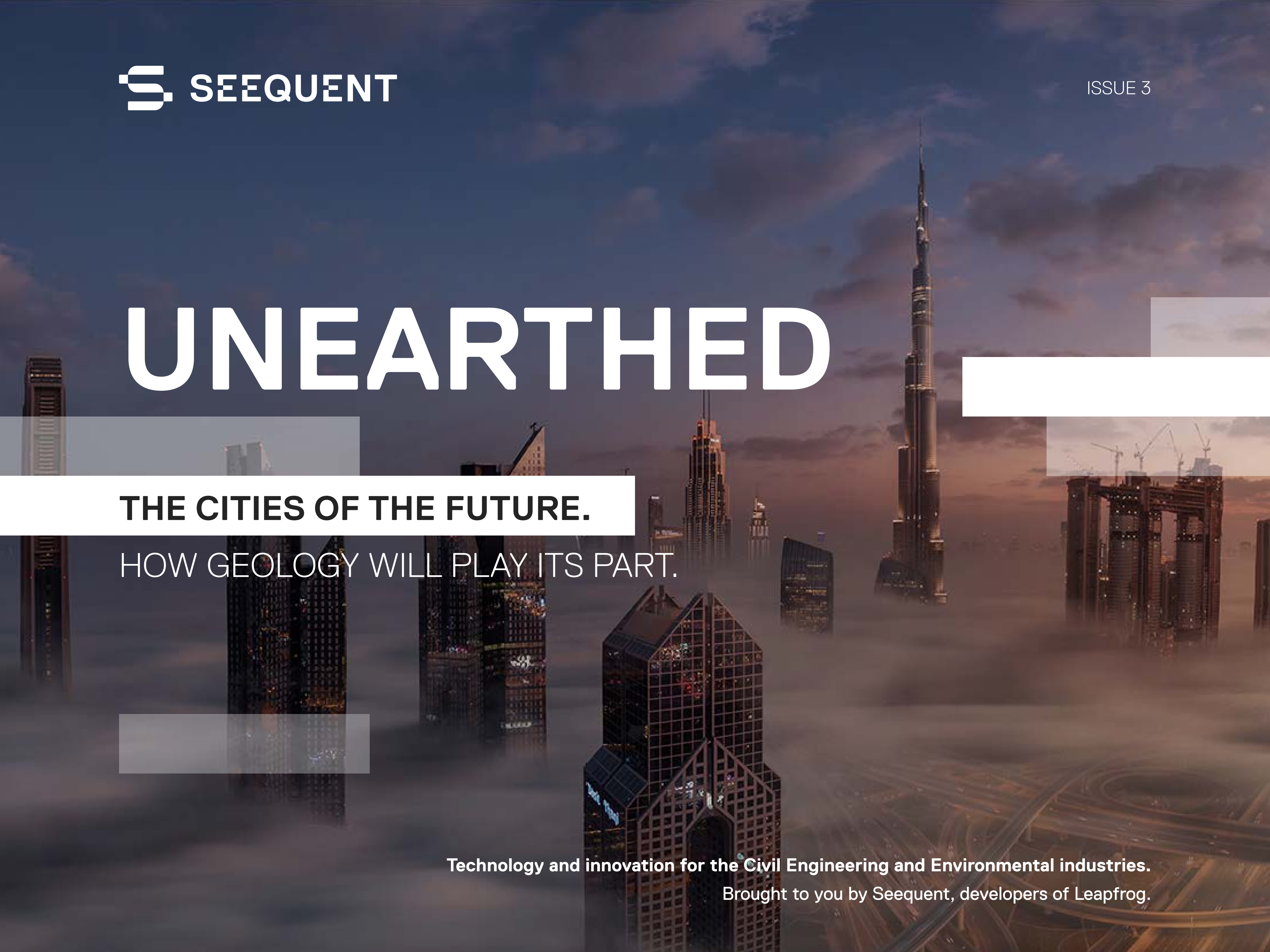


SEEQUENT

ISSUE 3

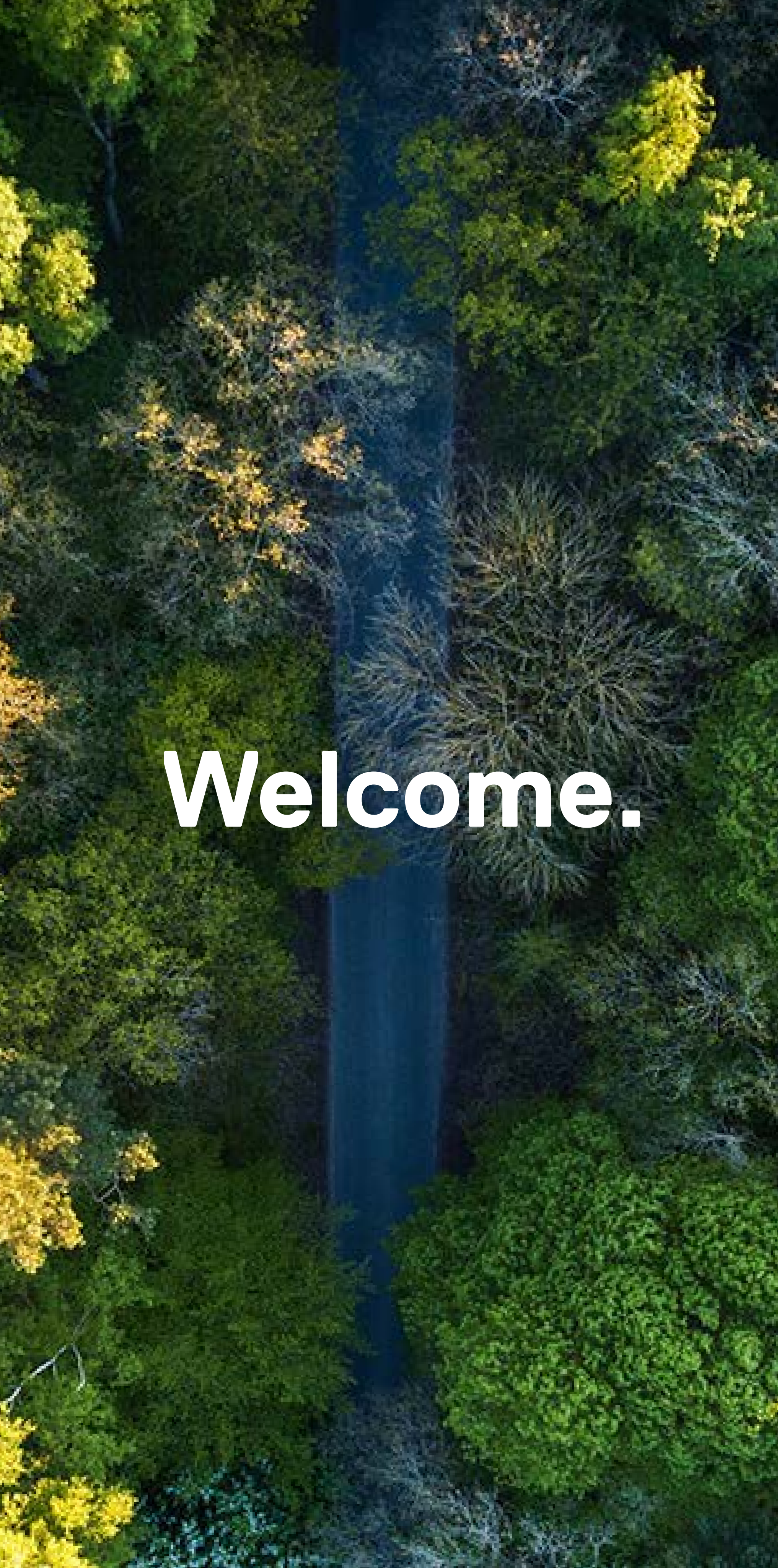
# UNEARTHED

## THE CITIES OF THE FUTURE.

HOW GEOLOGY WILL PLAY ITS PART.

**Technology and innovation for the Civil Engineering and Environmental industries.**

Brought to you by Seequent, developers of Leapfrog.



# Welcome.

**Hi, I'm Daniel Wallace. I'm the General Manager for Civil and Environmental Industries here at Seequent, and I'd like to welcome you to our third edition of Unearthed. For those who haven't seen Unearthed before, it's a global technology briefing designed to bring you innovative thinking and industry relevant perspectives for those with an interest in what's going on beneath the surface.**

In this edition we explore future cities and the latest thinking and developments on building a sustainable city in the future. We already know that cities are growing at an astonishing rate. By 2050, 68% of the world's population is expected to live in cities, and those cities will be vast. At the same time climate change in coastal areas and demand for adjacent land to remain accessible for food production are constraining the expansion of our cities horizontally and driving a need to expand both upwards and downwards.

There are many underground metro projects underway around the planet, and lots more projects to increase the capacity of aging infrastructure underground. The big question is what are we going to find when we start increasing our investigations under our cities, and how will we rise to the challenge of understanding and communicating the ground risks in these increasingly crowded subsurface spaces?

