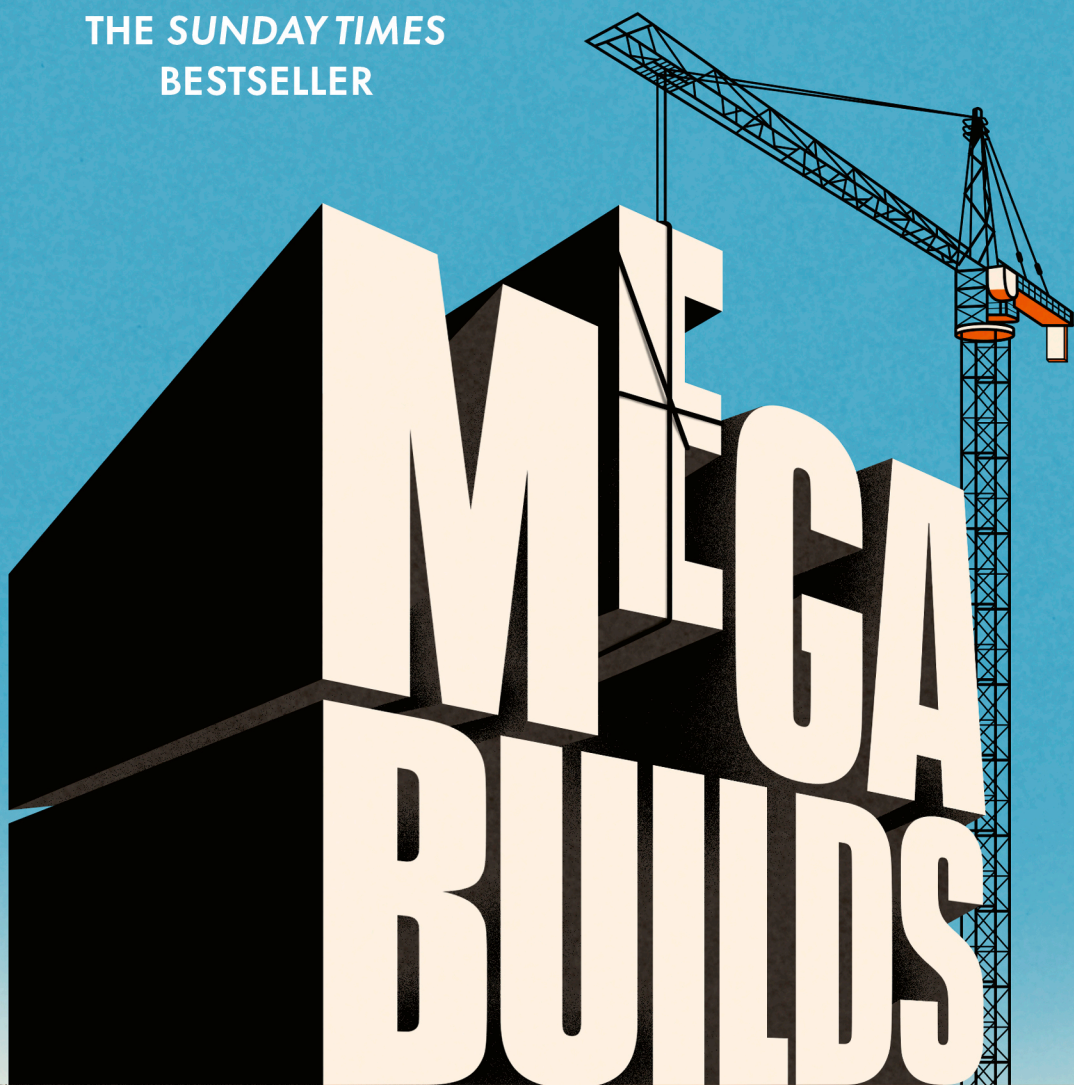


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For everyone shaping our world, and those who'll follow them.

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PROLOGUE

The Decision

It was about 7.45pm when the familiar amber glows started rhythmically illuminating my body. The lights washed over me in quick succession before fading just as rapidly as they'd appeared.

The freezing December air began to rush around my head, growing more violent and cutting with each passing second. A deafening roar filled my ears, drowning out the world save for a dull repetitive rumble as I moved forward. I was calm, cold and thinking more clearly than I've ever done.

