

ROMA AGRAWAL

...THE AWARD-WINNING
ENGINEER WHO
LIKES TO BUILD BIG

ILLUSTRATED BY
KATIE HICKEY



THE STORIES BEHIND AWESOME STRUCTURES

BLOOMSBURY



INTRODUCTION

Humans have been building for tens of thousands of years – in fact we spend most of our time inside the structures we’ve created, from the places we live, study and work, to the bridges and tunnels we use to get around.

Our ancestors started off seeking shelter in caves, then created tents and mud huts. Since then, our structures have evolved into skyscrapers of steel that soar towards the sky and bridges that cross the widest and deepest of rivers.

From a young age, I have been fascinated by how our human-made world came to be. When I first saw the incredibly tall skyscrapers in New York that towered above me, my head filled with questions. What were these ENORMOUS things? How could I climb them? What did they look like from above? When I got home, I used my own miniature cranes, stacking building blocks to recreate what I had seen.

Now, I’m a structural engineer and it’s my job to make sure these structures stand up and keep us safe.

In this book, we’ll explore amazing structures across all seven continents. We’ll learn about the forces that act on our structures and how we resist them, what materials keep our structures strong and how to make them tall and stable. We’ll find out how to build underwater and even on the Moon, and hear stories about some of the amazing engineers who created our world.

Once you read this book, you’ll see the world through different eyes – the eyes of an engineer.