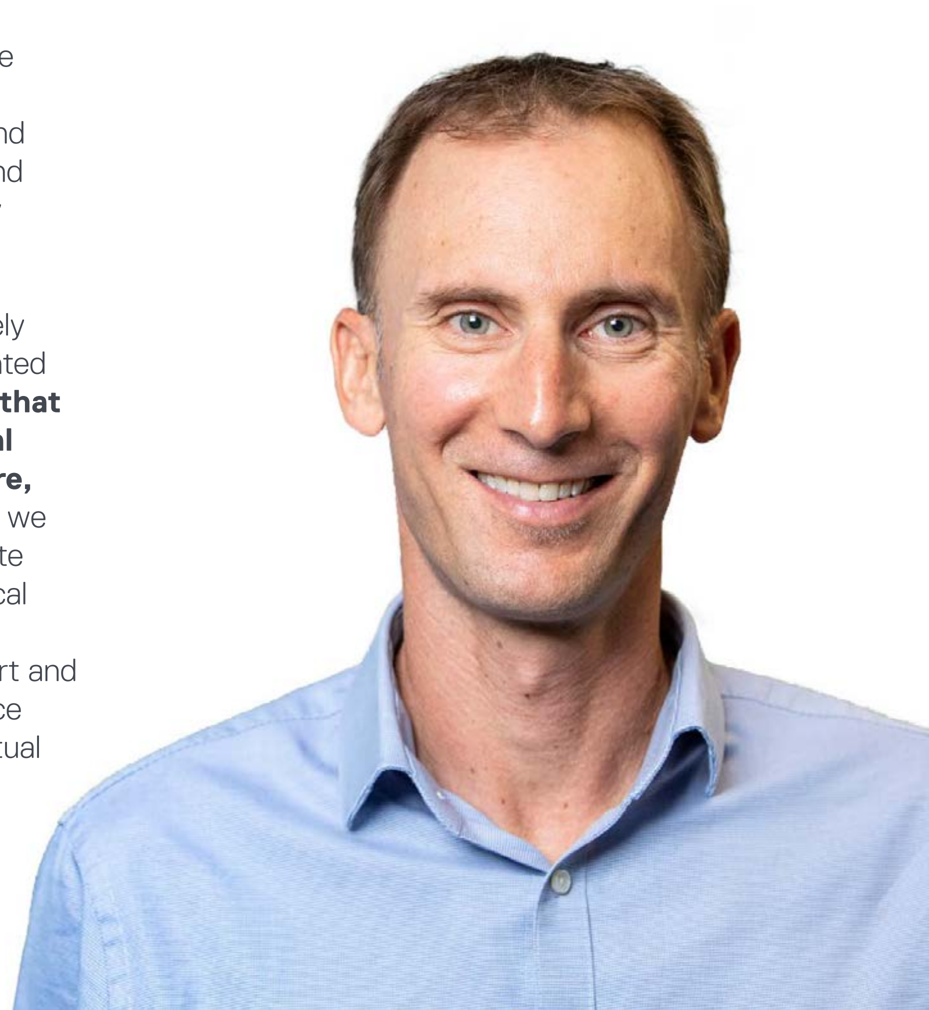
In future cities, subsurface real estate will be as closely managed and regulated as we currently take for granted in our daily lives above ground. **It stands to reason that the successes of recent collaborative and digital based smart city initiatives like that in Singapore, will be replicated for the subsurface.** As a planet we need to focus on initiatives and solutions that promote the sharing of ground investigation data and geological interpretations in the close quarters of the urban landscape to avoid duplication of data collection effort and costs. That involves building a data rich 3D subsurface understanding common to everyone, with the perpetual addition of as-built underground structures, and accessible 3D visualisation.

Seequent solutions are bridging the gap between ground models that have been traditionally considered static once construction starts, and live models that continue to be developed throughout the course of the construction. **Each phase of excavation increases our understanding of the model's certainty and upcoming phases of the excavation can be better informed, and surprises better dealt with.** Our technology is in a prime position to make this a reality because 3D dynamic modelling is in our DNA at the core of our software.

I believe the features in this issue show it is now no longer a question of whether we should develop 3D subsurface models of our cities. It's how will we do it most efficiently, and how will we manage and maintain the many model versions that will be created so that a single common understanding can be reached.

Warm regards

**Daniel Wallace**



# 42KM

London Crossrail is currently Europe's largest infrastructure project, adding 42km of tunnels and 118km of track to the world's oldest underground system. Since May 2012 **eight tunnel boring machines** have been excavating two eastbound and westbound tunnels 40 metres below the capital. Teams have worked 24 hours a day to weave the route between existing underground lines, sewers, utility tunnels and building foundations. Around **8 million tonnes of earth** have been excavated (now usefully employed in a wetland habit for birds) and **200,000 concrete segments** created to line the tunnels. The project (originally costed at £14.8bn) will lift central London's rail capacity by 10% – the largest increase since WW2. Crossrail should carry 200 million passengers a year and services are due to open in 2019.

# SUSTAINABILITY

## TOMORROW'S CITIES WILL BE VAST.

CAN THE DRIVE FOR SUSTAINABILITY KEEP PACE WITH THEIR GROWTH?


**DR THOMAS KROM**

HEAD OF SUSTAINABILITY SEEQUENT

# TOMORROW'S CITIES WILL BE VAST.
## CAN THE DRIVE FOR SUSTAINABILITY KEEP PACE WITH THEIR GROWTH?

**Dr Thomas Krom**
Head of Sustainability Seequent

**As city populations grow ever larger – and move from 'mega' to 'giga' status – what fresh sustainability challenges will they meet? We asked Seequent's Head of Sustainability, Thomas Krom, to highlight just a few.**

"If you look at the number of people who are going to be living in cities in a reasonably short period of time, the figures are astronomical. Everybody is moving into town and there are a lot more of us. In fact, there are already more people living in cities today than were living on the planet when I was born... and I'm not even that old!"

As population densities rise, cities face a plethora of challenges. Initially, it might seem efficient to congregate a large number of residents in one place. But the assumed sustainability of proximity is quickly cancelled out by resource strain, and then there's the additional heat that high-rise, air-conditioned buildings generate, stressing the microclimate.

People are starting to understand the importance of sustainability in infrastructure. As surface space becomes prohibitively expensive, or simply isn't available, more infrastructure is going underground. [See our feature on 'Going Underground' further on in this edition.] "That can be a good solution," notes Thomas "but we're already starting to see competition for that underground space as cities move water treatment, ring roads, stations and ever more of their infrastructure below the surface."

**"Unfortunately many mega cities will develop in places where you wouldn't ideally choose – like the coast, which will be threatened by rising sea levels. But we have to work with what we've got."**

### The world's fastest sinking city

Indonesian capital Jakarta is sinking by as much as 15 cm a year. Almost half the city is now below sea level, and some projections say as much as 95% of north Jakarta, closest to the sea, will be submerged by 2050. The city, home to more than 10 million, sits on swampy land, criss-crossed by more than a dozen rivers. The problem has been exacerbated by extraction of groundwater to support an inadequate piped water supply, creating even more subsidence. A $40bn, 32km outer sea wall across Jakarta Bay has been proposed to help control water levels when the heavy rains come. It's unknown whether this will solve the problem.

## Water stress

The increase in population densities and demand on water create an increased risk of water shortages. According to the United Nations recent report on World Water Development, at present, there are an estimated 3.6 billion people (nearly half the global population) living in areas that are potentially water-scarce at least one month per year, and this population could increase to some 4.8 to 5.7 billion by 2050.

“And as people move out of rural areas, potable water is going to be a major problem for mega cities. Says Thomas. “Certainly, we need to be better at reusing our waste, and we can no longer afford to pump our sewage and waste water into oceans and rivers, even if it is treated. However, while the technology exists to extract drinkable water from waste water, there are also psychological and cultural hurdles to overcome. When you tell people they are drinking yesterday’s waste, they tend not to be incredibly enthusiastic about it...”
According to a source at the UN Water Development programme, $114bn per year, or more than three times the current level of capital investment, is needed to achieve the Sustainable Development Goals on water supply, sanitation and hygiene (WASH).

Accelerating pressure on water supplies means cities are looking at drastic solutions that would have been considered foolhardy even a few years ago. For example, LA wants to remediate their saltwater plume under the city. A history of pumping more water than the groundwater system can bear has caused saltwater from the ocean to move into the groundwater. “Since the 1950s LA has been spending an amazing amount of money preventing that saltwater from coming even further inland, but now it wants to get rid of the saltwater in the aquifers altogether. Nobody has ever done anything like it on that sort of scale anywhere. It could take more than half a century to achieve.”

## A will for wider solutions

There is much debate over the cause of these challenges, but the fact is that temperatures are rising and clearly sea levels are rising too. You can sit there with a ruler and measure it. Lots of cities are under water stress. We know these are real problems and we need real solutions. “Clearly, we need a holistic approach to look at the problem as a whole, but these are always hard decisions to make, and cities and countries are not always good at that.”