The speedometer – the only consistent light illuminated in front of me – steadily climbed. *45 miles per hour. 50. 60.*

I can't say I would recommend driving along a UK motorway with your windows open in December. But for me, at that moment, it certainly did the job. The cold air brought with it an icy clarity. The white noise of the roadway shut out my most whirring thoughts. For the first time in weeks I felt refreshed, present, alive.

It had been another difficult day for me working in the construction industry. I felt dejected, disappointed and worst

of all trapped. This wasn't what I had signed up for but I was in it. It was my life. I had a mortgage, responsibilities to meet, and expectations that I couldn't live up to. What to do?

Well at that moment I decided that a cold and noisy drive home along a somewhat deserted M25 the week before Christmas might help. I wanted to feel human again, at least for a moment. My whole life had brought me to that glamorous place: feeling lost on a dark, excessively wide stretch of tarmac, between two unremarkable road junctions. I reflected on the journey.

Growing up I had always loved building things. I was that kid who constantly played with LEGO – adapting, tweaking and reinventing different setups to help play out whatever improvised story had captured my imagination that day. When the guys painting the outside of our house had left their scaffold tower parts disassembled and stacked up in our garden for weeks on end one summer, my sisters and I used them to build the ultimate den, entertaining us for hours. Looking back now it was actually incredibly dangerous. Don't play with scaffolding, kids.

Sunday mornings often consisted of building elaborate pillow-forts. Architecture through upholstery. We'd combine every sofa cushion with our duvets and turn the living room into a small city, much to my parents' dismay.

I guess in those early years of my life I really began to understand the power of constructing things as a means to enabling something greater to happen. Though, granted, for me back then it was just helping me act out my imagination or play more elaborate games in the garden.

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I followed my growing passion for building through school. Who needed to be a part of the ‘popular kids’ group when girls would undoubtedly be impressed with my manly ability to turn a wooden lamp on a lathe in design and technology class?

After school, I spent four years studying Architectural Engineering and Design Management at Loughborough University, a course that was worryingly discontinued not long after I graduated from it.

And at that point I got a graduate job in the construction industry. My dream had come true. My career trajectory seemed almost unparalleled.

But less than three years later here I was on the motorway. Construction wasn’t what I thought it would be. Worse: it wasn’t what others thought I had the potential to be.

My friends and family were confused. My mates were going from uni into fancy careers in the City. Banking, finance, law, medicine, you name it. The so-called ‘proper’ jobs. I was dealing with an air of disappointment and comments like: ‘Ah, construction. That makes sense. You’re quite built. I bet you’re good at lifting bricks.’

In reality, I was working on a £140 million school building programme that was going to shape how almost 5,000 kids in South London started out in life. I was a graduate design manager in the preconstruction department of a general contractor: part of a team of architects, engineers and quantity surveyors making huge decisions about hospitals, local education and affordable housing. We were shaping the world. The disconnect between what

construction actually does and the stereotypes people saw it through was stark.

At the same time, the business and ruthless contractual side of construction had left me a very long way from that passion I had first felt playing LEGO. I found myself in a world where people had forgotten why they do what they do. Where the process and challenge had taken them so far from the vision and the why. They were forgotten cogs in an unfair system. Their impact never seen, their dedication taken for granted, their success measured in near non-existent profit margins.

I was scared. I had worked my arse off to end up in a job that I now wasn't sure about. For the first time I felt lost. I couldn't change course and restart now, could I? Twenty-four-year-old me couldn't bear to imagine the embarrassment or guilt of letting people down, most of all my parents.

It felt like I only had two choices: throw in the towel and start a new career from scratch (the nuclear option) or miserably soldier on where I was. But in that moment as I thought about it all, something in me snapped. I've come to realise that I am someone who doesn't much like binary options, especially when both suck, and, sure enough, a third way started appearing before me, right there on the road that my industry had built. The world's misunderstanding of construction was what needed to change. It wasn't to just be accepted. The system I was in had to be fixed. I love this sector and I wasn't about to let some isolated experience of it bring me down. I wasn't going to quit and walk away. If

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I wanted change to happen, I had to step up and be a part of it.