HOW TO BUILD TALL

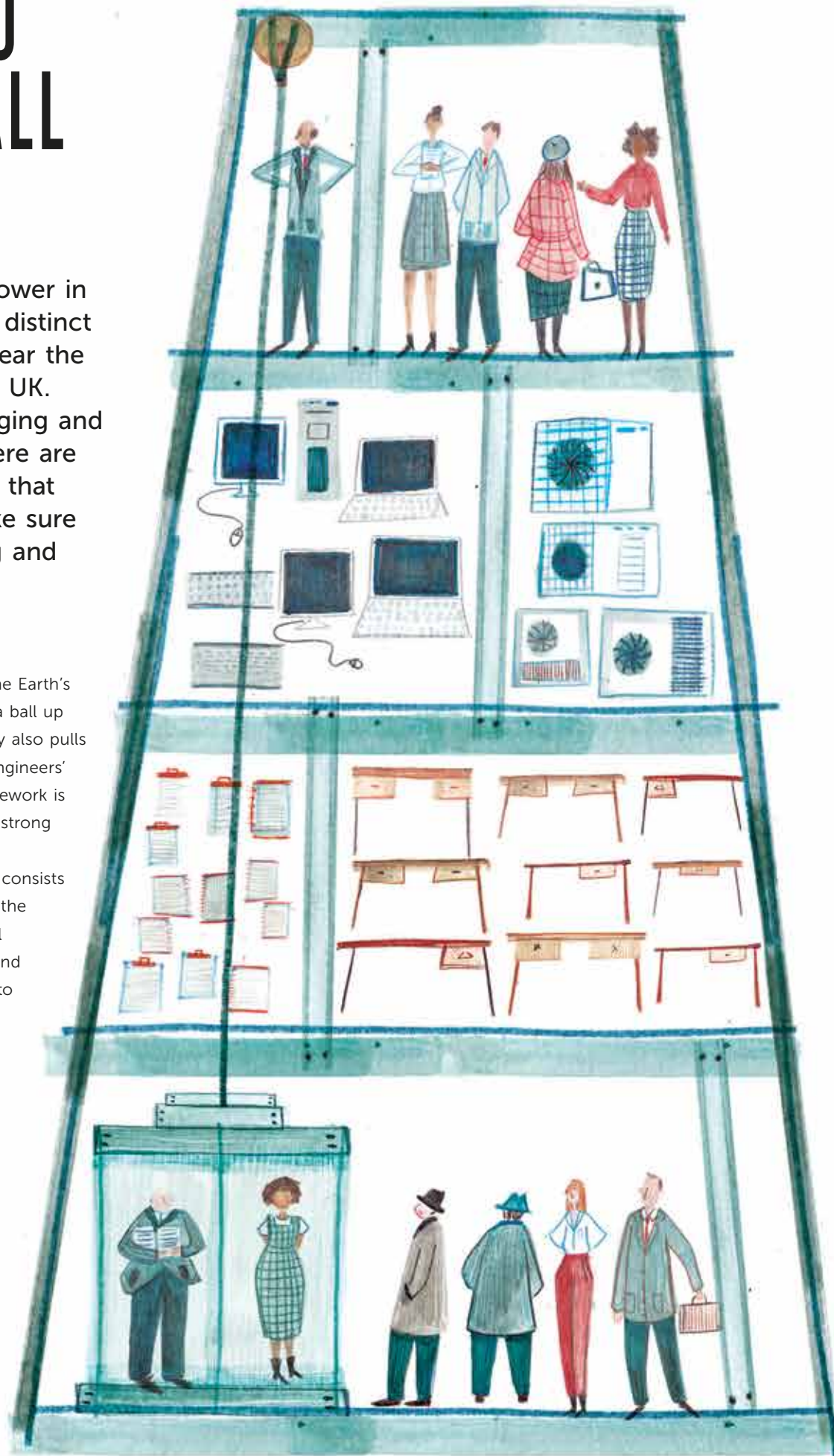
THE SHARD

The Shard is the tallest tower in Western Europe. It has a distinct triangular shape and is near the River Thames in London, UK. Tall buildings are challenging and interesting to design. There are different forces in nature that we need to resist to make sure skyscrapers stay standing and don't collapse.

What makes a building stand?

Gravity attracts everything towards the Earth's centre – that's why when we throw a ball up into the air, it falls back down. Gravity also pulls down on all our structures. It's the engineers' job to make sure the structure's framework is made from the right materials and is strong enough to fight this force.

The main framework for buildings consists of horizontal beams, which make up the floors, ceilings and roofs, and vertical columns, which hold up the beams and form walls. In a skyscraper, we have to calculate how much the materials it's made from will weigh, and also how much the stuff inside it will weigh, from lifts and air-conditioning units, books, computers and desks to all the people! We can then do the maths to check that the steel or concrete beams and columns won't get crushed by this weight and that our skyscrapers will reach brilliant heights.



Beams

Imagine holding a carrot lengthwise between your hands and bending the ends up to form a U-shape. The top side gets squashed and the bottom gets pulled apart. Engineers call the squashing force compression and the pulling force tension. When the tension is large enough, the carrot snaps. When the compression is large enough, the top crushes. This is how beams work. Engineers check the forces acting on beams to make sure they won't move too much or break.

Columns

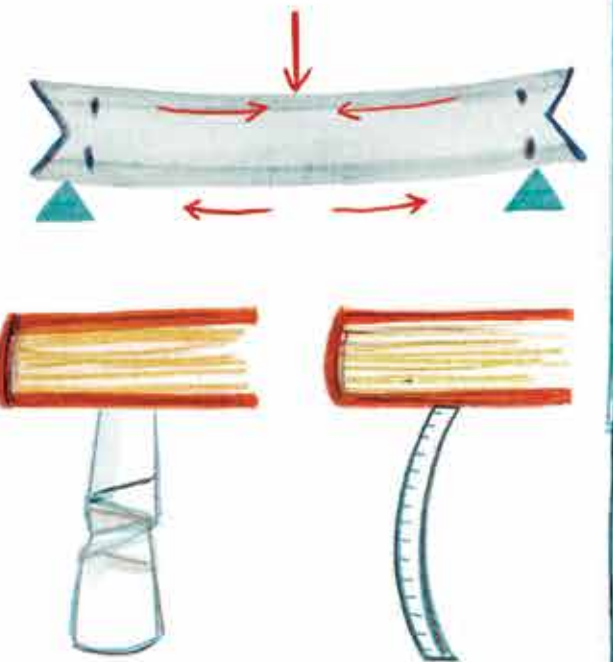
Try these two simple experiments to see how columns can fail. Roll up a piece of paper into a tube and tape it together. Stand it up on a table and put a small, light book on it. You'll see the tube is strong enough to hold the book up: that's what a good column does. But if you put a really heavy book on top, the tube will crush and the book will fall down. That's a bad column, which has failed by crushing. To hold up the heavy book, you would need a much stronger tube. Columns can also fail by bending. If you hold a ruler vertically on a table and push down on it, you will see it bowing. Don't push too hard or your ruler will snap!

Steel for strength

Millions of tiny atoms, arranged in patterns to form crystals, make up metals such as iron and steel. The earliest metal used in big buildings was wrought iron. But this is a relatively soft metal because its crystals slide around a little when pushed and pulled. To make iron stronger, engineers added carbon. The atoms of carbon sat within the iron crystals and stopped them moving as much, and made a metal called steel. When you try to pull steel apart, the crystals don't move as easily, and so it's a stronger material for building. But you need the perfect amount of carbon: too much makes metals brittle, which means they can crack easily.