“People are trying to fix things, but I think the sheer scale still challenges many people psychologically. It’s such a huge issue to get your head around.”

That's not to say there are not some clever ideas out there. In continental Europe, where district central heating is widespread, some authorities cool the return water by running it through the sidewalks during the winter. This keeps the sidewalks warm, so there's less need to combat ice with salt, and all its environmental drawbacks. It also means the return water is colder when it reaches the district central heating plant, which is better for the plant and the process.

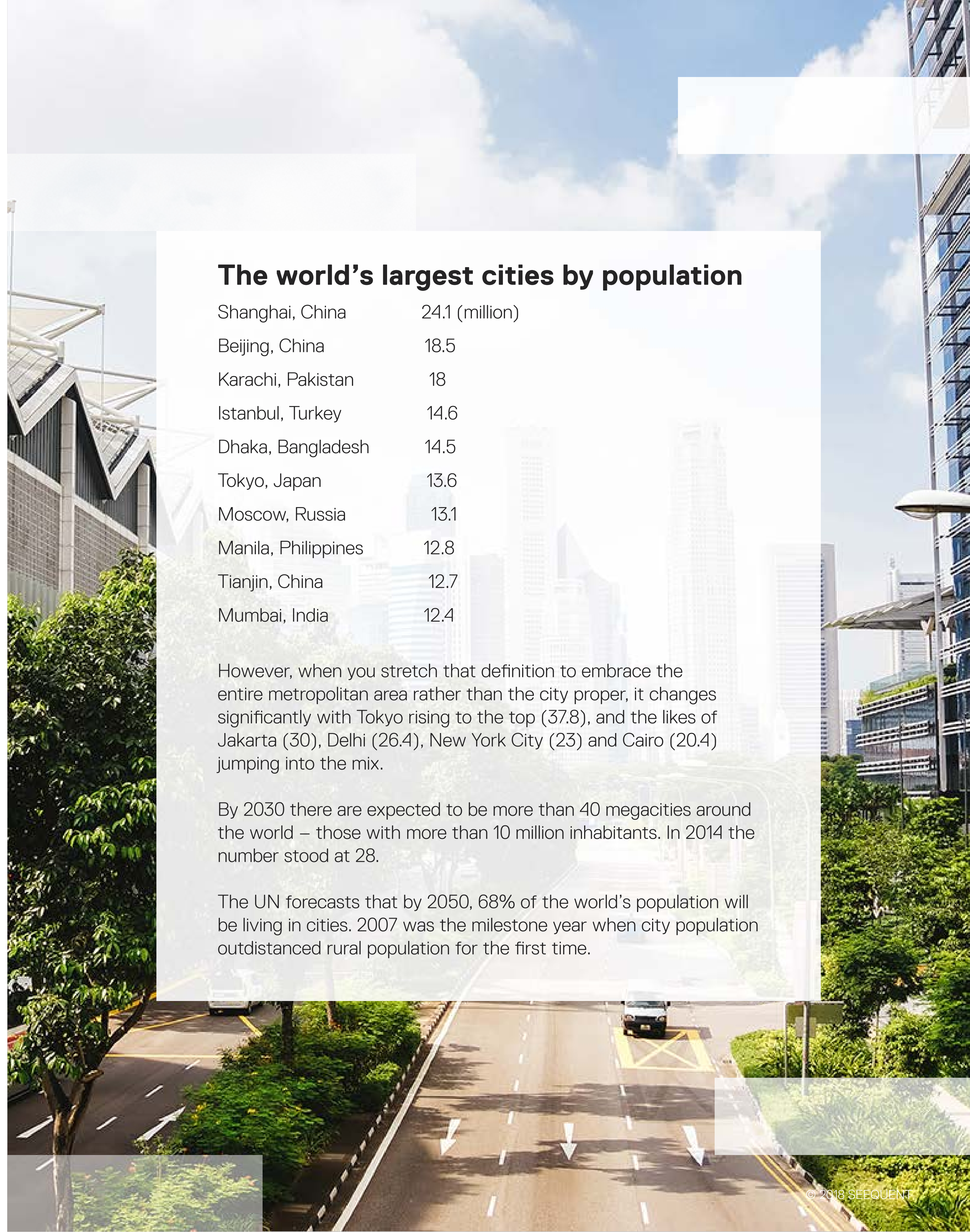
The UN's World Water Development report reviewed nature-based solutions to solving some of these challenges. The report looked at urban green infrastructure, including green buildings. This emerging phenomenon is establishing new benchmarks and technical standards that embrace nature-based solutions and become sustainable ways of improving the environmental challenges of these large conurbations. "But clever as they are, these are just small ideas. We only have so much money and time and so much grey matter resource, and we need to focus that where we have the most bang for the bucks," says Thomas.

## Hope and help

There are some areas where you can see wider action being taken successfully, "and one of those is rainwater management," observes Thomas, "largely because it's an obvious financial winner, it's easier to implement and it delivers immediate gains. Many of those advances are around being better at separating rainwater from sewage and then trying to get the rainwater into the ground as close to where it fell as possible."

"It's also one of the areas where Leapfrog can help. If you're trying to infiltrate water into the city, there will be lots of hard surfaces you need to avoid, and you'll want to do that in some engineered fashion that understands not all the soil underneath is equally permeable.

"Everything will become much more interdependent and complex, which is where Leapfrog Works can contribute. It can give you a better understanding of the entire system below the surface to help these projects happen more efficiently. But it can also help to improve communication, addressing concerns about interference by creating models from our software so people can understand this interaction. The subsurface is only going to become more important in the cities of the future, so that understanding and communication is only going to become even more important."



## The world's largest cities by population

| | |
|---|---|
| Shanghai, China | 24.1 (million) |
| Beijing, China | 18.5 |
| Karachi, Pakistan | 18 |
| Istanbul, Turkey | 14.6 |
| Dhaka, Bangladesh | 14.5 |
| Tokyo, Japan | 13.6 |
| Moscow, Russia | 13.1 |
| Manila, Philippines | 12.8 |
| Tianjin, China | 12.7 |
| Mumbai, India | 12.4 |

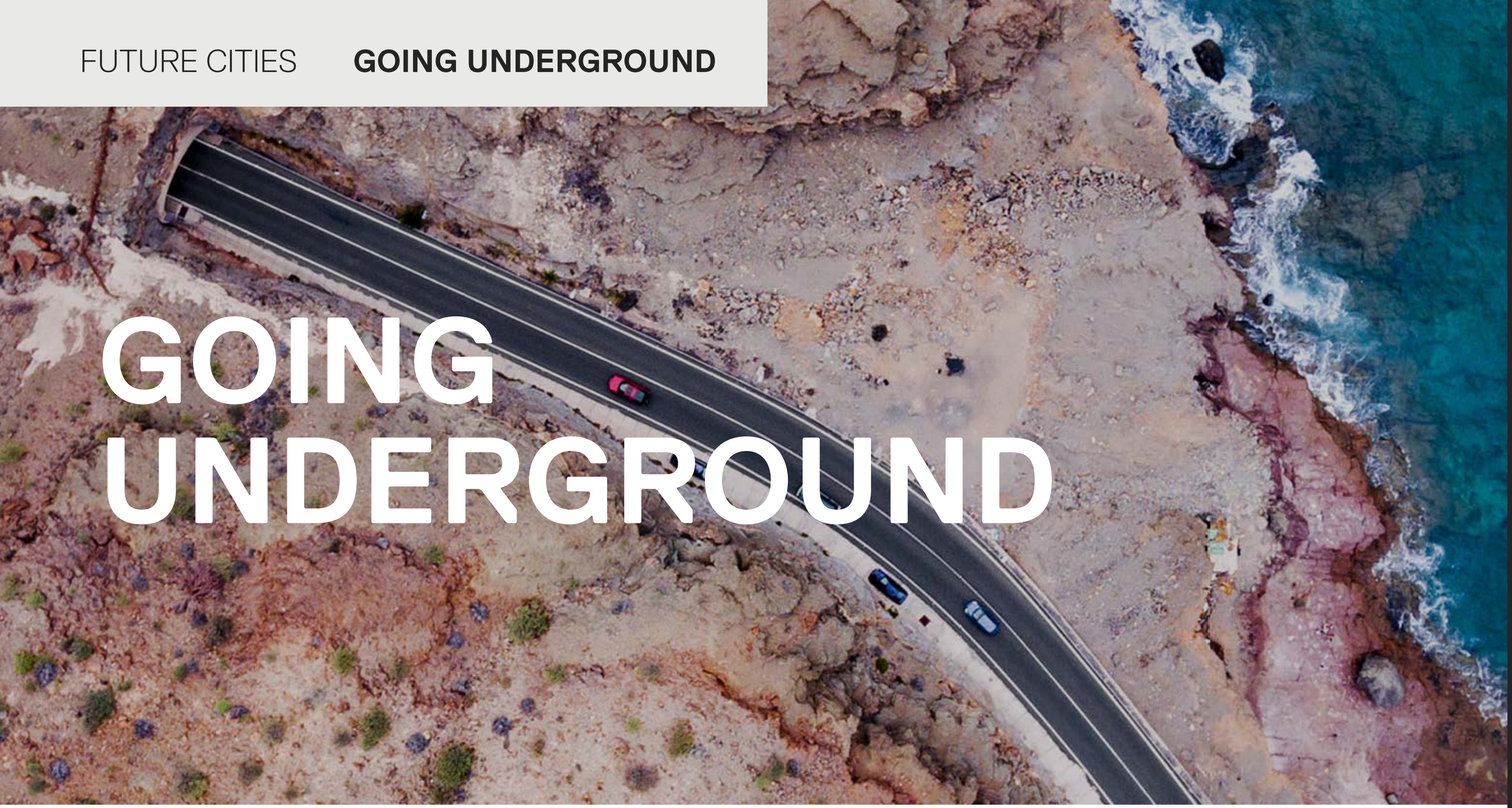
However, when you stretch that definition to embrace the entire metropolitan area rather than the city proper, it changes significantly with Tokyo rising to the top (37.8), and the likes of Jakarta (30), Delhi (26.4), New York City (23) and Cairo (20.4) jumping into the mix.