Construction is the most important industry in the world. I have witnessed that fact first-hand for more than a decade and I will argue it with anyone, all day long. The homes we wake up to, the schools we raise our children in, the transport infrastructure we all use, the hospitals we rely on – all of it was built and enabled by construction.

I have heard so many arguments to the contrary over the years. ‘It’s surely medicine?’ Well, where are our clinical drugs being produced? In a factory. How are they getting to hospitals? On a road. Where are we conducting operations? In a state-of-the-art theatre. Try treating anyone without built infrastructure.

‘Well, it’s gotta be food production. We can’t live without that.’ Again, our farms, transportation infrastructure, factories and supermarkets were all built by this industry.

For millennia, construction has shaped our world. It’s what has made societies rise, economies grow and trade flourish. Our built environment stands as a series of silent chapter markers in the long story of human progress. Each structure is a product of its context and time. Each is an influencer of what followed.

It’s all around you right now. Whether you’re sitting at home, on a train or in an airport. Start thinking for a moment about how much of your life interacts with or is enabled by things that human beings have built and you quickly realise it’s all-encompassing.

The world needed to see construction the way I did, and

I decided right there and then to put all my energy into making that happen. I wanted my passion to become my job. I wanted to visit the world's biggest and most impressive mega projects, to *show people* what they were missing. It felt like a huge and unreachable goal, but it was also exciting.

People weren't getting construction because they weren't hearing about it. We had engineering magazines writing boring articles for engineers, inaccessible architecture magazines writing for architects, and a mainstream media that only covered our projects when things were late and over budget.

Young people weren't aware of construction's potential and that had contributed to an acute skilled-labour crisis that is still affecting the industry worldwide. We had a generation looking for more than just salaried jobs, that cared about social value and wanted to make a difference. If only they could see the power of construction! Come here and shape our cities, create fulfilling affordable homes and make an outsized dent on climate change – more than 40 per cent of all carbon emissions come from the built environment.

I needed to tell construction's story in a way that it hadn't been told before. We had to link what was happening in the industry to the world people experienced. There had to be cause and effect between our buildings and our lives. We had to reach beyond the edges of our sector and communicate what we really did. I could see it when it felt like no one else did.

And it was there on the motorway that I decided. I was going to put everything I had into tackling this issue.

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The early 2010s was a time of seismic change. Seeing the huge shifts in how people consumed information and the massive engagement that could come with social media, I decided to try something that hadn't really been done before. I would make my own videos about construction, put them on YouTube, pop a few posts out online and see what happened. Not a magazine. Not a stand at a careers fair or trade show. Not a one-off talk to a school or university. Not a pamphlet. I didn't want people to have to go out of their way to find construction. To have to opt in. I wanted to go where they already were. To put these amazing stories onto the platforms that billions of us scroll through every day in a way that would be relatable. That would stop them in their tracks. I wanted to show why construction mattered to *all* of our lives, and why it had to be taken more seriously.

I knew that if this was to really work, I would have to do it full time. Since the age of about ten I had always wanted to run my own business – inspired by Saturday-morning trips to work with my dad at his company. But by my late teens and early twenties, the pull of wanting to be like him was strengthened by a push of wanting to get out of working for other people. I knew I would have to do everything I could to make 'The BiM' – the YouTube channel, and the diversified media company I have built around it – my main job as quickly as possible, working every evening, weekend or spare minute I had to reach that stage.

I guess that drive ended up becoming one of the most consequential of my life. The thought of the journey I was

embarking on filled me with hope and adrenaline and I didn't hesitate.

Now at this point I could make some clever comparison between physically coming off the motorway exit ramp and this momentous decision. Choosing a new path. The slip road to success! But I won't because I am not a twat.

What I can say is that everything that's followed pretty much began with this one moment. The years since have seen me quit my job and carve out a very different life. They've been filled with time spent negotiating site access, building a team, travelling relentlessly, taking a front-row seat on massive projects and fighting to earn construction a place in the zeitgeist. It's a journey that's grown me and broken me. Lifted me up and worn me down. A ride that's exceeded even my wildest expectations.

