Adventures in Engineering!

QUEENSLAND NORTHERN TERRITORY
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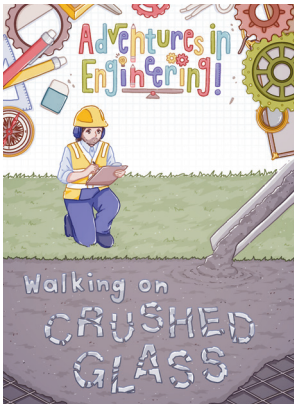
Walking on CRUSHED GLASS



Adventures in Engineering:
Walking on Crushed Glass

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Our thanks to our featured public works engineer, Josh Flanders for sharing his engineering project.

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Walking on Crushed Glass

First Edition

With thanks to the National Careers Institute

Chapter 1

Josh was enjoying his new job as a graduate civil engineer in Far North Queensland. The weather in Cairns, where he lived, was always warm, the landscape lush and green. He got to ride his bike to most of the places he needed to get to in a day. He could ride it to work, to the local pool, to his favourite restaurants. It was quite a relaxed lifestyle, all things considered.

Being an engineer was turning out to be a lot of fun, too. He felt very lucky to be able to turn the things he enjoyed doing as a kid, like playing with Lego and doing crazy science experiments, into a job that he got paid for. It was challenging to see a problem that needed solving, but he enjoyed the process of thinking through options, and working with colleagues at the Cairns Regional Council to come up with a good solution.

One day, during a work site tour, Josh got to visit the council's waste management facility – or, as he was used to calling it, the local dump. But this place didn't look like the big hole in the ground full of stinking rubbish that he was used to seeing when he was a kid. This place had a big shed, called a 'transfer station'. He saw people pulling up in their cars and taking out various kinds of waste – sometimes bottles and cardboard, and other times old washing machines and toys. His favourite place was the 'Buy Back Shop', where items that some people considered rubbish but were still useful were for sale. Josh had managed to buy an old bike frame and various parts to build his own unique mountain bike. It had turned out to be much

cheaper than a new bike, didn't look like anyone else's, and he had saved the parts from going into landfill!

Chapter 2

This day Josh was asked to visit the area where the recyclables were kept. There were big skip bins full of cardboard, plastics, paper, and even one full of clothes. The area that surprised him the most was where the glass was stored. Josh hadn't expected to see so much of it. He knew that as a solid, glass was not going to break down once it was put into landfill. It would remain there for thousands of years, if not millions.

Josh had researched a lot about recycling. For instance, he knew that Australians created about 54 million tonnes of waste every year. This worked out to be 2.2 tonnes per person, per year. He tried to calculate what that would look like. If one tonne was 1000 kilograms, and the average Australian male was about 85 kg, then 2.2 tonnes would be equal to almost 26 people. Josh found it a little sad that one person could create so much waste in one year that it weighed as much as 26 adults.

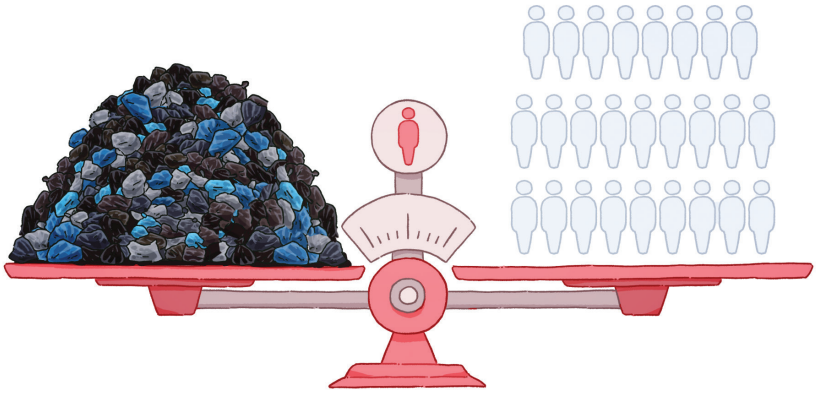


Figure 1: Amount of Waste/Person/Year

Josh was staring at the piles of glass when one of the managers at the facility walked past.