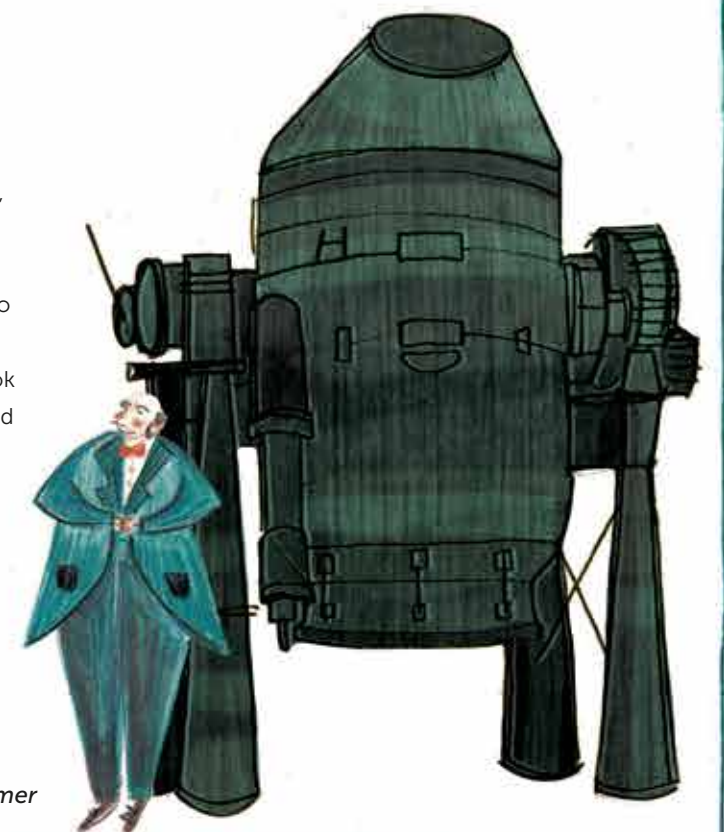
How do we make steel?

To build upward, first we have to gather materials deep inside the earth. Iron mined from the ground has a mix of different impurities, such as carbon, silicon and phosphorus. A British engineer called Henry Bessemer invented a process for making steel cheaply in the 19th century. He put iron pieces into a covered furnace and blew hot air into it. A chemical reaction happened. The oxygen in the air reacted with the carbon in the iron and released huge amounts of heat. This heat took away the impurities and left behind pure iron. Then Bessemer could add in the exact quantity of carbon needed to make the best steel. Since then, steel has been used all over the world to build our most exciting buildings, bridges, stadiums and railways.



TRY IT AT HOME: STEEL

Take a large plate and pour some Maltesers chocolates on to it. Roll your palm over them. You'll see that the chocolates move around easily – this is like the crystals of pure iron. Now sprinkle some raisins between the Maltesers and try again. The raisins block the Maltesers from rolling around as easily, which is how carbon atoms make steel stronger.



Henry Bessemer

THE SHARD

The Shard is 310 metres tall, and its core is made from concrete. The core is at the centre of a tall building and makes sure that it can resist wind forces.

The Shard has 11,000 glass panels, which would cover eight football pitches!

The Shard was built using some clever cranes that were assembled at various points during construction. One of these was on top of the core of the tower. As the core grew taller, this crane was simply able to rise with it.

Another crane, which attached about halfway up the tower, was used to continue building right up to the steel Spire at the very top. To take the crane down after it finished its work, a smaller crane was built at level 72 – but how did we take this one down? We used yet another crane, this one at level 87!

Concrete was used in the hotel and apartment zone, where there are lots of walls and different rooms. Here, it's better to use concrete because the concrete floor is thinner and saves space, and the concrete also absorbs more sound so guests can sleep better!

Steel beams, which are strong in tension and can go a long way without columns supporting them, were used for office levels where big open spaces were needed without too much structure.

The Shard has 44 lifts including double-decker lifts.

The Shard uses extra-white glass, which makes the building appear to change colour according to the weather and seasons.

Renzo Piano is a famous architect who designed The Shard. He also worked on the Pompidou Centre in Paris. His design for The Shard was inspired by the spires of London churches and the masts of tall ships.

On 5 July 2012, an amazing laser and spotlight display celebrated the completion of the outside of The Shard.

The open steel structure in the Spire has special paint to protect it from the wind and sun.

Five tower cranes were used during construction.

This final crane at level 87 is a telescopic crane, which means it can be expanded for carrying out jobs and made smaller for storing away. It lives permanently at the top of The Shard and is still used to clean windows. Sometimes, if you're lucky, you can see it in use.

I was one of the engineers who worked on the tower!

Roma Agrawal

The structural steel in The Shard weighs about 12,500 metric tonnes. That's more than 900 London buses or 70 blue whales!

54,000 cubic metres of concrete were used in the building – enough to fill 22 Olympic-sized swimming pools.