Today, The BiM is the world's largest and most subscribed-to video channel for construction. An astonishing 32 million people watch our content each month, something I still struggle to get my head around. We employ a talented full-time team of 16 people across 2 continents. We have video journalists, content producers, video editors, motion graphics designers, and production managers all working to help me share construction's story with the masses. They're more than a team. They're friends and like family. An incredible group of people that has taken me a decade to build, retain and train, all of whom are invested in our mission to get the whole world to love construction.

We produce new videos every week. There's a website, a podcast, huge social media accounts, events around the

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world, merchandise, fan websites and people stopping me in the street for selfies from Tokyo to Los Angeles. It's honestly all a bit crazy for a boy from Surrey. But, as I have slowly come to learn, testament to the power of following your passion and believing in yourself.

The gap between the life I was leading and the life I wanted felt light years apart on that cold motorway drive. An impossible leap. Yet today, more than a decade on, I look back and pinch myself. I now get to do what I wrote down as my dream job for a living. I am traversing the world, seeing its best and most epic construction projects, and helping to educate and inspire people.

For years I beat myself up. I told myself I wasn't good enough. I pushed for The BiM to become bigger and bigger. I battled an industry stuck in the past, that didn't see the value of what I did and told me to my face I was a fool. I have seen people who just wanted a piece of my success come and go. I have faced sharks wanting me to sell out on my vision. I have been robbed of moments with my wife and two amazing kids as I worked to build a future for them. I have struggled with my mental health, and in particular with depression.

But I got here. I made it happen. Me.

I have taken myself from that drive of doom to my dream job and learned so much about who I am on the way. The people around me today are the ones who stuck with me through thick and thin. Who told me I was right when others were screaming that I was wrong. It's an incredible feeling and one that now gives me a sense of quiet self-belief

and conviction that never seems to wear off. Of course, as a British man, the disarming self-deprecation is always front and centre; a kind of defence and deflection mechanism. But deep inside me there's now a real pride in what I have achieved – something I have only really acknowledged and accepted as legitimate in myself over the past 18 months or so.

Discovering so much about who I am has been an unexpected by-product of the journey, but it was nothing next to the surprise I got about construction, a world I thought I knew so well. The truth is the more I have travelled, explored and investigated some of our planet's most jaw-dropping projects, the more stunned I have become. I knew these builds were impactful, I knew they were moulding our world, but not like this. Not to such an extreme and fundamental extent.

Over the pages that follow, I'll take you through ten of our planet's most exhilarating mega builds and reveal what I discovered from getting up close to each of them. As you read on, you'll come to see – as I have done – that the die of our future is already cast. The trajectory of our civilisation is being authored today, all around us, not in words on a page but in steel and concrete, by an industry that most people completely overlook.

By the end, my hope is that you'll be left with a newfound respect for the built world and become more engaged in where it's headed. It's the environment you'll have to live your life in, so it's pretty important that you take notice and have a say.

That December car journey ended unusually for me. I remember it as if it were yesterday. I pulled up outside my

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house but instead of sitting in the darkness with the engine off for a moment, exhaling with the sigh of defeat I had felt in the months before, I got out of the car with a sense of determination in my step. I walked up to the front door to face the Christmas and New Year period with excitement, not the dread of having to mark another year rolling by in a job I had come to loathe, as I had done in times past.

I knew the journey ahead of me would be extreme in every sense of the word. But never in my wildest dreams did I imagine what I would see next.

I

The Hollowed Mountain

I pulled my legs together and grabbed my groin. It was a deeply visceral reaction to the last thing any man needs to hear on a Friday morning.

I had just read about ‘neutrinos’ for the first time in my life: tiny, microscopic particles that had been passing through my body for years without my knowledge. All parts of my body. Tens of trillions of them moving through me every second.

I was excitedly diving into a new mega build, when this unnerving revelation hit me like a train. It turns out these ghostly particles exist all around us, yet we know almost nothing about them. They’re so small that no one has ever been able to measure their mass. They don’t interact with other matter at all. They can just pass through any kind of material or object unimpeded, from the human body to solid concrete or even an entire planet.

Scientists have spent decades desperately trying to decode their mystery without any kind of rapid progress. Things have been slow and gruelling. The existence of neutrinos was first hypothesised by the Austrian physicist Wolfgang Pauli

in 1930, but it took a further 26 years of graft to actually spot one. Frederick Reines and Clyde Cowan first pulled it off in South Carolina in 1956.