'Excuse me? How much glass do you process here every day? There seems to be so much of it,' Josh asked.

'We process seven to 10 tonnes of glass every single day that we are open,' replied the manager. 'You're right. There is a lot of it.'

Josh did his mental calculation again. 10 tonne is the same as10,000 kg, which, divided by 85 kg, was equivalent to about 118 people worth of glass. Every. Single. Day.

Josh remembered reading that not even half of the glass brought in for recycling was reused again. This meant half of the glass did end up in landfill, never to **biodegrade**. He imagined people like archaeologists digging up this area in 300 years and wondering what all the glass was used for, and why it was being kept underground. It didn't really make a lot of sense now, so he didn't think it would make any more sense in 300 years' time.

Josh knew excess recycled glass was a significant problem, and one that needed a good solution. For his council, and for the environment.

Chapter 3

Later that day, Josh was riding his bike home from work. He was proud of himself for making a bike from recycled parts. He couldn't very well make glass bikes though - that would be very dangerous indeed. Imagine the number of flat tyres and cut feet from the sharp-edged glass if the bike broke.

Josh was deep in thought as he rounded the corner and rode past the local primary school.

'Aaaaah,' he yelled, surprised by a series of big cracks in the footpath. Josh squeezed his brakes but too hard, too quickly. His tyres locked. His bike came to a sudden stop. But Josh's forward momentum continued, and he fell off his bike. Fortunately, he hadn't been going very fast, and so the crash landing wasn't too bad. He'd managed to put his hands out, which absorbed some of the force of the fall.

Josh raised himself up to the sitting position to check for any injuries. After he'd dusted off his hands and the knees of his pants, he looked at the offending footpath. It was cracked and broken.

'I bet I'm not the only person to fall over this footpath,' Josh thought to himself. 'There must be hundreds of people walking along here every day.' He was lucky he hadn't really hurt himself. He was worried though that little kids, or even worse, someone's grandparent, could trip on the cracks and really injure themselves.

'Right,' said Josh to himself, getting up off the ground and righting his bike. 'Now I've got two problems that need solving.' Josh picked up a small part of the footpath that had cracked off, as a reminder of the second thing he had to really think about.

Chapter 4

The next day at work, Josh pulled the small piece of footpath from his pocket and rested it on his desk. Next to it he placed his glass of water. Sometimes it helped him to see the problem that he was trying to solve.

Josh had spent some time that morning talking to his engineering colleagues about the recycled glass problem. He also reported the broken footpath to the right people at the council so that they could fix it before anyone else hurt themselves. They added it to their list and told him that they fix many kilometres of footpaths every year, and that they would get to that one soon.

Josh picked up the piece of the footpath. By examining it closely, he could see that it was made of **concrete**, flecked with the occasional chip of gravel.

He remembered when he had helped his parents pave a path from the back door of their house to their new clothesline. His job was to help his Dad mix the **concrete**. It was just like making a cake, but with **cement** powder, sand and water. Picking up the glass of water to have a sip, Josh held both the **concrete** and the glass in his hand. He moved them together, side by side.

'I wonder,' he said to himself, 'if I could mix the glass with the **concrete** and make it stronger?' A stronger footpath made with bits of glass could help to solve both of his problems – too much glass going to landfill and **concrete** footpaths that break too easily.

Josh knew his **hypothesis** needed further investigation.

Chapter 5

Now, Josh had accidently dropped and broken glass before and knew that he couldn't put broken shards of glass into a **concrete** footpath. Imagine how badly he'd have cut himself if he'd fallen off his bike and into a sharp bit of glass. Ugh, it made him feel a bit nauseous. Neither did he think that councils would bury whole bottles or jars in landfill, because the same danger would occur. They would also take up too much space. He wondered what the council did with all that glass. Josh needed to make another visit.

Arriving back at the recycling section of the waste management facility, Josh found the same friendly manager who had helped him the previous day. He explained his idea and was led to the glass crushing area.

'You'll need these,' said the manager, handing Josh a set of safety glasses, earmuffs and face mask to go with the fluorescent high vis jacket and hard hat that he was already wearing.