Parts of its foundations are 54 metres deep.

To save time, the underground levels and upper levels were built at the same time: this is called top-down construction. It was the first time this technique was used on a core. Engineers installed steel columns inside the concrete piles and built most of the ground floor first. Then they dug downwards to create the basement. The steel columns in the piles supported the ground floor slab, and allowed workers to build up at the same time.



Renzo Piano



Roma Agrawal

THE MACHINES THAT BUILD TALL BUILDINGS

To build tall, we have to lift materials up high and we use machines called cranes to do this. Modern cranes are made of criss-crossing pieces of steel with a large arm at the top. At the end of this arm, or jib, are strong steel ropes and a hook to which we attach the heavy items that need to be moved. The ropes are wound back through pulleys, which lift the hook along with the materials.

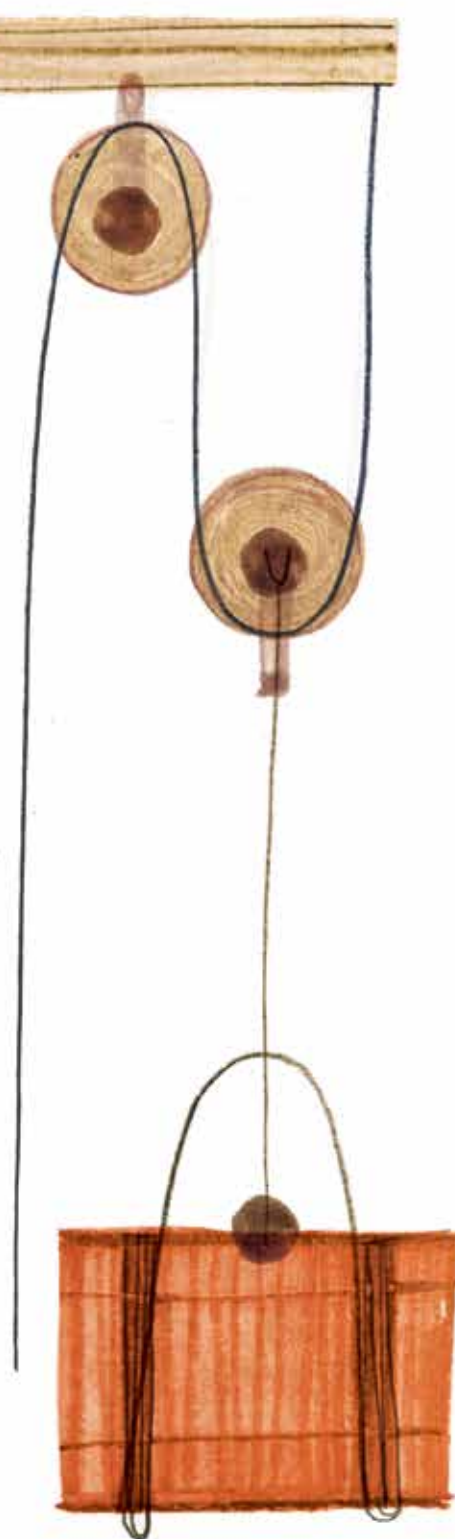
What is a pulley?

A pulley is a wheel with a rope wrapped around it. One end of the rope is tied to a heavy object that needs to be lifted, while a person pulls on the other end. Ancient civilisations used pulleys to raise a bucket full of water from a well and humans have found lots of uses for pulleys since then.

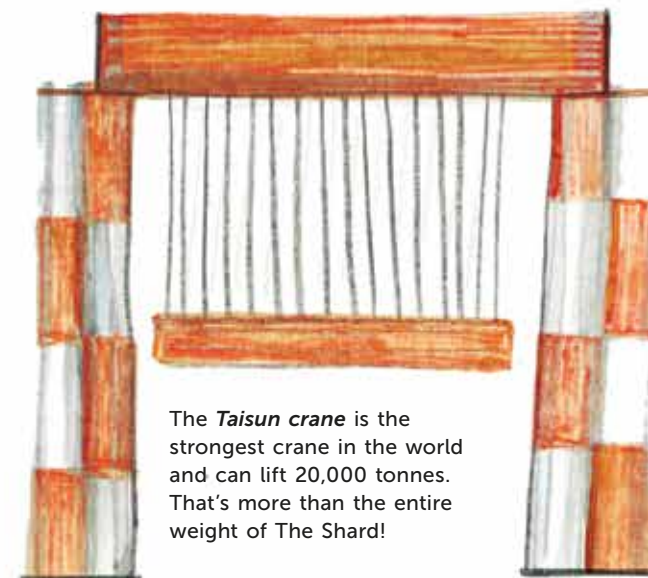
But to lift very heavy objects, we need ancient Greek scientist Archimedes' invention called the compound pulley, which is made up of lots of pulleys with a single rope weaving its way through them. This helped lift heavier loads because the person pulling on the other end of the rope didn't need to use as much effort. If you have two pulleys instead of one, you only need half the amount of force. This made it much easier to lift materials high into the sky. The Romans used compound pulleys in their cranes, and were able to build tall structures – such as their multi-storey apartment buildings called *insulae* – thanks to this invention.