By 2030 there are expected to be more than 40 megacities around the world – those with more than 10 million inhabitants. In 2014 the number stood at 28.

The UN forecasts that by 2050, 68% of the world's population will be living in cities. 2007 was the milestone year when city population outdistanced rural population for the first time.

# FUTURE CITIES

## ON GOING UNDERGROUND



# GOING UNDERGROUND

Though skyscrapers will continue their race to the clouds, designers and engineers are increasingly looking at what they can do with the space beneath our feet.

**Just like investments, it turns out that future city development can go down as well as up...**

At the end of the 19th century, architects coined a new term for buildings ascending the impossible heights of 10 whole storeys. They called them ‘skyscrapers’.

For decades, upwards became the most alluring direction of travel or cities, ultimately giving us the 829.8 metre high Burj Khalifa in Dubai. But what if the city of the future was to go down instead of up?

Though skyscrapers will continue their race to the clouds (the Jeddah Tower aims to hit a staggering 1km when it opens in 2020) designers and engineers are increasingly looking at what they can do with the space beneath our feet. Not so much for homes or offices, but primarily for the infrastructure that supports them. There’s a growing movement to bury transport, utilities, warehousing, storage and more below ground level to free up valuable surface space.

## Who owns the ground beneath our feet?

As cities increasingly grow down rather than up, it begs the question, who owns the depths? The UK’s Guardian newspaper recently researched this subject (driven by Londoners’ obsession for extending their basements) and pointed out that historic law is a long way from present practice. Traditionally – and this 13th century maxim is held as the genesis of property law – whoever owned the land had title “up to the heavens and down to the depths of hell”.

Most people probably still harbour the belief that the land below their house is theirs all the way to the earth’s core. Quite what they’d do with it is hard to imagine, though the Guardian recorded that in the last decade, 4,600 London homeowners had received planning permission to develop their basements for anything from swimming pools to an artificial beach... However, in truth legal limits now vary hugely from country to country, even city to city.

For some time, it’s been customary for authorities to set their own restrictions. For example, in Australia, land titles prior to 1891 went to the centre of the earth, but after 1891 they were limited to 50 feet – around 15 metres. Unfortunately, that was still just deep enough to upset the Melbourne Metro. The Australian government recently had to compulsorily acquire the land beneath 260 properties, so the metro’s tunnel could run closer to the surface than that 15-metre limit.

Arup recently produced a benchmarking study seeking out best practice in underground development. The engineering company has been closely involved with Singapore's ambition to lead the world in underground urbanisation.

The ten benchmarked locations (Montreal, London, The Netherlands, Helsinki, Beijing, Shanghai, Honk Kong, Seoul, Taipei and Tokyo) identified three drivers for future cities to explore their basement resource...

**Topology and geography.** For example, in hilly regions such as China, delving into the steep terrain makes more sense than going over or around it.

**Climate.** Extremely cold winters have seen the likes of Helsinki and Montreal move increasingly underground to save energy and limit uncomfortable and inconvenient travel.

**Land shortage.** In cities such as Tokyo, Hong Kong and Shanghai, where nearly every square metre already hosts a soaring building, going down is often the only way to generate more centralised space.

Most commonly, underground developments were used for...

- Rail infrastructure. Seoul wins with more than 400km of rail below ground.
- Roads. 15% of Tokyo's urban expressways are below ground, reducing air pollution and helping to remove barriers between neighbourhoods.
- Underground pedestrian networks
- Utility tunnels. Taipei has 50km of utility tunnels and some 300km of smaller ducts, which means maintenance can be carried out without digging up roads, so reducing traffic congestion and therefore pollution.
- And caverns. Not available to every city, though Hong Kong uses theirs for waste transfer and treatment, and Helsinki boasts the world's most extensive use of rock caverns, turning them into commercial space, car parks, data centres and more. In fact, it was Helsinki that developed the world's first 'Underground Master Plan' to describe how it would extend and employ its subterranean resource in the future.

## Singapore beneath the surface

While others may dig for gold, oil or diamonds, it's been said that Singapore has become expert at mining something just as precious – space.

It's spent decades reclaiming land from the sea, but that's becoming increasingly difficult and fraught with long terms problems in the face of rising sea levels.

Now Singapore has its eye on becoming the world's most advanced centre of urbanized underground development. The government has enacted legislation that enables it to buy land beneath privately owned blocks. Meanwhile the Singapore Urban Redevelopment Authority (URA) is compiling a 3D master plan that will attempt to map the hugely complicated landscape of pipes, tunnels and other entombed assets.

And with good reason. As Arup's East Asia Director of Infrastructure Mark Wallace said earlier this year, if you are going to build underground, "you should do it properly. Tall buildings are dead easy to take down. The underground? Not so easy."

Arup's benchmarking study also emphasizes the point that underground development "is associated with higher uncertainties and risks due to the lack of information on what lies beneath the surface."

So far Singapore has already invested $188 million in underground technology R&D. With a population expected to hit nearly 7 million by 2030, it's not hard to see why the pressure is on.

Between now and that 2030 deadline, the URA is either building, planning or considering...

- an underground bus park that will sit below a car park and a garden
- a series of pneumatic waste transfer pipes and extensive air condition ducts
- a deep tunnel sewerage system that uses gravity to draw sewage across the island to two central reclamation plants
- a vast subterranean water reservoir at the very lowest level that will free up 3,700 hectares of surface space.

The first pilot areas of its Master Plan will be released to the public in 2019.

# WHAT YOU'LL FIND BELOW SINGAPORE

**3m down**

Pedestrian walkways and SecureMyBike, the city's first automated, underground bike storing service. Riders pop their bikes into kiosks above ground and they are then lowered into deep storage cells.

**10m down**

Utilities including the 3km long Common Service Tunnel in the Marina Bay area holding telephone cables, power lines and water pipes.

**50m down**

Eventually a complex of major road and rail networks, and below them a deep tunnel sewerage system.

**100m down**

Perhaps unexpectedly, a munitions dump. The Underground Ammunition Facility, apart from holding the dubious title of being the world's only large-scale munitions facility directly below a city, saved around 300 hectares of land when it was moved below the surface. Though 100m is only a guess. Exactly how far down it sits has never been revealed. Usefully, siting munitions and petro chemicals underground avoids the need for a one to two kilometre safety zone, which would take up even more space on the surface.

**150m down**

The Jurong Rock Caverns, five caves that form south east Asia's first underground oil storage facility. The caverns are nine-storeys high, and store nearly 1.5m3 of liquid hydrocarbons, saving 60 hectares of surface space.

## Behind the scenes

Singapore's determination to drive its infrastructure underground also has a deeper backstory, spurred on by its determination to be more self-sufficient.

1) Water. For example, Singapore still receives 50% of its water from Malaysia – a situation it is keen to change. So, as well as moving sewer lines beneath the surface, the Deep Tunnel Sewerage System should also be able to produce 80% of Singapore's clean water via recycling (the rest will come from forest collected reservoirs).

2) Construction materials. Singapore imports all its construction sand from Cambodia – expensively. The soil and rock extracted during this project will help offset that.

3) Energy. Harvesting gas from solid and food waste will make the most of all the waste created by 5.5million Singaporeans.

## Can't go up

Any higher than 90 storeys and buildings will start to disturb the flight paths of planes coming into Singapore.

## Can't go in

Spare land within Singapore is now so expensive that going underground, despite its complications, is actually cheaper. Eg, $900m for completing the Jurong Caverns whereas the land alone would have been $1bn+ on the surface, without construction.

## Can't go out

Singapore can't reclaim any more land from the sea without affecting its ports and compromising sea lanes and space.