'Hmm,' thought Josh to himself. 'This will be interesting ... and loud ... and dusty, I'm guessing.'

The manager, whose name was Mahana, led Josh into a big shed. Most of this shed was taken up with a very large and very loud machine. Recycled paper, cardboard, plastics, metals, and glass were poured onto a conveyor belt, where people pulled large items off by hand. The vibrating conveyor belt slowly sorted the paper, cardboard, metals and plastic from the glass.

The glass was tipped into the first machine called an imploder. Mahana explained that rotating blades crushed the glass and magnets removed any remaining small metal parts. The sound of the exploding glass containers would have been deafening without his ear protection muffling the volume. The crunching sound went on and on, like his food blender crushing ice when he made smoothies. The second machine, called a shearing unit, crushed the glass even further with rotating blades. Finally, the glass was processed through the sanding unit, reducing it into 5 mm particles.

'This glass,' said Mahana, 'is now called "cullet". Sometimes we keep cullet this size, or we pour it back into the sanding unit to make the pieces as small as 3 mm.' '

Well,' Josh thought to himself, 'no one will be able to cut themselves on glass this size.' Josh asked Mahana for a sample – a large bucket of the cullet.

'I need to do some experimenting,' said Josh, walking back to his ute.

Chapter 6

On his way back to the office, Josh spoke to the chief engineer of the road construction team. He wanted to know what made **concrete** good to use and work with. Josh remembered from one of his lectures a fact that had really shocked him. After water, **concrete** is the most consumed material in the world. This sounded like a strange fact, until he looked around and noticed how much **concrete** was around him. The footpaths he walked on, the walls of many of the buildings he could see. He finally understood what his grandpa meant when he complained about living in a '**concrete** jungle'. Josh realised that if he was able to find a useful way of mixing recycled crushed glass with **concrete**, that it could save a great deal of glass from landfill.

Josh was told that there were two factors that were important when using **concrete** that he should consider in his research and experiment.

1. Workability – How easy it is for the road construction workers to use the **concrete** mix – meaning, how easy is it to pour from the mixer into the formwork. Not too fast, not too slow.

2. Strength – How well it copes with the pressure of people walking on it.

The third factor that Josh felt was important was:

3. Environmental – If he replaced the sand with finely crushed glass, how much glass is saved from going into landfill, and how much sand would no longer need to be quarried.

Josh had conducted many experiments while completing his Bachelor of Civil Engineering and knew that he had to do some research before going into a laboratory. Although Josh felt that his idea about mixing glass with **concrete** was an original one, he had to make sure. If other engineers or scientists had tested this **hypothesis** before, then their results would save Josh a lot of time and energy. The information would also give him clues about how he should carry out his experiment if he felt there was more data that he needed to collect.

Chapter 7

Once at his desk, Josh logged into his computer and the online library catalogue. Being a member of the local library had always saved Josh a lot of time and money, by giving him free access to books and journals on many topics from around the world. Josh typed '**cement**', '**concrete**', 'recycled', 'glass', into the search engine and made notes of the information available in the journal articles.

Firstly, Josh was a little disappointed to see that other scientists had researched the idea of mixing **concrete** with glass over 30 years ago. Well before Josh was even born! Sighing, he started to write notes on the information he found. He was able to summarise his notes:

- Replacing the gravel in **concrete** with rough (**coarse**) glass makes it less strong and harder to pour and smooth out.
- Replacing sand with smooth (**fine**) glass was neither good nor bad. Results were mixed.
- Some studies found that replacing 10 to 30% of the sand with **fine** crushed glass worked well. But it did not work as well for higher percentages as it made the **concrete** less strong and hard to work with.

So, thought Josh, I won't replace gravel with glass, as that has been proven not to work. I should though, conduct experiments to decide if I should replace sand with glass. Other engineers and scientists haven't yet done this and provided clear answers, so perhaps I can. Josh decided, based on his

research, that he would test replacement of recycled crushed glass with sand at three levels – 20%, 40% and 60%.