Archimedes



TYPES OF CRANE

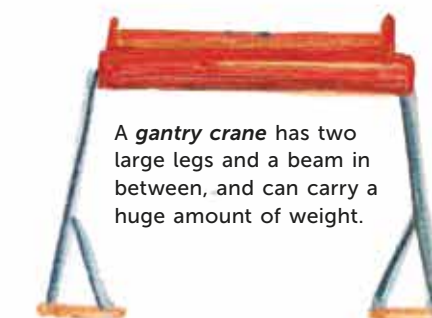


A **tower crane** is best for lifting materials high up in the sky and these cranes are frequently used for building tall structures.

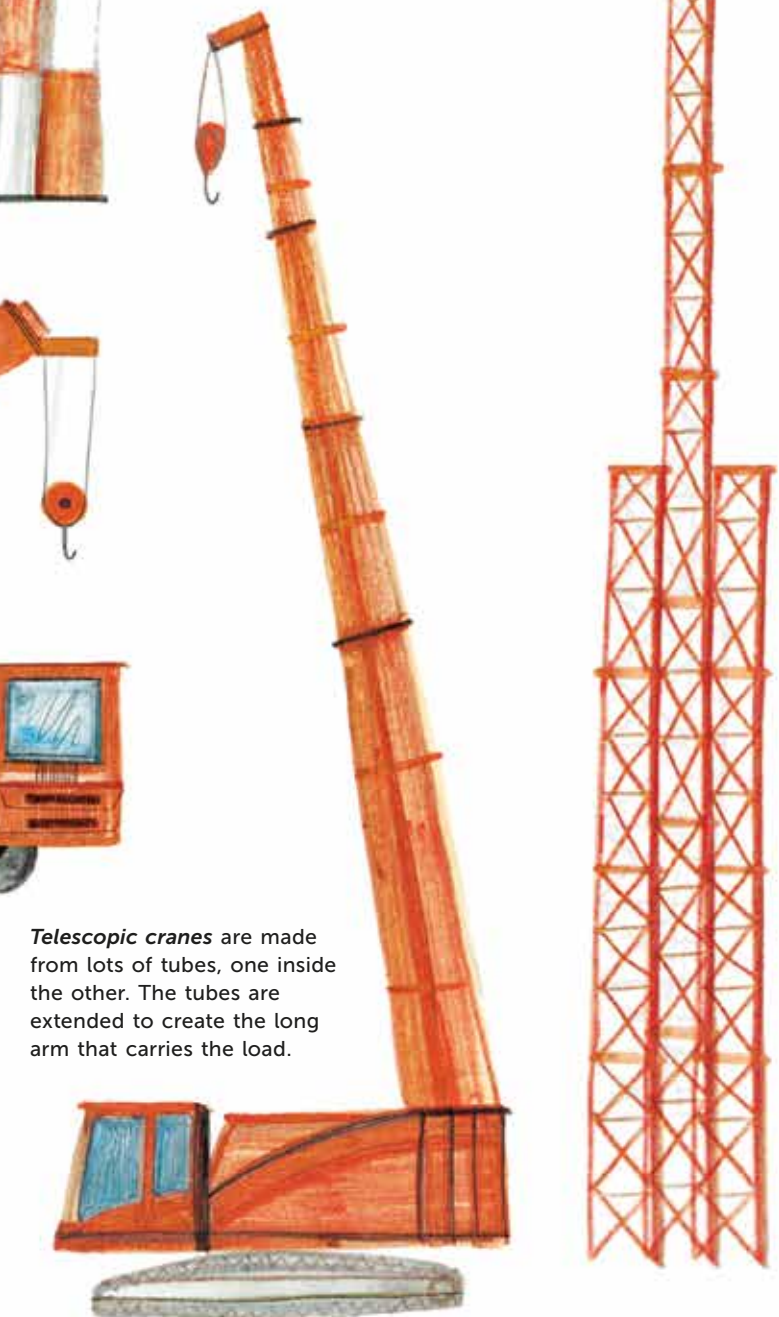
The **Taisun crane** is the strongest crane in the world and can lift 20,000 tonnes. That's more than the entire weight of The Shard!