## Can go down

Singapore's geology offers top layers of Marine Clay which is soft and difficult to work with, so anything built on top must have deep piles. But further down you'll find Granite and solid rock that can be securely dug through.

# FIVE OF THE WORLD'S MOST SURPRISING UNDERGROUND DEVELOPMENTS

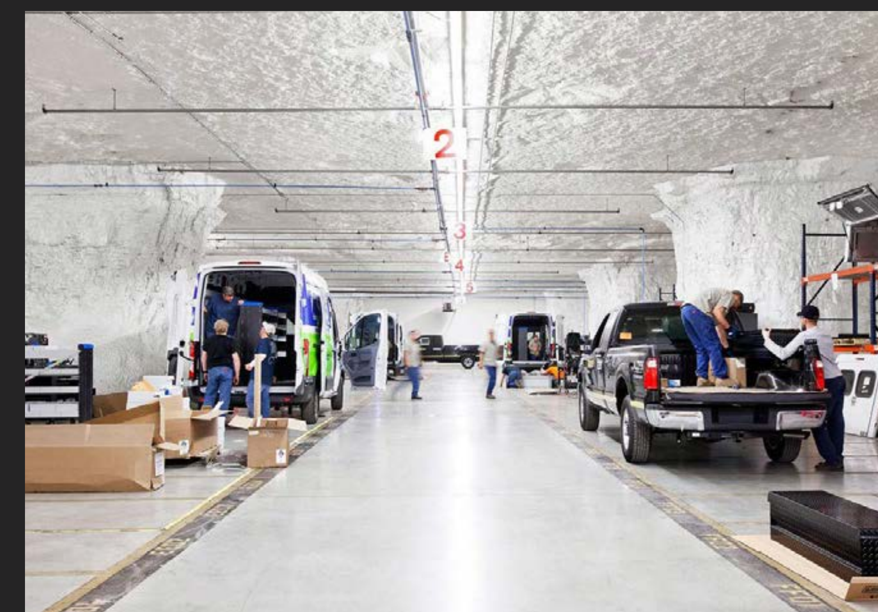
**Reso** – otherwise known as The Underground City – is the massive complex of offices, homes, convention halls, shops and more that's connected by a network of underground tunnels beneath Montreal. It exists to keep residents away from the harsh conditions of the region's long winters. Reso first took root (perhaps literally) in the early 1960s when a shopping precinct developed an underground space previously used by trains at the city's Central Station. Since then the complex has blossomed into 32 kilometres of tunnels connecting 4 million square metres of space. It's not uncommon for Montreal residents to avoid the frosty surface of their city for days on end by careful negotiation of its subterranean pathways.

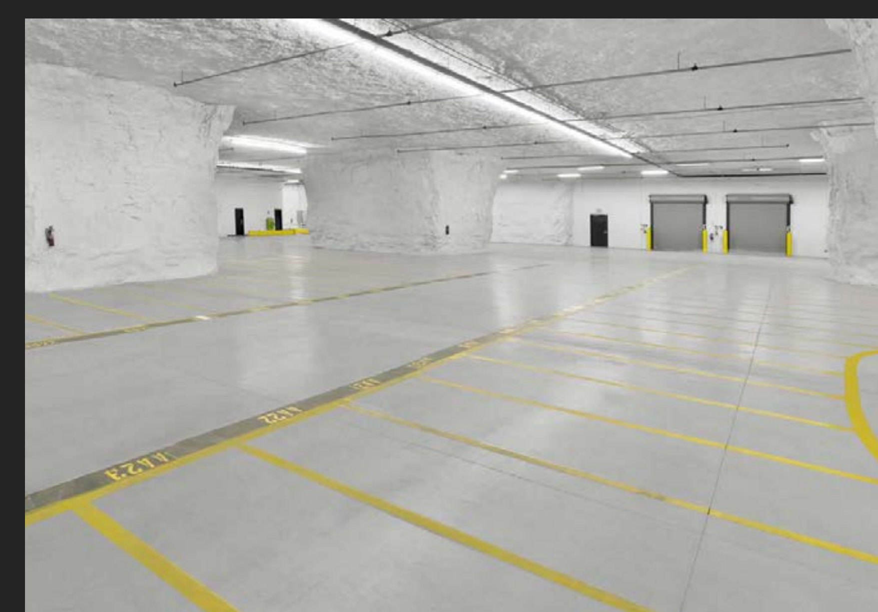
In 2015, the **Lowline Project** on the Lower East Side of New York began experimenting with new solar technology to bring daylight down into an old trolly terminal, with the ambition of creating a massive underground park lit by natural light. The project's Sunportal system tracks the sun through the day, then beams what it collects through a series of tubes to an underground distribution point. In 2017 the Lowline Lab closed, having successfully grown 3,000 plants across 1,000 square feet, and declared the concept proven. When it can raise the finance and support, it aims to open a full-scale version, hopefully by 2021.

A little less likely to move from concept stage any time soon, is the **Earthscraper**, proposed and designed by BNKR Arquitectura. Even so, it must take the award for the most audacious underground project proposed for a capital city. It envisages driving a 65 storey development down into the ground of Mexico City, beneath the capital's central square (incidentally, the largest in the world). The inverted pyramid would effectively be one enormous hole with multiple terraces of green walkways covered by a colossal glass ceiling that would form the square's new floor.

On a far smaller scale, but nonetheless remarkable for its location, is **Growing Underground**, London's first (and probably only) underground farm, which raises herbs in an old Second World War bunker. It uses hydroponics and LED lighting to grow crops all year round in pest free conditions, while 33 metres above, the busy streets of London's Clapham thunder with traffic. Leading chef Michel Roux jr has lent his support, and advocated Growing Underground's ability to get fresh herbs from soil to the capital's kitchens within four hours.

Touted as "the World's Largest Underground Business Complex", **Subtropolis** comprises 6 million square feet of industrial space scattered across abandoned limestone mines near Kansas City. In the process of excavating the 270 million year old limestone deposits, the miners left a series of 25ft square pillars supporting the ceiling. It's in and around these dazzlingly white structures that the likes of Fed-Ex park their trucks and production lines churn out products from food to pharmaceuticals. Around 1600 people work down there every day.





# FUTURE CITIES

## ON WASTE DISPOSAL

# WILL TOMORROW'S RUBBISH FEEL THE PRESSURE?

**Cities are in search of a cleaner, faster, neater solution to the rumbling garbage truck. Pipes, suction and automated disposal could be the answer.**

How we dispose of our waste in the coming decades is a subject big enough to fill up a dozen Unearthed reports. This complex topic spans issues from bi-degradable plastic, to mandatory composting, to 3D printing, to changing the makeup of cigarettes so they can be more easily recycled. Nearly 40% of city street litter is cigarette and tobacco waste.

Here we're just going to look at one facet, waste disposal and transport. We take you now to Songdo, South Korea's privately built smart city, designed as something of a sci-fi experiment to lure businesses and families away from Seoul, 40 miles to the east. In 2000 it was still a stretch of tidal flats until the Korean government added 500 million tons of sands to create a new commercial district near the international airport.

Of all the innovations attempted in the city, the one most often quoted is its waste disposal system. Garbage trucks simply don't exist here. When rubbish is placed in trash cans across the city's apartments, kitchens, halls and offices, it's then automatically sucked out through a series of pressurised pipes to an underground sorting centre where it's separated to be recycled, buried or burned for energy. It's a proper Jetsons future – cleaner, quieter, more efficient, with trucks off the streets, pollution down, and rubbish not humming gently in the heat until collection day.

**Automated trash has a history**

While slick, behind the scenes, vacuum collection of waste frequently pops up as a must-have in future city plans, it's not as new or radical as it sounds. The technique actually dates to the 1960s and was first introduced in Sweden for hospital use.

Obviously there have been advances. For example, today's automated trash cans are remotely monitored to check when they're full and ready to be emptied. And Songdo's set-up is so highly mechanised that when the BBC visited the plant in 2016, they could only count seven employees.

In the past, less hi-tech systems have called on users to separate waste out before popping it into the appropriate chute – cardboard, food, etc. An early example would be Roosevelt Island on the East River in New York. Since the 1970s, 16 tower blocks have fed the island's entire waste through a series of pressurised chutes into a now rather dated extraction system. Disneyland was an early proponent too.

But increasingly, as in Songdo, the smart cities of the future will handle that automatically at the sorting centre. Tough waste, such as glass and metal, can still give the system a hard time though, abrading the pipes down which it's transported. Finnish company MariMatic has become something of a world leader in this technology, in part through the patents it developed for specially durable bends to solve the issue.

Songdo's set-up is so highly mechanised that when the BBC visited the plant in 2016, they could only count seven employees.

MariMatic is also behind what's claimed to be the largest AWDS (automatic waste disposal system) in the world, at work under the largest mosque in the world, the Al-Masjid al-Haram in Mecca, Saudi Arabia. It collects 900 tons of solid waste every day, and transports it through a 30 km network of pipes to a waste station where it's compacted.