He was excited about the prospect of recycled crushed glass being useful in **concrete**. If he could replace sand with glass, then more recycled glass would get used and not end up in landfill. It would also mean that less sand had to be mined from the bottom of riverbeds, which caused problems like erosion and poorer water quality. That had to be better for the environment.

Chapter 8

It had been a little while since Josh had been in a laboratory doing experiments. Luckily, he was friends with other civil engineering students who were still studying at the local university campus. Even better, was that they had access to science labs, and were very keen to let Josh run his experiment on mixing **concrete** and glass. It felt just like the old days.

As with a lot of engineering, Josh couldn't conduct this experiment all on his own. Firstly, he had to get access to the **concrete**. Lucky for Josh, there was a **concrete** supplier in Cairns who helped him to work out the correct mixes for the **concrete**. Josh knew that, like a cake, **concrete** needed both wet and dry ingredients:

- **cement**
- **aggregates** – **coarse** (gravel) and **fine** (sand)
- water

Just as a cake wouldn't cook properly if there were too many dry ingredients and too few wet ingredients, **concrete** won't set if there is an imbalance between its three ingredients. When Josh replaced some of the sand with recycled crushed glass, it would have an impact on how well the **concrete** worked. He would have to find the most effective proportion of mix by conducting his experiment in the laboratory.

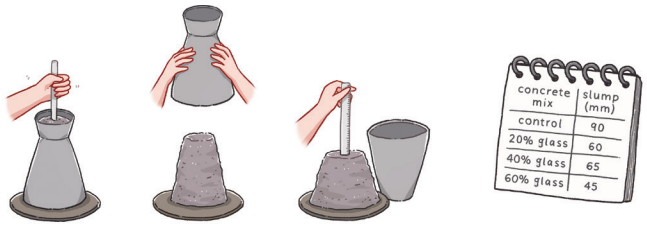
Chapter 9

In the laboratory, Josh and his assistants made batches of **concrete** mix in a small **concrete** mixer.

The first test Josh conducted was a 'slump' test. The results of these tests would help Josh determine how easy the **concrete** would be to work with – its workability. If the **concrete** slumped too far (fell too flat, like a pancake) then it would be too sloppy for the road construction workers to use and may not be strong enough. However, if the **concrete** hardly slumped at all, then it could be too thick, and too hard for the road construction workers to pour. Getting the right mix of **concrete** reminded Josh of Goldilocks and the porridge – it had to be just right.

To conduct the slump test, Josh and his assistants followed this process:

1. Pour **concrete** into a cone-shaped mould in three separate layers, hitting each layer with a compaction rod to remove air bubbles.
2. Pull the mould off the **concrete** and quickly place the mould next to the **concrete**.
3. Put a metal ruler to the top of the **concrete** to see how far from the top of the mould the **concrete** has slumped.
4. Record the results in a table.



1 2 3 4

Chapter 10

Josh took the data from the table and created a bar graph to better compare the results. The 'control' mix was the standard mix that the council construction team was already using to make their footpaths. Josh's aim was to find out if a mix of **concrete** with sand replaced with recycled crushed glass performed better than what the council crew were already using. If it was better, then Josh could justify to the council how they should solve their recycled glass problem by mixing it into their **concrete**.

Table 1: Concrete Mix v Slump	
Concrete Mix	**Slump (mm)**
Control	90
20% Glass	60
40% Glass	65
60% Glass	45

Looking at the workability results, Josh could see none of his recycled crushed glass replacement mixes performed better than the control. He knew his mixes would be different for the road construction crews to work with, compared to what they were used to.

Perhaps if there were other benefits, the council and the road construction crew would be happy to adjust to using his mix.