I guess I've always found something incredibly humbling about particle physics. Study this stuff even for a moment or two and your very existence as a human being is made to feel at once miraculous and insignificant. Unique, yet fleeting. I often think of Krystal Sutherland's words in the book *Our Chemical Hearts*: 'We are just a collection of atoms that come together for a brief period of time and then we just fall apart.'

It's all fascinating stuff, but it properly scares the crap out of me.

On that note, try and keep your atoms together for a quick bit of science. Every time atomic nuclei come together (in a process known as nuclear fusion) or break apart (fission), neutrinos are produced. Trillions of them constantly move through us, having travelled across space to our planet from the reactions happening inside our sun. In fact, those solar neutrinos are the most common source of the neutrino particles found here. Sixty-five billion of them pass through each square centimetre of the Earth's surface every second.

Neutrinos come from other sources too. Man-made nuclear reactors produce them, and they can emerge from the beta decay of atomic nuclei, though I don't pretend for a moment to know what that is.

Now, if you're anything like me, you'll glance down the big fat list of problems we need to sort out as a human race and conclude that studying random tiny particles is a pretty low priority. This feels like a fun investigation for an eager

bunch of scientists rather than a pressing international issue, right?

Well, not exactly. Learning more about neutrinos is key to understanding how our universe was created and what its future holds. It can teach us all kinds of things about how our world is formed and how it works. How heat is generated and the relationship between forces.

For centuries the development of particle physics has – for better or worse – helped us understand and shape our world. It's brought about medical accelerators that can treat cancer, medical imaging through particle detection, and the semiconductors in our laptops and phones. It's also infamously been harnessed for destruction, helping create the bombs that killed hundreds of thousands of people in 1945 and catalysed the end of the Second World War; bombs whose continued existence ultimately dictates much of our world order today.

As you might imagine with some of the smallest particles in the universe, even with advanced microscopes and technology neutrinos are pretty hard to spot. Actually, scratch that, they're a bloody nightmare to try and spot. It's basically next to impossible to see them. To do it you'd need somewhere incredibly calm and peaceful. Somewhere protected from all that noisy background radiation that fills our atmosphere blurring neutrinos from our view. According to clever scientists, to stand a chance of seeing a neutrino on Earth you'd have to be either very deep under the ocean or inside a mountain, and trying to build a highly sensitive neutrino observatory somewhere like that would just be mad.

Or would it? One construction team has actually taken on that extraordinary challenge. And faced with a choice between a rock and a wet place they've opted for the rock.

To spot neutrinos, an enormous observatory is currently being built inside a mountain. Yep, you read that right. While we all go about our lives, a group of crazy people are toiling away over half a kilometre below the Earth's surface moving monumental amounts of rock and stone.

The absurdity, the sheer audacity, of this project would surely put anyone off right at the outset. Who in their right mind would dare think it possible to hollow out a mountain and create something like this, let alone attempt it?

One can barely imagine the challenges that must run through the heads of those involved in this on a near-hourly basis. I've led many a project meeting on what now feel like comparatively simple builds – hospitals, schools – and that's tough enough. The mind boggles at the thought of what a planning and logistics meeting here might entail.

The journey to putting the first spade in the ground has been a long one. Ideas for this project were first presented back in September 1999 when epic hits like Eiffel 65's 'Blue (Da Ba Dee)' were gracing the radio airwaves. A formal letter of intent was signed 12 years later in September 2011, followed (finally) by a memorandum of understanding between the key parties involved in early 2015. Though it might sound tortuous, such drawn-out timescales aren't actually that unusual for builds of this scale and ambition. It takes years for ideas put forward in white papers to become policy, for policy to gain approval and funding, and for

procurement, precise design and preparation, and a myriad of pre-construction activities to be completed.

But here, paperwork was the easy bit. For the team behind this project things really got started with that most unusual of activities: mountain shopping.

Forget the house-buying lists that most of us have: two bedrooms, a decent rail connection and a south-facing garden. These guys needed somewhere with rock deep and dense enough to provide a radiation barrier. Somewhere peaceful, politically stable and in all honesty pretty chilled about having one of its mountains hollowed to help unlock the universe's darkest secrets.