**Bringing older cities up to speed**

Meanwhile, back in New York, the High Line project has explored a retrofitted solution for cities struggling with waste. It transports up to 30 tons of material a day through 1.5 miles of pneumatic tubing slung beneath an elevated parkway.

Such is New York's challenge in this field, the city's Department of Sanitization recently offered a $1 million contract to whoever could deliver a workable Save As You Throw program. Incentivized waste disposal, where a city's population receives micro-sized tax or rent rebates for everything they responsibly dispose of, is a holy grail for conurbations desperate to drive down the cost of waste disposal. Unfortunately, it's hugely complex because of the number of stakeholders involved.

A stepping stone to Songdo's all singing waste disposal system is the use of underground bin systems, which is starting to catch on across Europe. Bin chutes set into the pavement outside homes feed rubbish into underground containers that are then hoisted out by specialist vehicles. Homeowners no longer need individual bins cluttering up their property (when the system was installed in a UK suburb last year, it replaced 9000 wheelie bins) and trucks come out less frequently.

However, whereas as new smart cities can design their disposal systems from the (under)ground up, 'retrofitting' attitudes towards waste, such as Save As You Throw, might yet remain the more achievable target for older cities.

# FUTURE CITIES

## ON TRANSPORT

# ROBOTS IN THE AIR? IS THE FUTURE OF CITY TRANSPORT IN THE HANDS OF ROBOTS?

Passengers will use a Waymo app to call an autonomous vehicle, and have it turn up with no driver at the wheel.

**After years of sci-fi promise, some of the AI guided revolutions in autonomous transport are beginning to mature into real services. Maybe.**

### Rising above the traffic

In September last year, Dubai held the first full tests of its autonomous flying taxi service. The two-seaters, made by German aerospace company Volocopter, have 18 rotors and nine batteries, and are meant to cruise at around 30mph for 30 minutes at roughly 1000ft. The city is aiming for a fully operational service by 2022.

### Paris by robot

Last January autonomous shuttles began trundling back and forth across the Charles de Gaulle bridge in Paris, taking travellers over the Seine between the Gare d'Austerlitz and Gare de Lyon. The trial saw the electric GPS-guided six-seater vehicles run successfully for three months in a dedicated bus lane. No news yet on next steps, though feedback from passengers seems to indicate they found the buses a little slow.

### Driverless cars get real

When you read about self-driving taxis, the word 'trial' usually crops up fairly quickly (associated with ongoing safety concerns to be ironed out). Not so with Waymo. It recently announced that it would begin offering a full, for-real, self-driving taxi service to the public in Phoenix, Arizona at the end of 2018. Waymo (which sits within Google's Alphabet umbrella of companies) has been testing its AI guided taxis in Phoenix since October last year. At Google's I/O conference in May 2018, Waymo CEO John Krafcik declared that the cars were now ready for public use after driving more than 6 million miles on the road (and 5 billion miles in simulation). The plan is that passengers will use a Waymo app to call an autonomous vehicle, and have it turn up with no driver at the wheel. That's an important step, and a leap ahead of the competition, as human safety drivers are still a common requirement in many self-driving taxis. Why Phoenix? Consistently sunny weather, wide clear roads and a relatively easygoing regulatory environment have made it a favourite for robot cabbies learning the ropes.

### Smart data for travellers

The Kansas Smart Streetcar Corridor is a backbone of sensors, screens, wi-fi access and LED streetlights running through the city. It can respond directly to public movement and dole out information accordingly. The sensors collect data from traffic signals, the sidewalk and even water pipes to monitor how traffic is flowing, then relay it to kiosks along the two mile tramcar route. Kansas citizens use it to update their journeys as necessary and stay in touch with what else is happening in the city. The streetcar is free to travel and takes visitors around the key sites of downtown Kansas.

### When the state steps in

This year Moscow secured top spot as Europe's most congested city (London was second). The dubious accolade throws even more emphasis on Moscow's State Programme for Transport Development – a scheme to make its public transport system one of the smartest and most data driven in the world. Since 2011 the programme's Intelligent Transport System has linked 2,000 video cameras, 3,700 road detectors and 6,000 traffic lights to improve traffic flow. Meanwhile a huge spend on the metro fleet has added thousands of train cars and a high-tech ticketing system where more than 85 percent of journeys are made using transport cards. Is it working? Earlier this year Deputy Mayor for Transport, Maksim Liksutov, declared that Muscovites were now making 2.8 billion full fare trips a year against the 1.9 billion when the program began. And while Moscow's congestion was still severe, average speed in the city had gone up by 13%.

# FUTURE CITIES

## ON EARTHQUAKES

# HELPING TOMORROW'S CITIES STAND FIRM AGAINST EARTHQUAKES

Apple Park 2 in California recently became the largest base-isolated structure in the world.

**How engineers are creating buildings that can resist seismic disturbance.**

Given four of the world's biggest economies  are cities sitting along fault lines, protecting buildings against earthquakes, and especially making high-rise offices and homes resistant to seismic activity, is becoming increasingly critical. So, what are the techniques currently in use, and where are research and application going?

**Base isolation**

This technique effectively separates the substructure of a building from its superstructure. Most commonly it's achieved by suspending a building on lead-rubber bearings. A solution that came to the mind of New Zealand seismic engineer William Robinson back in 1974, and is thought to sit beneath more than $100 billion worth of structures around the world. Some designers have been trying to take the base isolation concept even further. Japanese engineers have experimented with using huge compressors that can pump air between a home and its foundations within a second of receiving a warning from seismic sensors. They've been able to lift the superstructure by a couple of centimetres. It's a solution that could be valuable for smaller structures, but it's hard to see how it could be scaled up for larger buildings. Base isolation is effective but expensive, so it's often reserved for buildings that would be vital during an earthquake, such as hospitals or airports. For example the Sabiha Gökçen International Airport in Turkey incorporated 300 isolators into its construction. Theoretically the 2 million square foot complex can withstand a quake of 8 on the Richter scale. And interestingly, Apple Park 2 in California recently became the largest base-isolated structure in the world.

**Internal dampers**

Taiwan's 1,667ft tall Taipei 101 (until 2010 the world's tallest building) uses a vast internal pendulum to counteract vibrations, either from earthquakes or high winds. The 730-ton ball of steel hangs between the 87th and 92nd floors within a sling made of steel cables. The Shanghai Tower adopts the same concept but outdoes it with a 1,000-ton damper and throws in 980 piles, nearly 300ft deep, encased in more than 2 million cubic feet of concrete. In each instance these mass dampers are tuned to match the building's natural vibrational frequency and help them absorb and cancel out seismic movement.

A different take on the damper solution was developed for Japan's Mori Tower, one of the tallest buildings in Tokyo. Nearly 200 shock absorbers are filled with thick oil. As the building moves, the oil shifts in its containers, in the opposite direction to the movement, helping to neutralise it.