A **mobile crane** can be driven around and parked wherever it needs to be used.



A **gantry crane** has two large legs and a beam in between, and can carry a huge amount of weight.



Telescopic cranes are made from lots of tubes, one inside the other. The tubes are extended to create the long arm that carries the load.

THE BROOKLYN BRIDGE

Each caisson used during construction was 50 metres wide and 30 metres long. A doctor was hired to supervise the condition of the men working in them.

The Brooklyn Bridge was the longest bridge in the world when it opened. It was also the first suspension bridge to use steel wire.

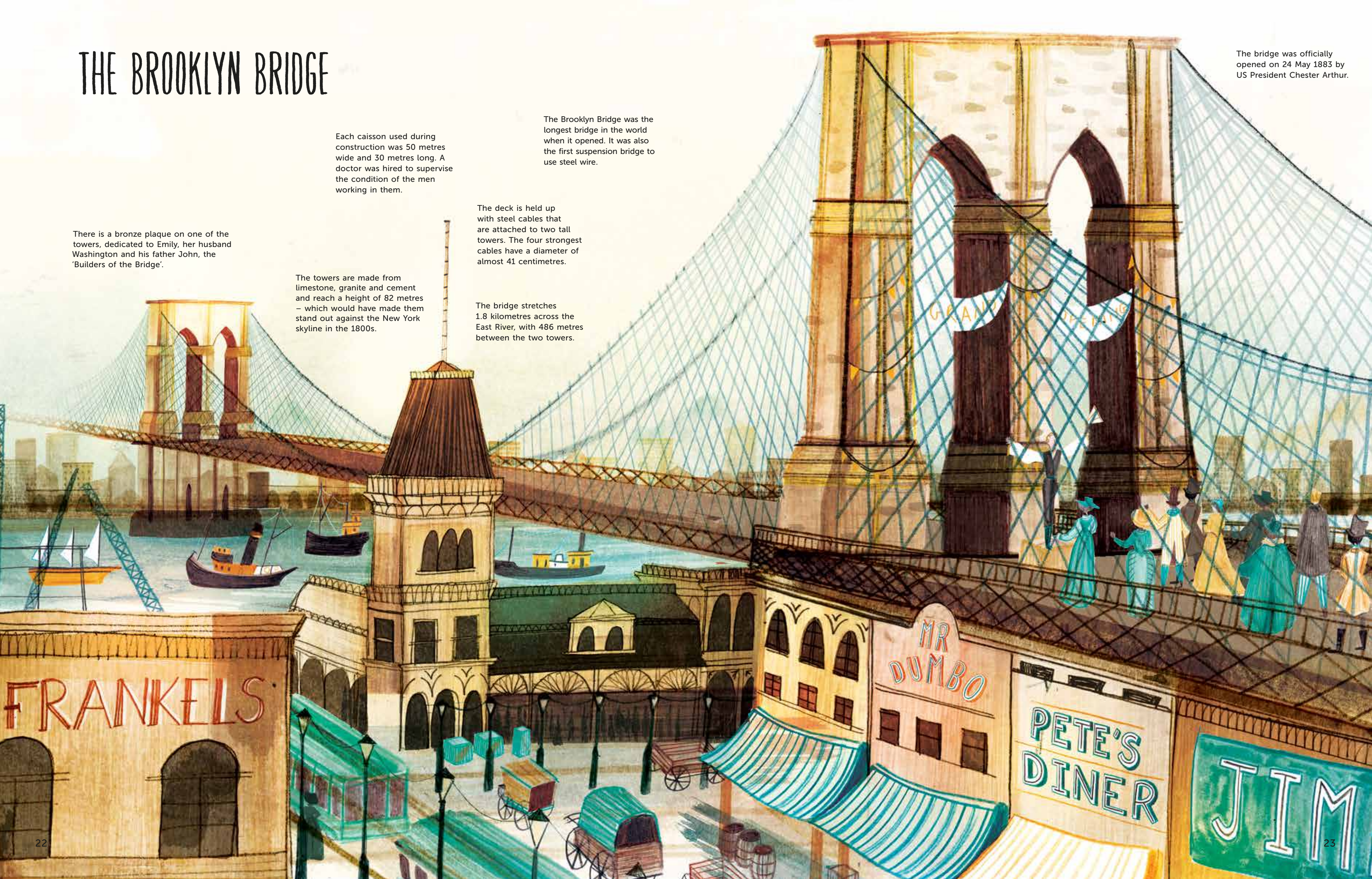
The deck is held up with steel cables that are attached to two tall towers. The four strongest cables have a diameter of almost 41 centimetres.