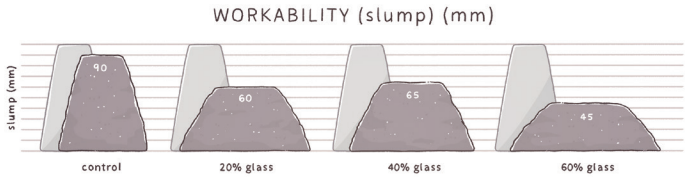


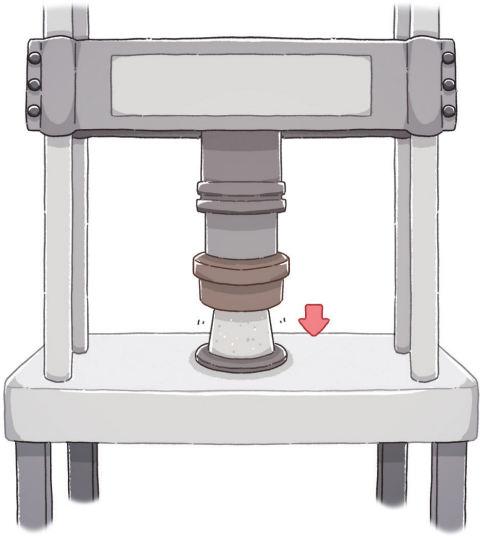
Figure 2: Workability of Concrete Mix

Chapter 11

Workability of the **concrete** was only one of the factors that Josh was researching. He hoped that perhaps his crushed glass mixes would be stronger than the control mix.

To test the strength of the **concrete**, it was poured into metal cylinders and allowed to set for a few days. It was then removed from these cylinders and 'cured' by putting them in a water bath to increase the strength even more. Each cylinder was labelled as to the percentage of recycled crushed glass that replaced the sand.

The cool part of this experiment was the machine used to test the strength of the **concrete** cylinder – A **hydraulic** press (see picture below).



To test the strength, a **concrete** cylinder was placed in the **hydraulic** press. Pressure was then forced on to the cylinder.

This test certainly needed Josh and his team to wear their safety equipment – glasses, long sleeves and pants, and covered shoes. When the **concrete** eventually broke, the machine showed how much pressure it had taken to break it. The higher the pressure, the stronger the **concrete**. This meant that, when used in a footpath, the **concrete** would cope better for longer with the weight of the people, bikes and scooters that travelled across it.

Josh and his team tested each cylinder 28 days after it had been poured – meaning they'd had almost a month to harden. To be safe to use, the **concrete** had to withstand 32 megapascals (MPa) of pressure. Again, Josh recorded the data in a table and created a bar graph for comparison of the four mixes.

Table 2: Concrete Mix v 28 Day Strength	
Concrete Mix	**28 Day Strength (MPa)**
Control	38.8
20% Glass	41.4
40% Glass	26.8
60% Glass	37.1

It was clear to see from his graph, that the 20% and the 60% mix could withstand the 32 MPa of pressure and that the 40% could not. The 20% mix was stronger even than the control mix.

Josh made a note of his conclusion from this laboratory research.

'Although workability is slightly less than the control mix, replacing sand with up to 60% recycled crushed glass does not make it significantly weaker'.

Chapter 12

Josh was really pleased with the work he had done in the laboratory and was ready to put his findings to the test. It wasn't enough to know that the problem could be solved in a laboratory; he had to test the **concrete** and glass mix in real life. How would it behave with hundreds of people walking, riding, and skating on it every day? He had noticed the previous day that the footpath where he had fallen off his bike had still not been fixed. This was the perfect chance to test his **concrete** and glass mix and fix the dangerous footpath. Josh sought permission from the Council, and once given permission, he put his plan into practice.

The following fortnight, having received permission, and with a team of road construction workers, Josh returned to the front of the primary school. He watched on as the crew demolished the old broken footpath, using diggers and shovels to clear an area 2 m wide by 90 m long. This meant that Josh and the crew had enough space to lay three different versions of **concrete** mix.

One section they called the 'control' section. This section was made using the same **concrete** mix as all the other footpaths in Cairns. This would allow Josh to test how well his **concrete** and glass mixture worked in comparison to what the council usually used. The other two sections involved his **concrete** and glass mix in two different proportions, chosen because of his laboratory testing. One mix was 40% glass sand mixed with 60% regular sand. The other was 60% glass sand mixed with 40% regular sand. Josh thought these two mixes would

be best to test in a real footpath as they had the potential to use the greatest amount of recycled crushed glass. This would be useful for the Cairns Waste Management Facility as it would reduce the amount going to landfill. It would also be better for the environment. Pouring these out in 30 m lengths, side by side, with the control mix in between, made it easier for Josh and the others to assess how well his mixes worked in comparison to the usual **concrete**.