**The Earthquake Invisibility Cloak**

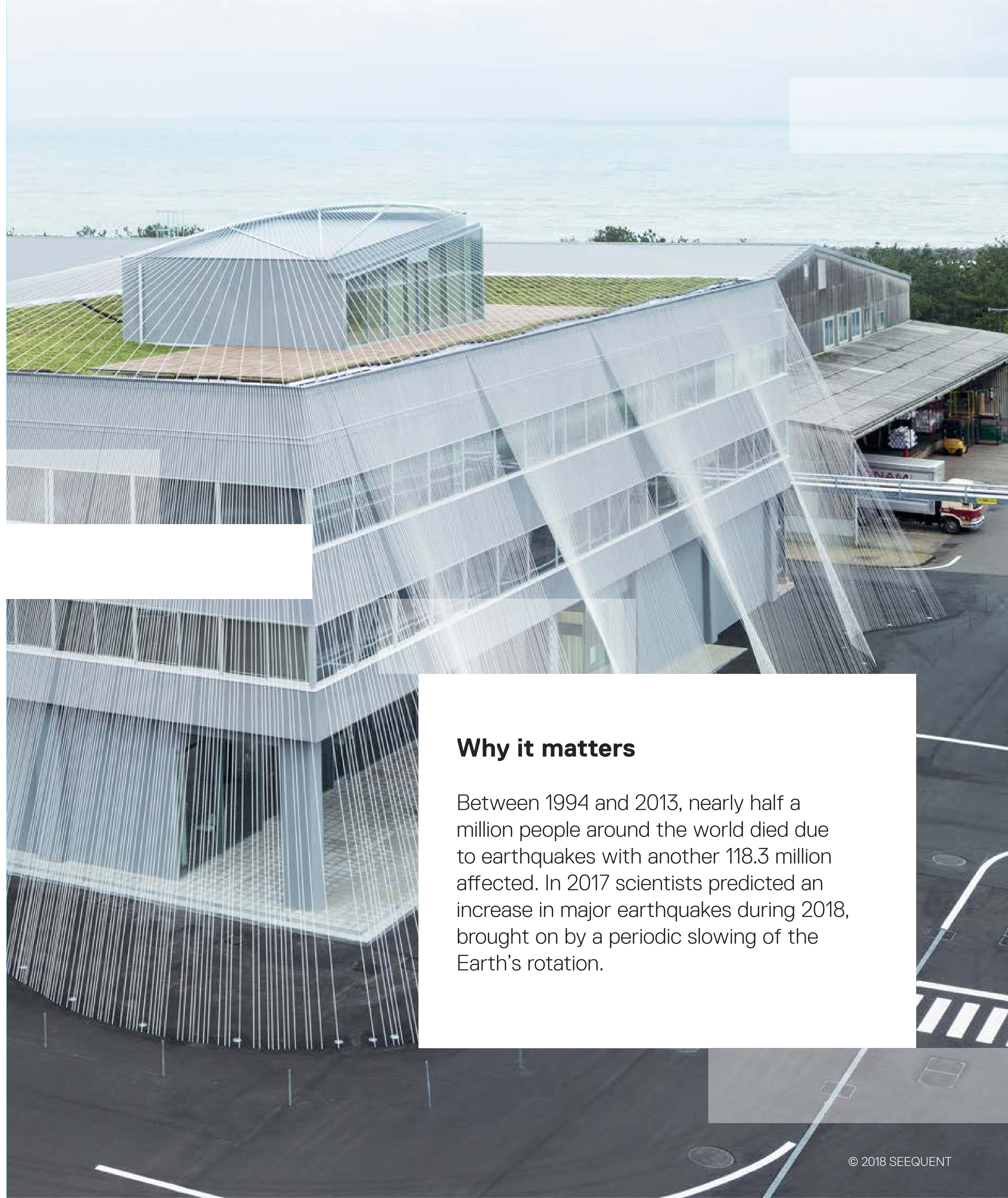
This futuristic concept (perhaps from a Harry Potter fan) proposes avoiding the need for dampers or base isolators by ensuring the earthquake never reaches the building in the first place. It calls for enormous concentric rings of plastic to be set into the earth's surface around structures to break up and divert the damaging waves that ripple towards them during seismic activity.

**Resilient new materials**

Engineers have been experimenting with special polymers and metal foams developed for the aerospace industry to see if they can be scaled up to fit into energy-absorbing joints. Shape memory alloys might even help re-centre a building following a quake to reduce repairs. Nickel titanium or Nitinol is one of the earliest materials to exhibit both shape memory and super elasticity. It actually dates to 1959 when it surprised missile designers with its ability to return to its original shape. Concrete containing self-healing capsules can repair cracks. There are even materials that can be made to soften when an electric current is passed through them, so absorbing the energy of an earthquake, then re-stiffened later when the current is removed.

**Pre-stressed laminated timber**

While engineers continue to hunt out exotic new materials that promise seismic defiance, New Zealand's Trimble Navigation turned to a more familiar technology. Wood. After losing its Christchurch offices in a fire following the 2011 earthquake, the company set about looking for a high tech, seismically strong but sustainable replacement. It became the first commercial building in New Zealand to use post-tensioned laminated veneer timber frames and walls. Their natural resilience helps them disperse the energy created during a quake and control the movement of the building itself (which at 6000 m2 became the largest pre-stressed laminated timber building ever constructed). Research at the University of Canterbury helped develop the techniques used by engineering consultancy WSP Opus. The building has since won awards for its innovative use of wood in an engineering project.



## Why it matters

Between 1994 and 2013, nearly half a million people around the world died due to earthquakes with another 118.3 million affected. In 2017 scientists predicted an increase in major earthquakes during 2018, brought on by a periodic slowing of the Earth's rotation.

**High power bracing**
When opened last year, the New Wilshire Grand Center became the tallest building on the Pacific Coast of America (though at 1,100ft it's still easily eclipsed by the 1,776ft One World Trade Centre on the far side of the continent). However, California's propensity for seismic activity made it a tricky project in its own right. Testing the original model against historic data from 11 earthquakes showed the upper levels whipping from side to side at a potentially greater acceleration than a NASA shuttle launch. A key part of the answer was to support the concrete core with a series of outriggers that could reinforce the building. But further tests revealed that the energy being transferred was so substantial it could end up damaging the concrete itself. So more than 170 buckling-restrained braces were added to yield or stretch and soak up the forces. The use of braces is not new, but the New Wilshire Grand now has the highest capacity system anywhere in the world. Just fitting the top one required loading each brace with 1 million pounds of force. Their dramatic shape has been left exposed as part of the design.

**Retrofitting**
While new buildings can explore the latest earthquake resistant technologies, old buildings need protection too, though retrofitting many of the latest solutions can be all but impossible. One technique that does work is carbon fibre wrapping. Concrete support columns are swathed, sometimes several times, with a mix of carbon fibres and bonding polymers before epoxy is pumped into the gap between the concrete and the wrap. This greatly increasing the columns' strength. Going one step further, Japanese architect Kengo Kuma retrofitted earthquake resistance into the three storey Komatso Seiren offices in Nomi by wrapping the entire building in the material, creating a carbon fibre curtain around it. It was Kuma's statement of how earthquake resistance and aesthetics can combine. In total, 1031 carbon fibres rods are tethered from the roof to the ground (with a further 2,778 inside) to pull the building back into shape when an earthquake moves it.

## Gravity wins

Distinguished architect and seismic specialist Leonard Joseph, who helped design the Petronas Towers, the New Wilshire Grand and Taipei 101 among others, once said there was a belief that with enough money, you could build anything. "Perhaps that's how it works in a real estate deal, but there are some things you can't negotiate. You can't negotiate with God or Isaac Newton."

leapfrog

FAST, DYNAMIC GEOLOGICAL MODELLING

# *In Action*

How Leapfrog is contributing to some of the world's most ambitious civil engineering and environmental projects.

# The Pūhoi to Warkworth project...

...is an 18km motorway extension that will provide a better connection between New Zealand's largest city, Auckland, and the neighbouring Northland region. With an estimated cost of more than NZ $700m (over 25 years), it is a major investment in the region's infrastructure and will play a key part in supporting Auckland's ambitions to be a city of the future with a global role to play. The project will improve the highway's safety – a number of fatal crashes have occurred along it – as well reliability and resilience. It should be open for traffic in late 2021.

**NZ$700m**

## The Challenge

The extension is a large and complex project. The road corridor cuts through steep hill country with numerous steep sided valleys, which are often filled with soft alluvial sediments. The final design requires several significant road cuttings and embankments to be created, with more than 7 million cubic metres of earth to be cut and 5 million cubic metres to be filled. The project also requires seven bridges to be constructed, three of which are large viaduct type bridges. A suitable project-wide ground model was required as a basis for the geotechnical design of the proposed earthworks and structures.

Understanding the material makeup of the 'Mass-Haul' balance is also crucial, as earth extracted from one part of the construction can be used to fill in another part of the site, providing it is of sufficient quality.

Environmental considerations are likewise a key aspect as the alignment traverses greenfield land, some covered in native forest. Approximately 162 hectares of vegetation are to be cleared followed by a substantial tree-planting programme.

## The Investigation

The project's Design Joint Venture turned to Leapfrog Works as the modelling tool of choice. Detailed design began in October 2016 and the team started collecting ground investigation data and used this to input into the model. The geotechnical model focused on three areas: North, which showed low-lying topography; Central, which has significant cut and fill embankments and South, which contained two viaduct structures.

"It was important that we could use a modelling tool that worked flexibly around the different geology and surface types to give accurate outputs", said Chris Monk, Engineering Geologist with Tonkin & Taylor, engineering consultants for the DJV. "We were able to continuously update the model as new investigation data was produced. We modelled 210 CPTs and brought in data from 420 boreholes, 355 hand augers and 220 test pits. Having a dynamic model that evolves as new data is provided has saved the team time from not having to re-create a new model every time, leaving us more time to focus on the analysis".

More than
**30,000**
cars expected to use the route by the early 2020s


IMAGE CREDIT: NX2 GROUP

## The Outcome

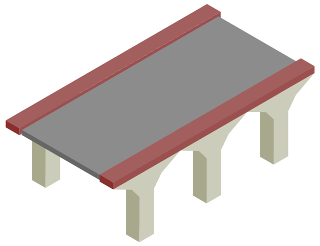
The DJV has been able to produce more accurate 3D surfaces as a consequence of using Leapfrog Works. The more accurate the interpretation of the geological model, the better the outcome of the design, with the team able to better highlight the risks and uncertainties. Using Leapfrog Works has delivered a smoother process as the geological surfaces have been able to be mapped by a geologist, rather than engaging a CAD technician to work alongside a geologist.

As project engineers needed sections, they were able to come straight to a single point of contact to quickly create the desired section, rather than have to draw something, then request a CAD technician to create this afterwards. This has saved time and reduced the effort in having to reproduce work.