The bridge stretches 1.8 kilometres across the East River, with 486 metres between the two towers.

The towers are made from limestone, granite and cement and reach a height of 82 metres – which would have made them stand out against the New York skyline in the 1800s.

There is a bronze plaque on one of the towers, dedicated to Emily, her husband Washington and his father John, the 'Builders of the Bridge'.

The bridge was officially opened on 24 May 1883 by US President Chester Arthur.





Washington Roebling

EMILY WARREN: EXTRAORDINARY ENGINEER

Emily was born in 1843 and was one of twelve children. She had a close relationship with her oldest brother, Gouverneur K. Warren. He knew that Emily had a keen interest in science and made sure she was well educated. This was very unusual for young girls at the time, who were often not even allowed to go to school.

When her brother went to fight in the American Civil War, Emily went to visit him and that's where she met Washington Roebling, one of the other soldiers. They fell in love and exchanged hundreds of letters.

Emily and Washington got married and after the war she visited Germany with him to study caissons.



Emily Warren



Emily's father-in-law, John Roebling, started the design of the Brooklyn Bridge but died after an accident at the dock during the planning stages. Washington then managed the project until he became ill with caisson disease.



Emily was very worried that she would also lose her husband. She took notes from Washington to preserve his knowledge about the bridge. Then she started answering his letters and helping him with his work.



In the mid-1800s, it was considered extraordinary for women to learn about engineering, but that didn't stop Emily. She studied complex mathematics, cables and construction anyway.



Soon, Emily was supervising the work and visiting the construction site – a woman on site was unheard of at that time.



It was a difficult construction, and one which was trying new techniques and materials. Emily was soon faced with challenges.



More and more money was needed to fund it.



Workers were dying in accidents on site.



Then, in 1879, the Tay Bridge in Scotland collapsed and people worried that a similar disaster might strike the Brooklyn Bridge. The mayor of Brooklyn wanted to remove Washington Roebling from the project.



The project was even taken to court in an effort to stop it, and the Roebling family was accused of taking bribes.



But Emily slowly solved the design problems. She was very good at working with all types of people and spoke to the workers and politicians to reassure them. She convinced everyone to allow the Roebling family to continue their work.



Emily spent 11 years managing the project and must have been very proud when the bridge was finally opened. She was the first person to officially cross the bridge before the opening ceremony. She rode in a horse-drawn carriage and it's said she carried a rooster with her for good luck.

HOW TO BUILD IN OUTER SPACE

At the moment, space exploration by humans relies on the International Space Station or spacecraft. But some engineers and scientists are studying how to build structures on the Moon! Then researchers could live there for a long time to carry out their experiments and learn more about outer space.

What's it like on the Moon?

The force of gravity on the Moon is six times less than that on Earth. The amount of force pulling down on objects is smaller and so a lighter material could be used to build a structure on the Moon compared to the Earth. It won't float away – even this smaller force of gravity is enough to make sure of that. In past missions to the Moon, lunar landers and rovers didn't need to be anchored to the surface.

The challenges

The lunar environment is even harsher than Antarctica. The temperature on the Moon varies hugely. When the sun is shining on its surface, the temperature reaches 120°C, but then it plummets to around –170°C when it's in darkness. Unlike Earth, which is surrounded by gases that protect it, there is very little atmosphere on the Moon. Not only does this prevent humans from being able to breathe without help, it means the Moon is exposed to cosmic rays and radiation. These are types of energy that are made of waves and particles and they hurtle through space like light. Some types of radiation are very dangerous for humans. The Moon is also very, very dusty, with micro-meteorites, which are tiny space rocks, constantly bombarding its surface. Then there are the 'moonquakes' to contend with ...

DID YOU KNOW?