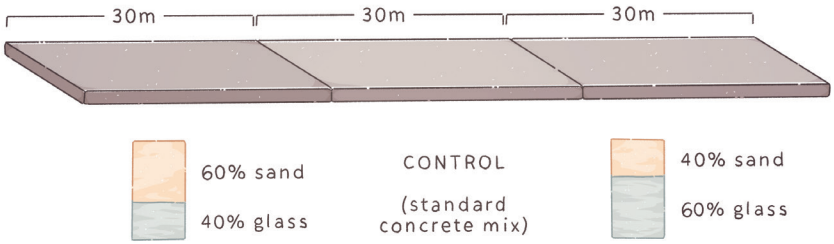


Figure 2: Control Mix v Sand/Glass Mixes

As the slabs were being poured, Josh observed and questioned the road construction workers, so he could determine his first criteria, the workability of the mix. He watched to see how quickly the mixes came out of the concrete truck. Was the mix too sloppy (like when a cake batter doesn't have enough flour in it) and come out of the machine too quickly for the workers to control? Or was it too thick and slow to pour (like when he made muffins)? Josh knew that for the small length of footpath they were pouring for his project it may not matter very much. However, when the construction teams would be laying out hundreds of metres of footpath each day, they would become tired and annoyed if the mix was too fast or slow for them to work with easily. At the end of the day, Josh spoke to one of the construction team.

‘Excuse me, Bronwyn. Can I just ask, which of the mixes did you find the easiest to work with today?’

Bronwyn looked thoughtful and replied, ‘Well, in my opinion, the 60% glass sand mix was too thick, and it made it difficult to pour and spread out into the formwork. The 40% glass sand mix was okay, but not as good as the control mix, the one we’ve always used.’

‘Thanks Bron,’ replied Josh. He was a bit disappointed that his mixes hadn’t been better than the control mix. He was hoping he’d be able to make the construction team’s work a little easier and quicker.

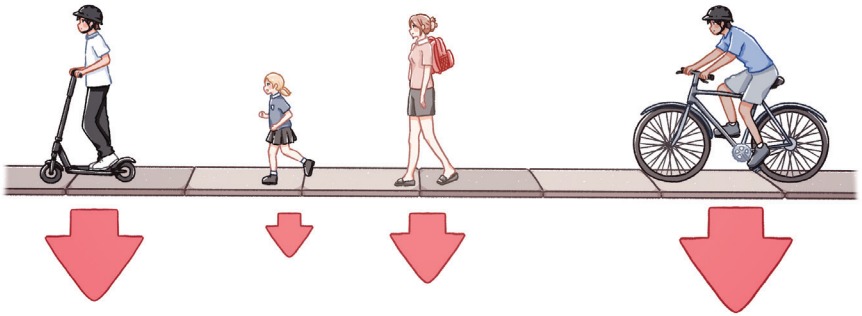
‘I’d better ask the others if they agree with you,’ said Josh, knowing that he couldn’t just rely on one person’s opinion. That wasn’t very scientific at all. Other workers may have found his mixes easy to work with and their opinions were valid, too.

He was hoping to get answers that he liked better, but he knew he had to have an open mind. What he wanted didn’t matter when it came to doing scientific experiments. Facts were more important than feelings in this situation.

Chapter 13

Seven days later, when he knew that the concrete would have had time to dry and set properly, Josh returned to the laboratory. He needed to test the strength of the concrete cylinders that had been poured at the primary school footpath site, and how well it coped with weight and force on it. He used the **hydraulic** press again and collated his results.

Living in the area meant that Josh had a reasonable idea how the footpath was used and how often. School drop-off and pick-up times would be when the footpath would be under the most pressure, with so many people walking in and out. In addition, there were people like him who rode their bikes, and others who rode scooters and skateboards. All would have different impact on the footpath in terms of weight, **friction** and force. This would determine how long the footpath could stay in one piece without cracking or breaking up.