That place turned out to be Japan. The Gifu Prefecture in the beautiful Japanese Alps to be precise. It's here, in solid granite, around 650 metres under the peak of Hida City's Mount Nijuugo, that a massive neutrino observatory is being carved out of the rock. A new chapter in our understanding of the universe moving closer with each truckload of rubble hauled out of the landscape.

Now, there are a few reasons why this particular mountain won the neutrino observatory equivalent of *The X Factor*. It offered homogeneous hard gneiss and Inishi migmatite – a mix of granite rock that's ideal for tunnel stability and background radiation screening – good proximity to the scientific team's regional hub at the Kamioka Observatory in nearby Hida City, and crucially a prefecture up for having one of its mountains dug apart.

This region of Japan is also home to the Kamioka Mining and Smelting Company, meaning there was considerable

hole-digging expertise in the area. People, businesses and machinery that have bored into these mountains before and know the drill, if you'll pardon the pun.

So, having chosen a mountain and undertaken nearly 22 years of precision planning, design and research, day one of the mega build finally arrived: 6 May 2021.

Can you imagine what that morning must have been like? Walking up to the towering Mount Nijuugo, looking at the approved plans in your hands and knowing what lay ahead? The task of somehow turning solid rock into an advanced laboratory. No pressure, guys.

The first task here was to 'drill and blast' an access tunnel horizontally, deep into the side of the mountain. I'll make a basic engineer out of you with this book, and drill and blast is our first lesson. It's a pretty straightforward process that does exactly what it says on the tin.

First, you use a machine to drill a series of holes into the face of the mountain, normally in a large circle that's about the width of the tunnel you want to create. You then fill those holes with carefully calibrated doses of explosives, stand a very long way back, press a big red button and cover your ears.

Assuming everything goes to plan, the resulting explosion will convert solid rock to a pile of rubble that an excavator will come in and pick up with its bucket, dropping all the stone and grit into the back of a nearby truck.

Once everything's cleared up, you then drill more holes in the rock face ahead of you and repeat the process. Slowly but surely, you'll start to form a tunnel. Daylight will fade. It'll

start to grow cold and damp. Your commute will get longer. GPS tools and surveyors will keep you on track. Oxygen tanks and toxic-gas warning instruments will be installed to monitor the environment. Evacuation plans will be regularly reviewed. Local residents will hate your guts. The nearby aggregate merchant looking to sell crushed rock will be rich.

At Mount Nijuugo this process took a gruelling nine months to complete. That might sound like an age, especially when you're working in a place like that, but it's a pretty standard rate for drill and blast.

As works progress, crews follow behind spraying wet concrete onto the exposed rock walls with huge hoses. There are a couple of reasons for this. The first is to stabilise the material and prevent rock slips or slides into the tunnel. That's important on any project but it's critical on major pieces of infrastructure that millions of people use every day. A failure on something like a road or rail tunnel could be deadly for those in it and have a huge knock-on effect to an urban area: blocking emergency services in gridlocked traffic, stalling businesses and wiping billions off stock markets. If that all sounds a bit dramatic, I can assure you it's not. If New York's Hudson Tunnel between Manhattan and New Jersey were to become blocked, a staggering 20 per cent of the United States' entire GDP would be instantly put on hold.

The second reason for concrete spraying is to create a watertight seal. Often with deep tunnels – and especially on those running beneath lakes or oceans – you'll be interrupting the groundwater table. That's water sitting below ground in between the rocks, dirt and sand.

When I was a kid, I always enjoyed digging small holes around our back garden in my vain attempts to create a pond. If you've ever done the same in soil or on a beach you'll know that, after a point, water will keep seeping back into the bottom of your hole no matter how many times you scoop it out. That's groundwater and it's invading your hole at that stage because you've hit the water table – the point below ground where water saturates the space between the rock and soil. Now the water-table level varies massively depending on where you are and can even change in one fixed location depending on the seasons, weather or big changes that have happened nearby, like a new construction project.

For those building deep tunnels, groundwater will forever want to enter your tunnel and cause havoc unless you seal everything up.

In fact, many tunnels resort to running constant pumping systems to keep water at bay. They collect water that's seeped or run into the tunnel space and carry it back out again to nearby rivers, lakes or the sea.