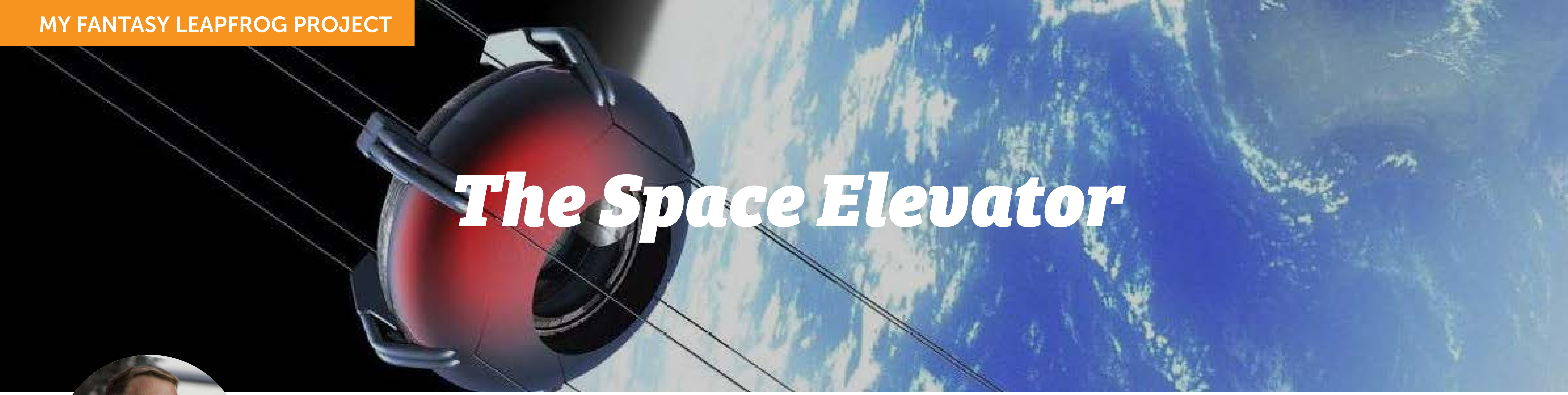
Being able to show the model in 3D and cut sections at any desired location instantaneously has also enabled others on the project to visually understand the geological conditions of the site with much better clarity.

As major infrastructure projects become increasingly large and complex, with multiple stakeholders, having a 3D ground model to support the understanding of the geology allows geotechnical teams is an enormous advantage in improving the efficiency of the design.

**7 million**
cubic metres of earth to be cut



**7 Bridges**
to be constructed



# The Space Elevator

**Tim Schurr,**
Solutions Architect, Seequent

The premium for space on our planet is making us look below the surface... and above it too. But how far above the surface of earth should we consider, and how can we make that incredible leap possible? We speak to Tim Schurr, Seequent's Solutions Architect, about his thoughts on the Space Elevator.

**Why it fascinates me**

In recent years I think we've rediscovered our fascination for space exploration and the amazing engineering that makes it possible. The world's most powerful rocket is now SpaceX's Falcon Heavy, which features incredible new propulsion technology and re-usable boosters. Even so, it's far from being a sustainable vehicle, burning some 440 tonnes of fuel and costing US$90M with each launch. Entering and leaving Earth's atmosphere is incredibly difficult, to say the least, but it's possible that access to space might one day be disrupted by a new approach – a technology that could render the traditional rocket business obsolete. And that's the Space Elevator.

**How it works**

It's essentially an upside-down plumb bob of collosal size. A cable literally runs from Earth into space, held in place by a counterweight that sits beyond geostationary orbit, and elevator 'cars' glide up and down it. In 1895 Russian rocket scientist Konstantin Tsiolkovsky first wondered whether a free-standing tower could be built tall enough to reach geostationery orbit (far from feasible as no material could withstand the compression from its own weight). In 1959 the concept moved closer to reality when a tensile design was proposed instead, and today a number of R&D teams around the world continue to explore the concept.

**What it offers**

Imagine taking a smooth ride up the escalator through the atmosphere and out into space. What could this do for our access to space, space stations and getting to other planets? Co-author of Leaving the Planet by Space Elevator, Philip Ragan, estimates the cost of moving 1kg of payload into orbit would drop from US$25,000 to just $220. And it's not so far from science fiction as you might think. The International Academy of Astronautics estimates that carbon nanotube technology is less than 20 innovative years away from achieving the necessary strength-to-weight ratio.

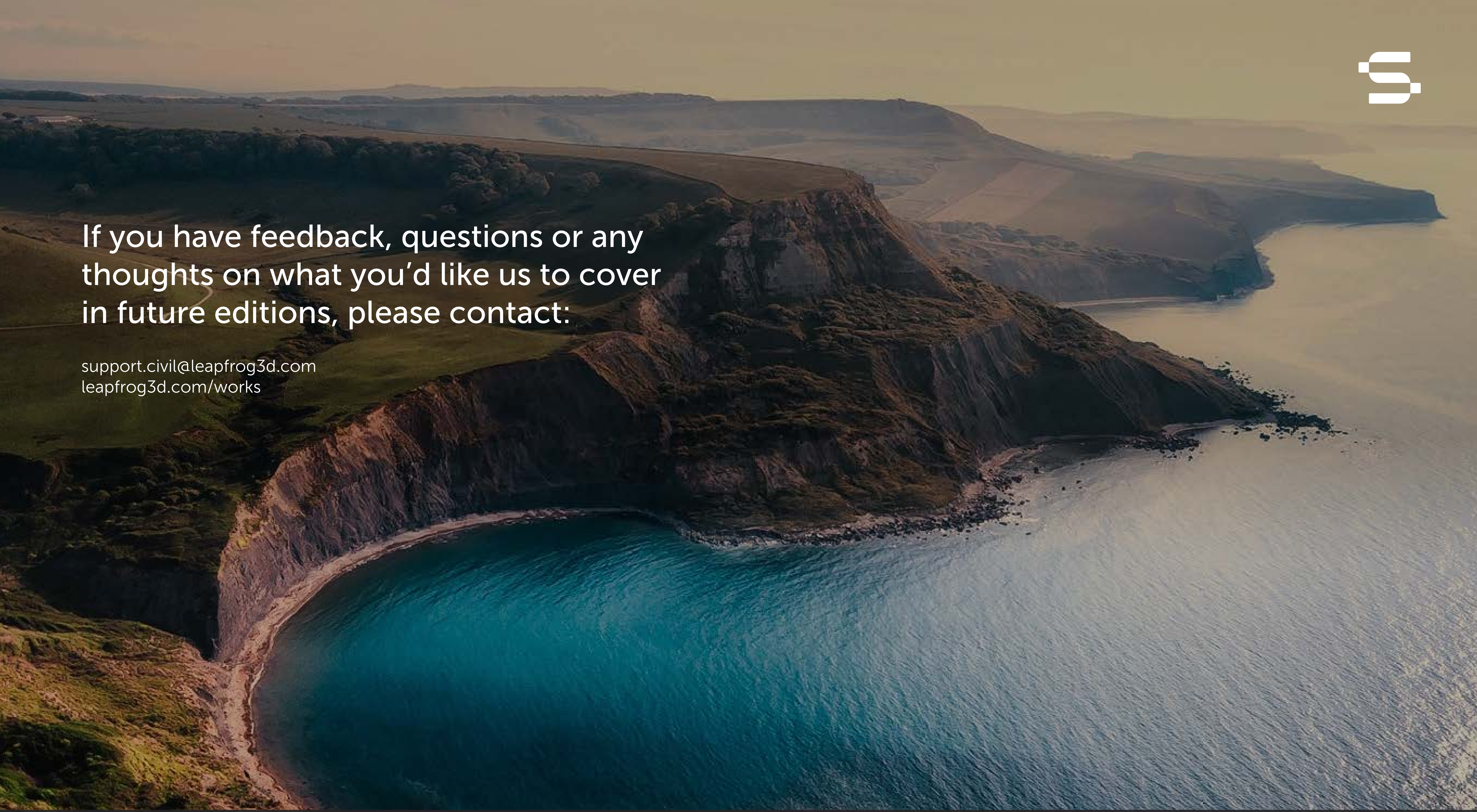
**Geology's role in lifting us into space**

In its natural state, the base station would need to support a rather unnatural, completely vertical force constantly acting on in – like a guy-wire and peg on a camping tent. The local ground conditions and geologies would be critical components of the design of the base station on Earth, providing the vital 'earth-anchor' for the mass in orbit. Exhaustive investigations to find stable rock in a non-seismically active zone would be essential. Leapfrog Works would be ideal for the investigation team, allowing geoscientists to rapidly form a hypothesis and support their decisions with geology and geotech models. What an incredible project to contribute to.

**35,000km**
of cable

**100 fold**
reduction in cost

**5 days to space**
estimated transit time for early systems



## If you have feedback, questions or any thoughts on what you'd like us to cover in future editions, please contact:

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### COMPLEXITY TO CLARITY

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