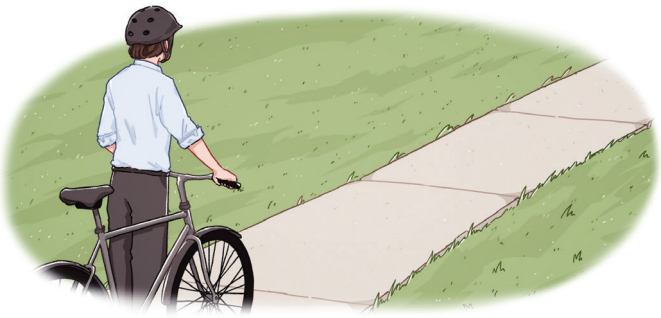


Now that Josh had collected data from his experimental testing and observations, he had to write it up into a report that he could share with his managers and the Council. Josh needed to provide accurate information to help others make good decisions about how excess recycled crushed glass could be used, and how footpaths could be built in Cairns.

Chapter 14

Five months later, Josh was riding his bike by the primary school. He was very pleased to note that there was no damage or cracking on his **trial** footpaths. He was also pleased with the response from the Council about his report. They felt that he had conducted an excellent experiment and **trial** of the concrete with recycled crushed glass. They could see the benefit in using up their large stockpiles and not sending it to landfill. They were keen to conduct further experiments and trials to try to find the perfect mix – one that was workable for the road construction crews, and one that remained strong over a long period of time. Josh was looking forward to getting back into the laboratory again.

Best of all for Josh was knowing that, even in his one experiment and **trial**, that he had saved 8.46 tonnes of recycled crushed glass from going into landfill, and 8.8 tonnes of sand from being quarried. When they found just the right mix, Josh knew his idea would have a positive impact on the environment, and on the residents of Cairns. It was a work in progress! Josh was very glad he had decided to become a civil engineer.



Glossary

aggregate	(n) sand or broken stone that is used to make concrete or for building roads, etc.
archaeology	(n) the study of cultures of the past, and of periods of history by examining the parts of buildings and objects found in the ground
biodegrade	(v) to change back, by the action of bacteria, to a natural state that will not harm the environment
cement	(n) a grey powder made by burning clay and lime that sets hard when it is mixed with water. Cement is used in building to stick stones and bricks together and to make very hard surfaces.
coarse	(adj) rough; consisting of relatively large pieces (opposite of fine)
concrete	(n) building material that is made by mixing together cement, sand, small stones and water
cure	(v) to treat something with smoke, salt or heat, etc. in order to preserve it
fine	(adj) made of very small grains (opposite of coarse)
friction	(n) the action of one object or surface moving against another
hydraulic	(adj) moved through pipes, etc. under pressure

hypothesis	(n) an idea or explanation of something that is based on a few known facts but that has not yet been proved to be true or correct
implode	(v) to collapse into the centre
trial	(v) to test the ability, quality or performance of something to see if it will be effective or successful

Glossary definitions sourced from
https://www.oxfordlearnersdictionaries.com/

Activities

Chapter 1

The author describes Cairns as being 'always warm, the landscape lush and green'. Considering where Cairns is located, why is it like this? What three words would you use to describe the town that you live in?

Chapter 3

On pages 8 and 9 the author describes Josh falling off his bike. What happened that made him fall off the bike? How could Josh have avoided this?

Chapter 6

Why do you think it is important for engineers and scientists to share their knowledge and results of experiments with each other?

Discuss

Josh works for the Cairns Regional Council. Reading back over the story, what services does the Cairns Regional Council provide to its' residents?

What is the name of the local council where you live?

What services do they provide to the people who live in your area?

Which of these services do you and your family use?

Research other ways that recycled materials are used. In a group, brainstorm other ways that recycled glass, cardboard, paper and plastic could be reused.

What kind of tasks did Josh perform in his job as a civil engineer?

What skills did Josh use to help solve the problem?

Are there any aspects of Josh's job you would like to do?

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It had been an eventful day for Josh. A trip to the waste management depot showed him just how many tonnes of glass isn't recycled. Then he fell off his bike when he hit a cracked footpath. Could these two events lead Josh to solve both problems?

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