I vividly remember being shown inside a pumping station, 90 metres beneath the remote Faroe Islands. I stood inside a small but fascinating rock chamber filled with noisy pumping kit at what was the very deepest point of that tiny island chain way up in the freezing North Atlantic. Those steel maintenance doors we all zoom past in underground tunnels hide a world of machinery that helps make our journeys possible.

And that's the process. Drill, blast, spray, repeat. Drill, blast, spray, repeat. For nine months.

It's one of the toughest parts of any construction project. The thankless period (or periods) of chipping away at a massive task. It's important. You're making steady progress. Things are moving forward. But my God is it dull.

At times like that, stoicism is a helpful characteristic. If you don't have any, don't worry. Those phases will quickly help to build it up in you. In all seriousness, it actually takes considerable mental focus to navigate times like these, especially when rough weather, dark winter days, deadlines, tight budgets, or long working hours are thrown into the mix. Strong team dynamics, good camaraderie, the support of your work mates and a collective awareness of the potential mental health risks are so important.

Looking back now, I realise that construction taught me so much of my own 'keep going' mentality. I have found similar periods of unforgiving grind when building a business or training in the gym. It's all the moments people don't see that count most and deliver the real progress. The times you keep turning up and chipping away, bit by bit, in the dark, out of sight, out of the limelight.

Having reached the heart of the mountain (and with the monotony of tunnelling in a two-kilometre straight line finally behind them), the team in Japan started to construct an enormous dome-shaped circular cavern with the same technique. The space created is akin to a great stadium or cathedral. It soars and opens out above you, invoking awe while making you feel instantly inconsequential.

Through the ceiling above your head sits around 650 metres' worth of solid granite – a distance almost equivalent

to the height of Malaysia's 679-metre-tall Merdeka 118, the world's second-tallest building. The instantaneously pulverising weight of it all doesn't bear thinking about but dominates your mind.

Into this domed roof are set huge steel rings and braces, all welded together to create a near-invincible reinforcing roof structure that's capable of holding the mountain above it. The load of all that rock is channelled down through the steelwork and ultimately spread to the perimeter, maintaining the open cavern space beneath the frame.

Such an achievement in itself is immense, but this was just the beginning. In fact, by this point, merely the top of this laboratory had been constructed. The cavern was about to get substantially bigger.

The team next turned their attention not to the roof or walls, but to the floor. Drilling into the rock below their feet they began to take on the most monumental part of this mega build.

Steadily – painstakingly – they are drill and blasting their way downwards to create an extraordinary cylindrical chamber. When it's finished, this great void will be a remarkable 68 metres wide and 71 metres high – large enough to hold a 22-storey building or an entire Airbus A350 standing on its tail. The largest artificial underground cavern in the world.

The metre-thick concrete walls of this space are being carefully lined with layers of waterproofing. The budding engineer in you of course now knows that is probably to keep water out, but here it's to serve the opposite purpose: keeping water in.

THE HOLLOWED MOUNTAIN

You see, this vast cavern is in fact about to become the largest tank of water ever constructed by humankind. Set to contain 260 million litres of water, its volume will be a staggering four and a half times greater than that of the world's biggest aquarium: a sprawling tank over at the Chimelong Ocean Kingdom in China.

Cleverly, the persistence of the mountain's water table is being turned from foe to friend: harnessed by engineers to steadily fill this biblical-sized tank to the brim over a period of six months. Once inside, the water will be treated, taking it to an 'ultrapure' state. Forget those images you're conjuring up of Alp-filtered water brands sitting in a supermarket fridge on a hot day. Ultrapure water is dangerous stuff, capable of dissolving people. No swimming here please.

To put it simply, this water has been heavily altered and longs to go back to the way things were, though it's nothing to do with nostalgia. The water has been purified to such an extreme level that it lacks dissolved ions – the small atoms that normally make it essential to the key biological functions within humans, animals and plants.

Ultrapure water is looking to return to its original, regular-old water state, so it absorbs ions from its surroundings, including by corroding certain types of metals, plastics and even some of the human tissue that it comes into contact with.

Now at this point, you'd be excused for wondering what the feck is going on. Truth is, it's easier to explain this mega build steadily. Gradually revealing each part of the facility's purpose as it relates to its engineering so as not to leave