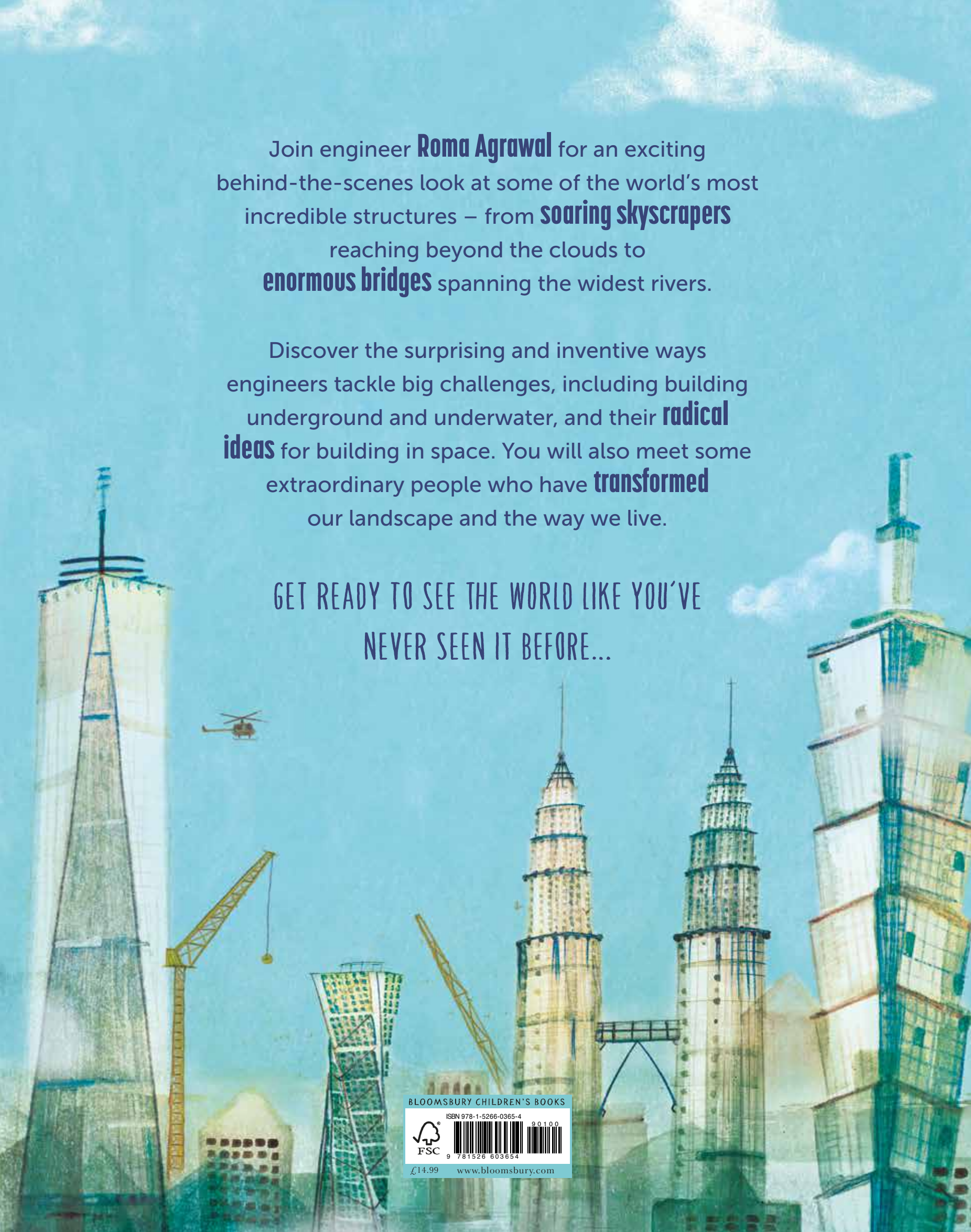
One possible design for the lunar structure is inspired by the igloo. One day on the Moon lasts about 29 Earth days, which means the Sun shines on a point on the Moon for about half that time, and it is in darkness for the other half. Compare this to Earth where our day is 24 hours long with an average of 12 hours of sun and 12 hours of darkness.

What can we build from?

It makes sense to use materials that are easy to find on the Moon, such as the top layer of regolith – the loose dust and particles of rock that covers the surface. There are two ways to turn regolith into a solid material. You could use a 'glue' to bind the grains together, or you could fuse them by melting the regolith. Scientists are investigating both options. If the glue method is used, it will form a paste, and this paste could be 3D printed by robots. This is ideal in a difficult environment because it cuts down on humans having to do complicated building processes, such as cutting or welding. But 3D printing works well on Earth because of gravity. Engineers are still studying what the Moon's low gravity means for printing there. On Earth, the gravity makes sure that as each layer of material is printed, they bond together well. With reduced gravity, the layers might not stick as strongly, so the material could be weaker. The 3D-printed robots have the added challenge of needing to withstand the dust, the extreme temperatures and the meteorites – things we don't need to worry about on Earth.

Will they get built?

The answer is: we don't know yet! It depends on whether the leaders of different countries decide that long-term exploration of the Moon is useful. It's an exciting project and things are still being designed and tested as we speak.



Join engineer **Roma Agrawal** for an exciting
behind-the-scenes look at some of the world's most
incredible structures – from **soaring skyscrapers**
reaching beyond the clouds to
enormous bridges spanning the widest rivers.

Discover the surprising and inventive ways
engineers tackle big challenges, including building
underground and underwater, and their **radical**
ideas for building in space. You will also meet some
extraordinary people who have **transformed**
our landscape and the way we live.

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